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On intensifying the research processes of regular motions transformation

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Abstract: The study is a review of the scientific and applied content of the research carried out over the years on the topic, both worldwide and by the authors. The research is structured in a way that presents the topic in its active development over the years, which substantially proves its permanent relevance. The development of the researches of the spatial transformation of motions, oriented towards the synthesis and analysis of spatial transmissions with innovative characteristics, at this stage and up to the present moment for Bulgaria are realized exclusively at the Institute of Mechanics at Bulgarian Academy of Sciences (BAS). The content of the researches carried out at the Bulgarian Academy of Sciences clearly determines their market orientation and, therefore, their place of development was in the "Centre of competence MIRACLE – Mechatronics, Innovation, Robotics, Automation, Clean Technologies" at the Institute of Mechanics. The above said makes it inexplicable the decision of the former management of the institute, in the face of Prof. Vasil Kavardjikov (Director) and Assoc. Detelina Ignatova (Project Manager), to ignore this topic when designing a project for the creation of the Competence Centre.

Keywords: SPATIAL TRANSMISSIONS, MATHEMATICAL MODELLING, ANALYSIS, SYNTHESIS, INNOVATIONS, COMPETENCE CENTRE

1. Introduction

1.1. Field of Researches

The activities of this type of researches are oriented towards serving one of the strategic directions of the science "Applied Mechanics" - "Analysis and Synthesis of Mechanical Transmissions". They constitute a systematic set of activities, differentiated in directions of the science and technology, and serving the theoretical and technical development and improvement of both the approaches to the research of processes of regular defined motions transformation, as well as the construction of more sophisticated adequate mathematical models, that describe them. The searched final result of the theoretical studies is the creation of algorithms and computer programs oriented to the synthesis of improved existing and new innovative products – multibody systems for the transformation of motions.

Actual existing multibody systems can be considered as a set of a finite number of interconnected material bodies, as the location and the motion of an arbitrary body is in dependence on the locations and motions of the rest of the bodies included in the system. In the context of the above definition, the body systems can be divided into two main groups, according to the way the relationships and interactions of the constituent bodies are formulated:

Multibody systems with random (spontaneous) occurred connections and interactions. These systems are a result of accidentally occurring and ongoing events. In this case, the connections and interactions between the bodies of the system are not subjected to a regularity. These systems could include those that occur in different types of accidents, catastrophes, and natural disasters.

Multibody systems with forced (regular) occurred connections and interactions. These systems are purposefully designed in such a way that they, as a whole or separate bodies (respectively parts) of them, to realize specific law for the motions transformation. In this case, the connections and interactions between the bodies exist indefinitely, or the duration of their existence is precisely defined. These systems may include predominant mechanisms and machines. The prevailing mechanisms and machines can be referred to these systems.

1.2. Object and Purpose of the Researches

The object of the researches extends to the second direction of the multibody systems in their most general type "spatial mechanical systems", which are dedicated to realizing a preliminary defined law of spatial motions transformation.

The purpose of the researches:

The existing incompleteness and imperfections in the theoretical and applied researches of the spatial mechanical transmissions is a motive to realize an adequate analysis of the state and development of this direction of the science of “Applied Mechanics” - the "Theory of Gearing", while adequate researches are planned subordinated to the idea on one hand of expanding the theoretical basis (on which synthesis is based) and on the other hand – on the basis of the obtained new theoretical results to be developed adequate practices in order to create innovative products.

2. Review of the Current State of Research Problems

The methods of the science, studying the processes of the regular motions transformation by means of preliminary defined law between coplanar and non-coplanar axes of rotations and between the axis of rotation and axis of rectilinear translations, by means of three-links mechanisms, having one or more high kinematic joints, will be applied in the present researches. This science should be treated as an autonomous direction of the scientific field “Applied Mechanics”. It studies the kinematic and the dynamic behavior of the mechanical multibody systems, in relation to the geometric characteristics of the elements of the high kinematic joints.

Structurally and functionally, the above mentioned three-links multibody systems can be divided into three main types [1, 2]:

- Mechanisms, realizing rotations transformation by means of one high kinematic joint. For them, the motions transformation is realized due to the friction forces between the elements of the joint, which have a tangential contact, caused by normal contact forces induced in the contact zone. Mechanisms that work on this principle are called friction drives.
- Mechanisms, for which the rotations transformation between coplanar and non-coplanar axes are realized by means of the system of high kinematic joints, which elements come into and go out from a tangential contact. These mechanisms are known in the literature as "gear drives". For them, the rotations transformation occurs as a result of the action of normal forces in the places of tangential contact of the elements of high kinematic joints.
- Mechanisms in which, for a given rotational motion of one of the movable links relative to the posture (the fixed link ), the other link performs an uniquely defined rectilinear translation, by means of a system of high kinematic joints, are called rack drives. The rack drive can be considered as a special case of the gear set, i.e. as a gear drive obtained from a three-link gear
mechanism, with the following structural and kinematic changes:
- increasing to “infinity” the number of the teeth (elements of high kinematic joints) belonging to one of the rotating links;
- the number of contacting elements (meshed gear surfaces) remains finite;
- the axis of rotation of the link with an “infinite” number of teeth moves to “infinity”;
- the rotation of the same movable link is transformed into a rectilinear translation.

In the years of the second half of the 20th century and the beginning of the 21st century, the vast amount of scientific and industrial (applied) researches in the mentioned direction of the science “Applied Mechanics”, called as a “Science of Gear Mechanisms”, gave a strong impetus for its development toward the formation of two relatively autonomous scientific directions: The Theory of Gearing and The Geometry of Gearing (Geometrical Theory of Gear Mechanisms).

**Theory of Gearing.** In essence, it is a theory of high kinematic joints, considering their application in closed multibody systems, which the main representative is “gear mechanisms”. The “theory of gearing” deals with the common principles to which the regular motions transformation is subjected, by means of three-links mechanisms with high kinematic joints, for all possible placement of the axes of rotation and direction of rectilinear translation. This theory offers a method for analytical and computational (computer) study of the various types of gearing. In this sense, the current theory is divided into the “theory of plane gearing” and the “theory of spatial gearing”.

**Geometry of Gearing.** It represents the geometric theory of concrete types of gear mechanisms. This direction of the science emerges as a result of the constantly changing demands of industry to the technological and exploitation qualities of mechanical transmissions. On the basis of the elaborated analytical method, in the theory of gearing, the following tasks are solved to a greater or lesser extent:

- Choice of rational form and geometry of the teeth of different types of gear mechanisms.
- Establishment and scientific justification of methodologies for defining of the quality characteristics of the theoretically conjugated and non-conjugated tooth surfaces (tooth profiles).
- Creation of specialized computational methods for basic and optimization synthesis of new classes of modern gear transmissions.
- Providing an adequate classification of the gear systems based on new and actual characteristics.
- Defining relations between the elements of the tooth geometry and the essential technological and exploitation features of modern gear mechanisms and etc.

Quite naturally, the first steps in the development of geometric theory are realized in the field of plane gearing, and in particular in the scientific fields dealing with involute gear mechanisms.

In the context of the commented studies, we will make a brief overview on that group of problems dealing with the spatial gear mechanisms, the solution of which has given a strong impetus and provided a rapid development of the geometric theory of the spatial gearing and as a final result - wide application of spatial gear mechanisms in various branches of technics. An object of analysis here is the spatial gear sets with crossed axes (shafts) of rotation (skew-axis type gears), known in the technical literature as “hyperboloid gear drives”. The family of these gears comprises the following two main groups:

- Gear mechanism, which mesh region is placed on the fixed surface that is located close or passing through the axis of the crossed axes, around which the rotation of the gears is realized. Typical representatives of these gear sets are helical and worm gear sets, as well as the gear mechanisms of type “Wildhaber”.
- Here it includes spatial gear drives, which mesh region is displaced from the axis (offset axis) of the crossed lines (axes of rotation) in the general case, both along one of the lines, as well along on the other one. Hypoid gear sets, as well as Spiroid, Helicon and Planoid gears, belong to this group. Here, it should be included as well, the gear mechanisms that mesh region is displaced from the axis of the crossed axes (lines) of rotation, along only one of the rotations’ axis (lines). They are some type of toroid gear mechanisms.

A number of scientists, in their researches, have elaborated tasks related to the geometry of gearing of different types of hyperboloid gear sets.

The geometry of helical gears with increased loading capacity was developed by V. Schultz and F. Litvin [Russia][3]. A number of monographs have been dedicated entirely or partially, as well as a number of publications, on the geometry of the helical surfaces and their application to the synthesis and design of worm gears. Methodological instructions for their geometric and strength calculations can be found in specialized handbooks. Cylindrical worm gears with a nonlinear profile of helical worm threads were studied by G. Nieman, E. Heyer, F. Litvin [Germany, USA] [3, 4, 5].

Widespread industrial application of hypoid gear drives is a result of the foundation of their geometric theory and technology of manufacture on the basis of a variety of advanced scientific and engineering studies, related to the theory and practice of their basic and optimization synthesis. Over the last few decades, scientists have been actively working on methods for the synthesis of hypoid gear drives. The researches of F. Litvin [USA] [5,6], K. Pismanik [7], G. Lopato, N. Kobatov, M. Segal [Russia] [8], K. Minkov [Bulgaria] [9-15] and many others are devoted to this scientific and technological problem. The Gleason systems – USA, Oerlikon - Switzerland, Klingelberg– Germany are well-known to the specialists, as they are applied in the world of industrial practice for the generation of the tooth surfaces of the hypoid gears.

The skew-axis gear drives of type Spiroid and Helicon are a relatively new type of hyperboloid gear transmissions, and it is not without reason that specialists consider them as one of the most attractive types of spatial high-reduction gear sets. The first information about this class of transmissions is contained in the publications of F. Bohle [16], O. Saari [17], N. Nelson [USA] [18-20], and others for the period of1955-1962. From the same period of time, the first patents and the beginning of the introduction of these gears in the USA from the Chicago Company “Illinois Tool Works” have been started. At the end of the mentioned period, the Spiroid gearing rises the scientific interest of a number of European researchers. Special attention should be paid here to the Russian scientists A. Georgiev [21-27], V. Goldfarb [27-33], S. Lagutin [34], V. Ganshin [Russia] [35, 36] and others who have devoted numerous publications, including their dissertations, to these gear sets. In this file are the studies of European scientists D. Schwager [Germany] [37-38], V. Bolos [Romania] [39], I. Dudas [Hungary] [40] and others.

In the context of the defined purpose, tasks and object of study here are briefly analyzed the current actual researches, which are grouped as follows:

- Summarizing much of the researches realized over the years by the Russian researchers L. Koresklev, A. Georgiev, V. Goldfarb [Russia], etc., as well as his own theoretical results, S. Lagutin [Russia] [41, 42] introduces into “scientific circulation” the term “space of gearing”, which is a fixed three-dimensional space defined by the rotation axes of the movable links of a three-links gear mechanism. The elements of this space - the vectors of relative velocities and the normals at them at each point, iso-surfaces and iso-lines in which the synthesized gear set has
certain features, etc. - are characteristics applicable to the synthesis of spatial gear drives.

- Geometric theory of spatial gearing includes studies defining geometric-kinematic characteristics that provide optimum conjugation quality for the specific types of hyperboloid transmission with an exact meshing of teeth. It should be noted that in the field of spatial conjugate gearing, a series of works have been written, oriented towards creating algorithms that limit and eliminate singularity of the active tooth surfaces. The most attractive publications in this field belong to I. Bernatsky [Russia] [43], A. Georgiev [Russia] [23, 24], V. Ganshin [Russia] [35, 36], K. Minkov [Bulgaria] [11, 12], F. Litvin [USA], W. Nelson [USA] [18], and others.

- Publications by L. Korestilev [44] and S. Lagutin [Russia] [41, 42, 44] also refer to the theme dealing with the type and quality of the mesh region. They propose the idea of worm gear sets’ design which conjugated tooth surfaces have instantaneous contact over the closed-loop contact line. Based on the defined hypotheses related to the character of the lubrication and the resulting from it hydrodynamic loading capacity, criteria for its control are formulated by control of the type and size of the tooth surfaces (limited in the frame of the contact line), lubricating fluid, etc.

- As a result of the analysis of the scientific research in the reference literature sources, the fourth group of publications was formulated oriented towards the creation of hyperboloid gear sets with linear tooth contact and reduced sensitivity to manufacturing and assembly errors, having the qualities for simple and secure regulation and elimination of backlashs in the gearing. The only gear drives that have these qualities as “organic” features are the high-reduction spatial skew-axes gears, of type Spiroid and Helicon.

3. Own Experience in This Field of Study

3.1. Brief Review

The authors of this review are devoted their theoretical and applied researches during the last few decades to the kinematic and geometric, and technological synthesis of spatial gear motions transformers.

The main focus in the researches is put on the definition and justification of concepts for kinematically oriented approaches for the synthesis of spatial gear sets, and on this basis - for the creation of adequate mechanical and mathematical models for the calculation, design, and construction of real engineering objects with innovative characteristics.

For many years, among the various gear mechanisms, from the viewpoint of the character of the tooth contact, the gear mechanisms with an exact meshing dominate. These gear drives, when achieving the optimal accuracy of elaboration and assembly, realize motions transformation with high accuracy of the preliminary given gear ratio.

The realized researches, as well the planned ones, are dedicated to the hyperboloid gear mechanisms with an exact meshing and spatial rack drives with exact meshing. The researches, summarizing the experience of the scientists from the Institute of Mechanics- Bulgarian Academy of Sciences, are a summary of their many years of researches on the analysis, synthesis, and practical experimentation of the mentioned transmissions.

The created approaches of the modeling are applied in the elaboration of new algorithms and computer programs for the design of less known and applied in the world practice and unknown for Bulgaria, classes of spatial gear mechanisms. The conducted theoretical researches are the basis for the created algorithms and computer programs for synthesis.

By using the elaborated algorithms and the computer programs, prototypes of hyperboloid gear sets and spatial rack drives (design specimens) are synthesized and designed.

On their basis, constructive-technological documentation for the realization of selected technological models as well as for the organization of regular manufacture of new type Helicon reducers and Helicon motor-reductors are elaborated. Twelve Bulgarian patents are elaborated in this scientific field, as two of them are implemented.

The researches over the last 10 years are summarized in the dissertations of the authors of the present research [1, 2]:


Scientific significance of the solved problems in the dissertations.

The development of mathematical models adequately describing the spatial motions transformation applicable to the construction of algorithms for the synthesis of the hyperboloid gear mechanisms and spatial rack drives determine the scientific significance of the studied problems in the dissertations. At the core of its theoretical essence, each of the dissertations is based on the definition and elaboration of mechano-mathematical models, which, as well as the corresponding computer software products, can be assigned to:

- Models and programs, realizing theoretical studies in order to establish new kinematic characteristics (properties) of the researched gear transmissions;

- Models and programs, oriented to the geometric and technological synthesis and to the virtual prototyping.

Practical usefulness and applicability of elaborations.

The theoretical methods, elaborated in the dissertations, are created the preconditions for defining new and advanced approaches for solving tasks, related to the analysis and synthesis of the spatial gear drives. On their basis, the following is realized:

- There are elaborated mathematical models, algorithms and computer programs for the synthesis of hyperboloid gear mechanisms of type – Spiroid, Helicon, Planoid and Wildhaber (see Fig. 1);

- There are elaborated mathematical models, algorithms and computer programs for the synthesis of conic, cylindrical and spatial rack drives from convolute, Archimedean and involute type (Fig. 2).

Fig. 1 Family of special hyperboloid gears
The results of the study for the practice are as follows:

- creation of innovative constructions of hyperboloid gear mechanisms and technological and instrumental equipment for their elaboration (manufacture), for some of them there are 12 Bulgarian patents.
- Development of constructive-technological documentation and elaboration of computer and technological models of the studied gears;
- Elaboration and implementation in regular manufacture of three types of Helicon gear reductors, which are the object of Bulgarian patent (see Table 1, Fig. 3).

### Table 1: Technical characteristics of motor-reductors type Helicon.

<table>
<thead>
<tr>
<th>Technical characteristics</th>
<th>RH 31</th>
<th>RH 45</th>
<th>RH 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset, mm</td>
<td>31.5</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>13.3..105</td>
<td>20..80</td>
<td>20..80</td>
</tr>
<tr>
<td>Maximum input power, kW</td>
<td>0.370</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Rated driving torque, Nm</td>
<td>50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Rated inlet revolutions, ( \text{rev/min} )</td>
<td>1500</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Theoretical efficiency, %</td>
<td>40..92</td>
<td>40..92</td>
<td>40..92</td>
</tr>
<tr>
<td>Weight without the motor, with:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cast iron housing parts, kg</td>
<td>12</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>- aluminum housing parts, kg</td>
<td>6</td>
<td>24.5</td>
<td>26.6</td>
</tr>
</tbody>
</table>

The five-fingered bio-robot hand (Fig. 4) is elaborated in „Kawasaki & Mouri Laboratory“ at the Engineering Department of Gifu University, Gifu Japan. The aim of this robot-hand is to be applied as a standard platform for an adequate grasping and manipulating of the various objects as well as for diagnostics of the tumors in female breasts.

### 3.2. 3D Software Technology

“3D software technology” is a specific technological approach for the elaboration of a small series of highly accurate hyperboloid gear sets with a small tooth module and miniature sizes of gear drive. In the last few years on its basis, models of gear transmissions with crossed axes and face mating gears, which is intended for incorporation into drivings of two type’s robots: bio-robot hand and a walking robot with four insect-type legs, are elaborated.

In the future, bio-robots will perform various complex tasks in communicating with the user-human. Such robots will be equipped with many anthropomorphic fingers, similar to the human ones. The main purpose of this mechatronic system, a bio-robot, is to replace the human presence when dangerous tasks are accomplished in areas such as industrial production, space, the seabed, and other similar places.

One of the other future applications of the bio - robot hand is to be send as a prosthesis for people with disabilities and also as a device for medical diagnostics. Therefore, the requirement for such bio-robot hands is to possess characteristics of exact positioning and smooth motion.

The purpose of the research is dictated by the need to improve the exploitation properties of the bio-robot.

The realized researches conducted over the years at the Institute of Mechanics at Bulgarian Academy of Sciences made it possible to formulate three approaches for the synthesis of hyperboloid gear sets (skew-axis type gears):

- Synthesis upon a pitch contact point;
- Synthesis upon a mesh region;
- Synthesis upon a pitch contact point and region of mesh.

In this concrete case, two types of Spiroid and two types of Helicon drives (with gear ratios respectively - \( z_2 : z_1 = 32 : 8 \) and \( z_2 : z_1 = 40 : 10 \) : \( z_i (i = 1 - \text{number of threads of pinion} \) and \( i = 2 - \text{number of teeth on gear} \) were developed (see Fig. 4 - Fig. 8) [45 - 47]. The gear sets were specially synthesized by choosing an optimal structure and geometric characteristics, after that - CAD modeled. From an exploitation viewpoint, these gear drives are suitable for integration into the existing construction of the bio robot-hand, as they have to be an alternative to a conic plane gear drive with the same gear ratio. The hypoid displacement (offset) \( a_w \) (see Fig. 1) and the curvilinear character of the meshing tooth surfaces (in the alternative chosen type of transmissions) result in an increasing of the overlap coefficient of the new types of gear drives. This and the possibility for the control of the backlash...
in the mating teeth, lead to improvement of the technical accuracy of the transmissions, which drive the robot hand’s fingers.

Fig. 4 Model of robot hand: a) whole hand; b) bevel gear with straight teeth with gear ratio $u_{z_1} = z_2 / z_1 = 4 : z_2 = 40, m = 0,5mm$

Fig. 5 Spiroid gear drive with offset $a_w = 3,25 \text{ mm}$, gear ratio $z_2 : z_1 = 32 : 8$ (axial module 0, 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)

Fig. 6 Helicon gear drive with offset $a_w = 3,25 \text{ mm}$, gear ratio $z_2 : z_1 = 32 : 8$ (axial module 0, 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)

Fig. 7 Spiroid gear drive with offset $a_w = 4 \text{ mm}$, gear ratio $z_2 : z_1 = 40 : 10$ (axial module 0, 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)

The novelty of this design solution is that the synthesized Helicon and Spiroid gear drives have small boundary gear ratios. This is a challenge for both their synthesis and design, as well as their technical realization. The reason for this is that Spiroid and Helicon gear sets usually ensure rotations transformation with a gear ratio $u_{z_1} = z_2 / z_1$ greater than 10 to 400. The extreme difficulty of elaboration with the available technical and technological equipment, as well as the high production cost, determine the reason for using “3D software technology” to produce the above-mentioned gear systems. With this technology, the final stage is 3D printing.

We will summarize in conclusion that the offered “3D software technology” includes the following stages:

- mathematical modeling for an optimization synthesis of hyperboloid gear sets “upon a pitch contact point”;
- elaboration of the mathematical model for synthesis upon “region of mesh” (development of 3D CAD model);
- 3D printing of the synthesized transmissions.

By using the same prototyping approach, two types of Helicon gear sets with gear ratios: $z_2 : z_1 = 41:2$ and available $z_2 : z_1 = 76:1$ (Fig. 9 and Fig. 10) are created.

Fig. 8 Helicon gear drive with offset $a_w = 4 \text{ mm}$, gear ratio $z_2 : z_1 = 40 : 10$ (axial module 0, 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)

Fig. 9. Helicon gear drive with offset $a_w = 17 \text{ mm}$, gear ratio $z_2 : z_1 = 41:2$ (axial module 0, 937 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)

Fig. 10. Helicon gear drive with offset $a_w = 17 \text{ mm}$, gear ratio $z_2 : z_1 = 78:1$ (axial module 0, 45 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)
They are intended to be tested as alternative mechatronic drives when they are incorporated in the transmissions of insect-type legs for a walking robot.

The usage of “3D software technology” is a guarantee for:

- Shortening the cycle “innovative idea - innovative product”;
- Impetus the development of innovative strategies and enhancing the quality of prototypes by improving their accuracy and rapid realization of various modifications (variants) of the physical prototype;
- Speeding the process of establishing a competitive environment;
- Stimulating the innovation activity of engineers, designers, and scientists.

4. Partnerships with Companies and Scientific-Researches Centers

4.1. Partnerships with Companies in Bulgaria

- During the period 1980-1990, with the cooperation of the Madara Group- Shumen, the first generation (cutting) of the gear pairs of type Helicon are realized. For the same period of time, prototypes of non-orthogonal hyperboloid gear drives with face mating, an object of Bulgarian Patent, are elaborated. During that time the first Helicon reducer is elaborated and tested (with the cooperation of the Madara Group -Shumen, Laboratory for Testing Automobile Aggregates at the Institute of Engines and Vehicles– Sofia and the Institute of Heavy Investment Mechanical Engineering – Ruse, with the assistance of State Enterprise “Heavy Machinery” – Ruse), a “Device to the Tooth Milling Machine” was experimentally implemented in accordance with another Bulgarian invention. Large-sized Helicon gear pairs were generated through the device with a big hypoid displacement (offset).

- During the period 1994-2006, three types of Helicon reducers were created and implemented at Business Innovation Centre “CIME” JSCo—Sofia city. The created products are the result of a license agreement for a patent implementation. The technical design documentation was developed by the patent author.

These partnerships are realized under the leadership and management of Prof. Sc.D. Valentin Abadjiev.

4.2. Partnerships with Non-Bulgarian Scientific Institutions

The next two partnerships are realized by Assoc. Prof. PhD Emilia Abadjieva:

- In the period November 2012 - November 2014 a post-doctoral specialization at the University of Gifu, Gifu city, Japan is realized. The subject of specialization is “Mathematical modelling for the synthesis of spatial gear mechanisms, oriented to integration in precision mechanical systems”. During the specialization period, an optimization synthesis of two constructive types of Spiroid gear sets and two constructive variants of Helicon type hyperboloid gears with \( z_2 : z_1 = 40:10 \) and \( z_2 : z_1 = 32:8 \) gear ratios are realized. These are small module micro-gears designed to be incorporated in a bio-robot hand, belonging to the Engineering Faculty of Gifu University, Japan, as an alternative of the plane bevel gear sets with straight teeth - an element of the bio robot-hand construction. The novelty of this design solution is that the elaborated Helicon and Spiroid gear transmissions have small boundary gear ratio. This is a challenge for their optimization synthesis and design in terms of their technological realization. The reason for this is that traditional gear-pairs of this type ensure reduction transformation of rotations with gear ratios above 10 to 400.

Transmissions with boundary gear ratios (in this case, 4) are rarely used in the technique. The necessity to use such gear mechanisms incorporated into the driving of the Japanese bio-robot hand is determined by the requirements for smoothness of the rotations transformation and to control the backlash between the mating teeth.

- The time between December 2014- October 2015 is determined for participation in post-doctoral specialization in the Department of Embedded Intelligent Technologies at the Institute of Information and Communication technologies- BAS under the project AComIn: „Advanced Computing for Innovations” - FP7-REGPOT-2012-2013-1, Contract 316087. The subject of the specialization is “Analytical and software synthesis of spatial three-links mechanisms through 3 D software technology”. As a result, the opportunity appears to formulate the principles of innovative technology through 3D printing, in the practical realization of the analytical and software synthesized small modules hyperboloid gear drives of type Spiroid and Helicon with a small gear ratios. In this way, participation in this project created an opportunity to continue the ongoing researches in Japan.

- From November 2015 to the present time, Dr. Abadjieva works as an Associate Professor at Akita University, Akita, Japan. This period is characterized by work on improving the 3D software technology for the practical implementation of small-module, small sizes miniature spatial gear transmissions.

5. Future Development

The process of Bulgaria’s joining to the European Union is accompanied by a continuous and extreme increase in the importance of enhancing the competitiveness of the Bulgarian industry companies and their ability to withstand competitive pressure and economic factors. In this regard, the implementation of scientific achievements and new technologies as well as the development of innovation potential are crucial for strengthening the Bulgarian manufacture and hence for increasing employment and achieving an economic growth. In accordance with the objectives set in the Economic Reform Program accepted by the European Union (EU) in 2000, Lisbon, expanded in Gothenburg and improved in Stockholm and Barcelona, the actions of the countries, which are members of EU have to be focused on certain priority areas and the crucial importance between them has given to the promotion of the innovations.

The Lisbon process requires instruments to be found in order to promote the competitive industries with a potential for future development that could have a major impact on the restructuring of the economy. A key instrument for achieving a high competitiveness of our economy is the elaboration and consistent application of a policy for the implementation of the Bulgarian (national) innovations.

Without going into details on our national innovation policy, we will note that by Decision No 723/08.09.2004, “The Innovative Strategy of the Republic of Bulgaria” was accepted by the Council of Ministers of the Republic Bulgaria; and the constructed and further improved “Innovative Strategy for Smart Specialization 2014-2020” (Council of Ministers Decision No 384 of 13.07.2017) again puts the emphasis on the development of the scientific-researches and innovation infrastructure of the Bulgarian industry, as well as on the technological modernization in the manufacturing sector.

One of the permanent main goals of the Innovation Strategy is to create conditions for stimulating researches, in order to create innovative technologies and products and their subsequent integration into companies. The commented strategy envisages a number of measures for its realization, among which the essential one is an optimization of the science-technology-innovation relations.
On 03.11. 2015, with the Decision No 875 (Council of Ministers of the Republic Bulgaria) the new project of the innovation strategy 2014-2020 is approved. Its aim is: By 2020, Bulgaria will move from the group of "modest innovators" to the group of "moderate innovators".

The objectives and measures contained in the two national innovation strategies show unequivocally that the traveled road of researches in the treated field is right. The optimal realization of what has been done so far and the adequate continuation and refinement of the research results would be guaranteed in the conditions of a laboratory established within the “Centre of competence MIRACle – Mechatronics, Innovation, Robotics, Automation, Clean Technologies” at the Institute of Mechanics.

6. Strategy for Achieving the Purpose

6.1. Summary Tasks

- Improvement of the created and applied kinematic approach to the mathematical modeling of spatial transmissions. The theoretical researches in this direction are dictated from the necessity of the motions transformers with nonypical characteristics, in order to be incorporated in various technical systems (transport systems, lifting equipment, robots and manipulators, measuring instruments, devices for military and space industry and etc.).
- Elaboration of theory of gearing and geometry of new spatial mechanical transmissions with internal and border (face) mating, intended for transformation of type “rotation into rotation”.
- Elaboration of hyperboloid friction mechanisms: application of the kinematic theory and kinematic geometry for analysis and synthesis.
- Elaboration of “3D software technology” with application of 3D printing for synthesis and prototyping of gear transmissions with crossed axes of rotations.
- Elaboration of models and prototypes of the synthesized innovation products by applying classical metal-cutting technologies, by means of 3D printing engineering plastics, polymers, including polymer nano-composite with graphene and etc.
- Synthesis, design and technical realization of hyperboloid transmissions, including nano-gear transmissions from nano-carbon materials.
- Incorporation of the innovative “pilot” spatial gear mechanisms in industry and mechatronics products.
- Testing of the functional characteristics of the created innovative products.

6.2. Activities to Solve the Tasks

- Formulation of the common approaches for conducting of the theoretical studies and researches: construction of the elements of the kinematic geometry of the spatial motions transformation.
- Expanding the field of application of the geometric and kinematic primitives (kinematic and geometric pitch configurations) of the synthesis.
- Creation of algorithms and computer programs for analysis and synthesis of the primitives, as elements of the kinematic geometry of the spatial motions transformation.
- Elaboration of the elements, which construct different technological approaches for virtual and real prototyping of the innovative products. Application of 3D printing using polymer nano-composites.
- Patenting of the created (established) innovative methods and devices.
- Development of methodologies in accordance with current world standards, for evaluation of the quality characteristics of the created products.

6.3. Educational Programs in the Research Field

- Studying the principles and approaches of virtual prototyping.
- Studying the technologies of the usage of software and hardware for implementation of the processes of 3D scanning and 3D printing processes.
- Studying the modern technology for teeth generation by cutting, when the researched spatial gear transmissions are elaborated, as well as through the application of 3D printing and adequate nanotechnology.
- Studying of nanotechnologies for the realization of nano-gear drives by using carbon nanotubes.
- Studying the European and world regulatory base, which controls the quality of existing spatial mechanical transmissions. Creating of databases.

7. Conclusion

This review-study was part of the authors’ offer to establish a laboratory for the analysis, synthesis, design and technical implementation of innovative spatial mechanical transmissions, as a structural element of mechatronic actuators in robotics. This laboratory, in our opinion and proposal, had to be structured within the framework of the elaborated Project NoBG03SM2IP001-1.002-001, with which the Institute of Mechanics - BAS applied to the Ministry of Education and Science of Bulgaria for the construction of the “Centre of competence MIRACle – Mechatronics, Innovation, Robotics, Automation, Clean Technologies” in 2019.

Competence centers are known to be established in order to meet the basic requirement of the measures envisaged within the Operational Program "Science and Education for Intelligent Growth", namely to reverse the negative trends in the development of Bulgarian science (outdated facilities, lack of modern management approaches, lack of professionally trained staff, lack of coordination and complementing the available facilities) in the direction of enhancing top-level and market-oriented scientific research.

Despite the theoretical and applied results achieved by the authors in the field of the theory and practice of spatial mechanical transmissions, which are corresponding to the above mentioned requirements, the management of the Institute of Mechanics, represented by its former director Prof. Vasil Kavardjikov and the head of the Scientific and structural unit “Mechatronics” - Assoc. Prof. Detelina Ignatova (project manager), they ignored the scientific topics presented. They did this authoritarian without informing us. In our opinion, this voluntarism in the policy of the former leadership of the Institute of Mechanics destroys an important part of the innovative competence of this institution and, consequently, of the Bulgarian Academy of Sciences! The authors of this review, publishing the study at this prestigious international scientific conference, express their disagreement with the unjustified action of the former management of the Institute of Mechanics - BAS. We will be grateful to the scientific community for its opinion on the usefulness of this type of researches for Bulgaria.

8. References


Exergy analysis of steam condenser at various loads during the ambient temperature change

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Abstract: The paper presents an exergy analysis of steam condenser at three different loads and in the ambient temperature range between 5 °C and 20 °C. An increase in the condenser load and increase in the ambient temperature resulted with an increase in steam condenser exergy destruction. At low load, condenser exergy destruction is for the order of magnitude lower if compared to middle and high condenser loads. Decrease of the condenser load and decrease of the ambient temperature resulted with an increase in condenser exergy efficiency. The highest steam condenser exergy efficiencies are obtained at the lowest observed ambient temperature of 5 °C and amounts 81.47 % at low condenser load, 76.10 % at middle condenser load and 74.54 % at high condenser load. From the exergy viewpoint, the optimal condenser operating regime is low load and the lowest possible ambient temperature.

KEYWORDS: STEAM CONDENSER, EXERGY ANALYSIS, LOAD CHANGE, THE AMBIENT TEMPERATURE CHANGE

1. Introduction

A constituent component of any steam power plant, regardless of plant type, operation or produced power is steam condenser. Steam produced in steam generator expanded through the turbine (or more of them) after which is led to the condenser. Condenser ensures steam condensation with heat transferring from steam to cooling water [1] (or in some cases heat is transferred from steam to cooling air [2]).

Pressure inside the steam condenser is significantly lower than the atmospheric pressure (usually vacuum between 90 % and 95 %), so condenser operation also has an important influence on the low-pressure turbine process, [3, 4]. Primary vacuum in the steam condenser is ensured with steam condensation process (significant decrease in the steam volume) after which the vacuum is maintained with steam ejectors, in the most of the cases.

For the steam condenser exergy analysis, heat transfer inside the condenser, number of condenser tubes or cooling water passages through the condenser, as well as condensation type which occurs on the condenser tubes are not essential elements. Steam condenser exergy analysis can be performed by knowing temperatures, pressures and mass flows of all the fluid streams at the steam condenser inlet and outlet [5].

In this paper are presented the results of the steam condenser exergy analysis at three different loads. The analyzed steam condenser is a water cooled condenser. As the exergy analysis is very dependable on the ambient temperature, at each condenser load the ambient temperature is varied in order to obtain steam condenser exergy losses and efficiencies at different ambient temperatures.

2. Analyzed steam condenser description, scheme and required operating points

Analyzed steam condenser operates in a cogeneration power plant [6]. Steam condenser main scheme and operating points necessary for the exergy analysis are presented in Fig. 1.

Condenser main function is to condense steam after expansion in a steam turbine. In an ideal situation, condensate temperature is the same as steam temperature, but in the real process due to losses, condensate has lower temperature. Analyzed condenser, along with steam condensation must ensure complete condensation of the additional condensate stream which is delivered to condenser from the low-pressure condensate heater (operating point 2, Fig. 1).

To ensure steam condensation, heat is transferred from steam to cooling water which passes through condenser tubes. Cooling water is delivered to steam condenser by pump from cooling tower, and after heat transferring, cooling water with increased temperature is delivered back into the cooling tower which decreases its temperature. There are several types of condensation process which can occur on the condenser tubes [7]. After steam condensation, obtained condensate at the condenser bottom is taken by condensate pump [8] and delivered to condensate heating system.

The analyzed steam condenser is closed heat exchanger (operating fluids exchange heat, but are not mixed together - heat exchange occurs on the condenser tubes). So, steam condenser exergy analysis can be performed as for any other closed heat exchanger [9].

![Fig. 1. Steam condenser scheme and marked operating points necessary for the exergy analysis](Image)

3. Equations necessary for the exergy analysis

3.1. Exergy analysis overall equations

Exergy analysis of any system or a control volume is defined according to the second law of thermodynamics, [10, 11]. The exergy balance equation for a control volume or a system in steady state, according to [12], can be defined by following equation:

\[
\dot{X}_{\text{heat}} - P = \sum \dot{m}^{\text{OUT}} \cdot e^{\text{OUT}} - \sum \dot{m}^{\text{IN}} \cdot e^{\text{IN}} + \dot{E}_{\text{ex,d}}.
\]

(1)

The mass balance equation for a control volume or a system in steady state, according to [13, 14], with assuming of no leakage occurrence, is defined as:

\[
\Sigma \dot{m}^{\text{IN}} = \Sigma \dot{m}^{\text{OUT}}.
\]

(2)

Specific exergy is defined by an equation [15]:

\[
e = (h - h_0) - T_0 \cdot (s - s_0).
\]

(3)

The heat exergy transfer (\(\dot{X}_{\text{heat}}\)) at temperature \(T\) [16], is:

\[
\dot{X}_{\text{heat}} = \Sigma (1 - \frac{T_0}{T}) \cdot \dot{Q}.
\]

(4)

The exergy power of any fluid flow, according to [17], can be defined as:

\[
\dot{E}_{\text{ex}} = \dot{m} \cdot e = \dot{m} \cdot [(h - h_0) - T_0 \cdot (s - s_0)].
\]

(5)

The overall definition of exergy efficiency is [18]:
Exergy analysis of the steam condenser is performed with the same equations at each observed load (the changeable elements were temperatures, pressures and mass flows in each condenser operating point presented in Fig. 1). Steam condenser exergy analysis (as well as exergy analysis of any control volume or entire system) is dependable on the conditions of the ambient in which control volume or system operates.

The selected ambient conditions for the steam condenser exergy analysis are the ambient pressure of 1 bar and the ambient temperature of 15 °C. These ambient conditions are declared as the base ambient state. Ambient state in the steam condenser exergy analysis will be changed with a change in the ambient temperature (the ambient pressure will remain unchanged and equal to 1 bar).

Several scientists performed an exergy analysis of steam systems [2] or its components [19] by varying the ambient temperature. Change in the ambient temperature during steam system or its component operation can be significant and can have a notable impact on the exergy analysis [20].

Equations for the exergy analysis of steam condenser investigated in this paper are presented in relation to steam condenser operating points from Fig. 1:

**Mass balance**

- Steam/condensate mass flow balance:
  \[ m_3 = m_1 + m_2 . \]  

- Cooling water mass flow balance:
  \[ m_4 = m_3 . \]

**Exergy balance**

- Steam condenser exergy power input:
  \[ E_{\text{ex,IN}} = m_1 e_1 + m_2 e_2 - m_3 e_3 . \]  

- Steam condenser exergy power output:
  \[ E_{\text{ex,OUT}} = m_4 e_4 . \]  

- Steam condenser exergy destruction:
  \[ E_{\text{ex,D}} = E_{\text{ex,IN}} - E_{\text{ex,OUT}} = m_1 e_1 + m_2 e_2 - m_3 e_3 - m_4 e_4 . \]  

- Steam condenser exergy efficiency:
  \[ \eta_{\text{ex}} = \frac{E_{\text{ex,OUT}}}{E_{\text{ex,IN}}} = \frac{m_4 e_4}{m_1 e_1 + m_2 e_2 - m_3 e_3} . \]

### 3.2. Analyzed steam condenser exergy analysis equations

Data for steam condenser exergy analysis (temperatures, pressures and mass flows of each fluid stream) are found in [6] for each condenser load. The steam condenser load is defined according to steam mass flow which enters into the condenser after expansion in the turbine (operating point 1, Fig. 1) - higher steam mass flow which enters into the condenser denotes higher load, Table 1, Table 2 and Table 3.

For any fluid flow stream at each observed steam condenser load specific enthalpies and specific exergies were calculated by using NIST REFPROP 9.0 software [21]. Specific exergy of each fluid flow stream is dependable on the ambient conditions; therefore specific exergies of each fluid flow stream in Table 1, Table 2 and Table 3 are presented for the base ambient state.

### Table 1. Operating parameters of the analyzed steam condenser - low condenser load

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (°C)</th>
<th>Pressure (bar)</th>
<th>Mass flow (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41.51</td>
<td>0.08</td>
<td>14.750</td>
<td>2348.00</td>
<td>187.880</td>
</tr>
<tr>
<td>2</td>
<td>41.51</td>
<td>0.08</td>
<td>1.833</td>
<td>490.80</td>
<td>31.415</td>
</tr>
<tr>
<td>3</td>
<td>41.51</td>
<td>0.08</td>
<td>16.583</td>
<td>175.80</td>
<td>4.878</td>
</tr>
<tr>
<td>4</td>
<td>29.41</td>
<td>5.00</td>
<td>826.389</td>
<td>123.70</td>
<td>1.857</td>
</tr>
<tr>
<td>5</td>
<td>38.84</td>
<td>5.00</td>
<td>826.389</td>
<td>163.10</td>
<td>4.306</td>
</tr>
</tbody>
</table>

* O. P. = Operating Point (according to Fig. 1)

### Table 2. Operating parameters of the analyzed steam condenser - middle condenser load

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (°C)</th>
<th>Pressure (bar)</th>
<th>Mass flow (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.42</td>
<td>0.12</td>
<td>22.361</td>
<td>2372.00</td>
<td>238.900</td>
</tr>
<tr>
<td>2</td>
<td>49.42</td>
<td>0.12</td>
<td>3.222</td>
<td>564.40</td>
<td>46.022</td>
</tr>
<tr>
<td>3</td>
<td>49.42</td>
<td>0.12</td>
<td>25.583</td>
<td>207.70</td>
<td>7.961</td>
</tr>
<tr>
<td>4</td>
<td>30.48</td>
<td>5.00</td>
<td>826.389</td>
<td>128.20</td>
<td>2.079</td>
</tr>
<tr>
<td>5</td>
<td>44.82</td>
<td>5.00</td>
<td>826.389</td>
<td>188.10</td>
<td>6.435</td>
</tr>
</tbody>
</table>

* O. P. = Operating Point (according to Fig. 1)

### Table 3. Operating parameters of the analyzed steam condenser - high condenser load

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (°C)</th>
<th>Pressure (bar)</th>
<th>Mass flow (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51.03</td>
<td>0.13</td>
<td>23.417</td>
<td>2358.00</td>
<td>246.960</td>
</tr>
<tr>
<td>2</td>
<td>51.03</td>
<td>0.13</td>
<td>3.139</td>
<td>553.60</td>
<td>46.399</td>
</tr>
<tr>
<td>3</td>
<td>50.40</td>
<td>0.13</td>
<td>26.556</td>
<td>211.00</td>
<td>8.320</td>
</tr>
<tr>
<td>4</td>
<td>30.58</td>
<td>5.00</td>
<td>826.389</td>
<td>128.60</td>
<td>2.100</td>
</tr>
<tr>
<td>5</td>
<td>45.44</td>
<td>5.00</td>
<td>826.389</td>
<td>190.70</td>
<td>6.681</td>
</tr>
</tbody>
</table>

* O. P. = Operating Point (according to Fig. 1)

### 5. Results of steam condenser exergy analysis at three different loads and discussion

Each calculated operating parameter in the steam condenser exergy analysis is presented for the various ambient temperatures. The ambient temperature was varied in a range from 5 °C to 20 °C, with a step of 5 °C.

The change in exergy power of three the most dominant exergy flows from the analyzed steam condenser are presented in Fig. 2 - at high condenser load. The exergy power of each flow stream, at any ambient temperature, is calculated by using Eq. 5.

The most dominant exergy flows are steam flow at the condenser inlet (operating point 1, Fig. 1) due to the highest specific exergy when compared with other steam flows. The second and third most dominant flows are cooling water flow at the steam condenser inlet and outlet (operating points 4 and 5, Fig. 1) due to the highest mass flows when compared with other steam flows.
Steam condenser exergy power input at each condenser load and at each ambient temperature is calculated by using Eq. 9. Considering of steam condenser load, the highest condenser exergy power input can be seen at the high condenser load, while the lowest condenser exergy power input is calculated on low condenser load, Fig. 3, regardless of the ambient temperature. Decrease of the ambient temperature resulted with an increase in condenser exergy power input, regardless of condenser load.

Fig. 3. Change in analyzed steam condenser exergy power input for the different ambient temperatures at three condenser loads

At each condenser load and at each ambient temperature analyzed steam condenser exergy power output is calculated according to Eq. 10. Change in condenser exergy power output at any load and at any ambient temperature has identical trend as the change in condenser exergy power input, Fig. 4. The highest condenser exergy power output is calculated at high condenser load and the lowest condenser exergy power output is calculated at low condenser load, regardless of the ambient temperature. An increase in the ambient temperature resulted with a decrease in condenser exergy power output, regardless of condenser load.

Fig. 4. Change in analyzed steam condenser exergy power output for the different ambient temperatures at three condenser loads

Exergy destruction (exergy loss) of the analyzed steam condenser at any ambient temperature and at any load is calculated by using Eq. 11. From Fig. 5 can be seen that condenser exergy destructions at low load are much smaller in comparison with exergy destructions at middle and high condenser load, therefore they cannot be presented at the same vertical axis. Regardless of the condenser load, decrease in the ambient temperature resulted with a decrease in condenser exergy destruction, so the lowest condenser exergy destructions are obtained at the lowest observed ambient temperature.

Regardless of the ambient temperature, steam condenser exergy destructions are the lowest at low condenser load and then increases with an increase in condenser load. At the base ambient state (the ambient temperature of 15 °C), condenser exergy destructions amounts 724.35 kW - low load, 1687.44 kW - middle load and 1921.92 kW - high load. From the lowest to the highest observed condenser load, exergy destructions are the lowest at the ambient temperature of 5 °C and amounts 701.16 kW, 1630.52 kW and 1856.39 kW, while at the highest observed ambient temperature of 20 °C condenser exergy destructions are the highest and amounts 735.82 kW, 1715.90 kW and 1954.87 kW, Fig. 5.

From the viewpoint of steam condenser exergy destruction only, for the analyzed steam condenser will be preferable to operate at the ambient temperature as low as possible.

Fig. 5. Change in analyzed steam condenser exergy destruction for the different ambient temperatures at three condenser loads

Eq. 12 is used for calculation of the analyzed steam condenser exergy efficiency at all observed ambient temperatures and at all observed condenser loads.

Exergy efficiency of steam condenser is the highest at low condenser load and ranges between 67.00 % and 81.47 % in the observed ambient temperature range, Fig. 6. In the same observed ambient temperature range, condenser exergy efficiency is between 62.03 % and 76.10 % at middle and between 60.23 % and 74.54 % at high condenser load. Therefore, it can be concluded that the lowest condenser exergy efficiencies will be obtained at the high condenser load - decrease in condenser load will result with an increase in condenser exergy efficiency, regardless of the ambient temperature. At each observed steam condenser load, the highest exergy efficiencies are obtained for the lowest observed ambient temperature of 5 °C - 81.47 % at low condenser load, 76.10 % at middle condenser load and 74.54 % at high condenser load.

An increase in the ambient temperature significantly decreases analyzed steam condenser exergy efficiency, regardless of observed condenser load, Fig. 6.

Fig. 6. Change in analyzed steam condenser exergy efficiency for the different ambient temperatures at three condenser loads

Further research of the analyzed steam condenser will be based on its optimization by using several artificial intelligence approaches [22, 23].

6. Conclusions

The paper presents an exergy analysis of steam condenser from cogeneration power plant. Steam condenser is analyzed at three different loads and in a range of the ambient temperatures (ambient temperature is varied between 5 °C and 20 °C). Presented analysis detected steam condenser operating regime and the ambient temperature at which the condenser operation will be preferable from the exergy aspect. The most important conclusions of the steam condenser analysis are:

- The change in steam condenser exergy power inputs and outputs has the same trend - condenser exergy power inputs and outputs increases with an increase in condenser load and also increases with a decrease in the ambient temperature.
8. References


Abstract: Vibration diagnostics of rotary equipment is one of the reliable methods for preventing accidents and predicting equipment life. This article will discuss the theoretical principles of the impeller’s fan bearings spectral analysis of vibration, as well as the method practical application.

KEYWORDS: VIBRATION DIAGNOSTICS, LIFETIME PREDICTION, ANALYSIS OF THE BEARINGS CONDITION.

1. Introduction

All metallurgical enterprises have a large amount of rotor equipment. All this equipment has rolling bearings. These bearings are very important components of the equipment. When the bearing fails, the equipment becomes unusable. Therefore, it is necessary to constantly monitor the condition of the bearings. It is very important to determine the defect in time, make a forecast for its development, order the necessary spare parts and to plan the repair. To do this, the company should have a non-destructive testing service for equipment, which should regularly examine critical equipment and provide recommendations. This is especially important for responsible equipment, which directly affects the manufacture of products. Therefore, timely repair of this equipment can save a lot of money.

2. Mathematical calculation of vibration information frequencies of rolling bearings

Rolling bearing’s work in centrifugal fans or electrical motors composition and at presence faults in it can influence on a vibration and modulating it processes with the followings fundamental frequencies [1]:

- Rotation frequency of movable ring in relation to immobile: \( f_{rot} \);
- Rotation frequency of separator in relation to an outer ring:
  \[
  f_s = \frac{1}{2} f_{rot} \left( 1 + \frac{d_{sr}}{d_{rot}} \cos(\alpha) \right) \tag{1} \]
  Where: \( d_{sr} \) - solid of revolution diameter;
  \( d_{rot} \approx \frac{1}{2} (d_{out} - d_{in}) \) - Diameter of separator;
  \( d_{out} \) - Diameter of outer ring;
  \( d_{in} \) - Diameter of inner ring;
  \( \alpha \) - contact angle of bodies and rolling paths;
- Rolling frequency of solid of revolution on an inner ring:
  \[
  f_{in} = \frac{1}{2} f_{rot} \left( 1 + \frac{d_{sr}}{d_{in}} \cos(\alpha) \right) + (f_{rot} - f_s) z \tag{2} \]
- Rolling frequency of solids of revolution in relation to the surface of rings:
  \[
  f_{sr} = \frac{1}{2} f_{rot} \frac{d_{sr}}{d_{in}} \left( 1 - \frac{d_{sr}^2}{d_{in}^2} \cos^2(\alpha) \right) \tag{3} \]

Expressions (Eq.1, Eq.2, Eq.3, and Eq.4) are evaluating only basic harmonics frequencies in the vibration spectrums and envelope of its high-frequency components at the different types of defects [1].

3. Vibration diagnostics of the main centrifugal fan.

The object of vibration diagnostics is the impeller’s bearings of the main centrifugal fan of the electric furnace.

To enhance the outflow of exhaust gases from the working space of the electric furnace, 4 fans are required: 3 main fans and 1 booster fan. An electric furnace installed at one of the metallurgical enterprises is necessary for the smelting of metal scrap and the production of fittings.

This article discusses an example of vibration diagnostics for the main fan Nr.1. The smoke exhaust unit consists of a centrifugal smoke fan and a driving electric motor. During the experiment, the bearings of the impeller of the main centrifugal smoke fan were controlled (see Fig. 1.).

On the impeller shaft of the fan, 2 control points were selected (see Fig.1): Point Nr.1 - Floating bearing TYPE SNL 226 TG (bearing C2226 - C3); Point Nr.2 - Fixed bearing TYPE SNL 226 TG (bearing 22226 E - C3);

The operating mode of the unit is round-the-clock. Vibration sensors - accelerometers were installed horizontally.
Fig. 1. The impeller of the main exhaust fan mounted in the bearing housings with control points of vibration.

Fig. 2. The part of vibration direct spectrum (point Nr. 1).

Fig. 3. The part of vibration envelope spectrum (point Nr. 1).
4. The vibration diagnostics route of the main fan impeller’s bearings

The vibration monitoring of the main fan impeller’s bearings is possible in two ways:
1. Use a portable system for collecting and analyzing information.
2. Using a stationary system for collecting and analyzing information.

Which system to use – the company must decide. If in the company is separate NDT (nondestructive testing) service, preferable to install a stationary vibration monitoring system.

The stationary monitoring system is needed above all things for a multimode strength equipment, guided an auxiliary personnel. Exactly personnel errors is more frequent than all are the defects multiplying reason of the guided equipment, which it must find out practically instantly (for a few turns of rotor) for failure timely prevention [2].

On Figure 4 the simplified structure of the vibration monitoring and diagnostics stationary system is shown [2].

Fig.4 Structure of the vibration monitoring and diagnostics stationary system [2].

1 - The computer with special software; 2 - The Signals transformation card in digital form; 3 - Vibration sensors; 4 – Supervising equipment [2].

During vibration monitoring of the main fan impeller’s bearings has been used route, consisting of the following components:

1. **Direct spectrum AS1 dB(A):** \(- F_a = 800Hz\); the number of lines in the spectrum - 400; the number of averages - 10.
2. **Envelope spectrum ES1 dB(A):** limit frequency - \( F_a = 400Hz \); bandpass filter - \( F_a = 10kHz \); the number of lines in the spectrum - 400; the number of averages - 12.
3. **Overall level of vibration OVLV dB(A):** Detector - RMS; bandpass filter - \( F_a = 10-25kHz \); the number of samples - 6.
4. **Time signal TS (m / s²):** the sampling frequency - 1024 Hz; bandpass filter - \( F_a = 8kHz \); the number of samples - 4000.

In the system of vibration diagnostics that was used in this study, there is the software for automatic diagnostics. But if in doubt, you can examine the spectra, the time signal of vibration and the vibration level manually. For instance, when checking and analyzing the vibration of the impeller bearings, the state of the points Nr. 2 is in satisfactory condition. The condition of the point Nr. 1 is much worse.

The automatic diagnostic program gives a warning that there is wear of the bearing’s rolling elements and the separator - 5% with 50% probability, as well as the imbalance of the rotor 12dB with 90% probability. Therefore, it was decided to reduce the time interval between the dates of control. Figure 2 shows the direct spectrum of vibration control with an interval of 2 weeks for point Nr. 1. Figure 3 shows the spectrum of the vibration envelope control with an interval of 2 weeks for point Nr. 1.

Figures 2 and 3 shows parts of the vibration spectra: the direct spectrum (see Fig. 2) and the envelope spectrum (see Fig. 3). Each figure shows the spectrum for 07/06/2012 (blue line) and 07/19/2012 (red line), respectively. In each figure, on the spectrum graphs, a frequency of 153.31 Hz is selected, which corresponds to the frequency of rolling elements rotation along the inner ring of the bearing.

Analyzing this example, we can conclude that the condition of the bearing is deteriorating and it is necessary to take appropriate measures, for example, to analyze the quality of bearing lubrication.

5. Conclusions

The analysis of the vibration spectra of the main smoke exhaust fan impeller’s bearings of the electric melting furnace conducted in this study allows to conclude that constant monitoring and analysis of the bearing’s vibration can significantly increase the equipment’s life. Based on the study’s results, it is obvious that the condition of the bearings of the equipment may gradually deteriorate, and may deteriorate very rapidly. Therefore, it is very important not only to know the condition of the bearings at the moment, but also need to analyze the situation to find out the reasons for the deterioration of the technical condition of the equipment. To ensure timely monitoring and analysis of vibration, it is necessary to have the appropriate equipment and trained personnel.

All these activities makes possible to significantly reduce the costs of the equipment, to extend the term of its operation, as well as improve the quality of products. The company must have a diagnostic service (NDT - nondestructive testing) that provides vibration monitoring and forecasting the state of the equipment. It is also necessary to establish the system of remote monitoring equipment and portable systems. The cost of equipment and software for the diagnosis is usually recouped within a year at its regular use.

**Literature**

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Методика за определяне на ресурса на работа на търкалящ лагер

Methodology of determining rolling bearing operation resource

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Abstract: The bearing is a standardized machine part that allows the relative movement (rotation) of a shaft relative to another stationary part. In this movement the bearing must also perform a number of functions: to assume a certain load by type, size and direction, to ensure precision of movement with minimal friction, etc. In the present-day machine-building, depending on the functions listed, different types of bearings are used, as the most commonly used are the rolling bearings. These bearings are manufactured with sufficiently high accuracy and precision, which ensures the minimum friction losses during their operation. However, over time, the bearings are worn out, i.e., they have a certain resource of work. In accordance with the most literary sources, the main factor, determining of the rolling bearing operation resource is the loading that it should bear. The purpose of the study is to investigate the influence of the static and dynamic loading on the rolling bearing during its operation, and to develop a methodology for determination of its operation resource, depending on the equivalent loading at reporting the specific conditions. The methodology thus created, suggests more complete and accurate determination of the rolling bearing operation resource, which is important in terms of scheduled servicing of the machine, and avoiding unintended production stoppages for emergency repairs and possible incidents.

Keywords: METHODOLOGY, OPERATION RESOURCE, ROLLING BEARING,

1. Въведение

Лагерът представлява стандартизирана машина част, която позволява относителното движение (въртенето) на вал спрямо друг неподвижен детайл. При това движение лагерът трябва да изпълнява и редица функции – да поема определено натоварване по вид и големина, да осигурира прецизност на движението при минимално трение и други. В съвременното машинопроизводствен в зависимост от избраните функции се използват различни видове лагери, като най-често употребяваните са търкалящите лагери. Най-общо конструкцията им се състои от външен и вътрешен пръстен, а между тях се намира търкалящият елемент – сфера (сачма), ролка с цилиндрична или конична форма и други, които осигуряват относителното движение на пръстените един спрямо друг (Фиг. 1).

Фиг. 1 Различни конструктивни изпълнения на търкалящи лагери.

Лагерите се изработват с достатъчно висока точност и прецизност, което осигурява и минималните загуби на трение при работата им. Въпреки това с течение на времето и под въздействието на натоварването лагерите се износват, т.е. те имат определен ресурс на работа. Ето защо е важно да се знае за всеки конкретен случай на използване на търкалящ лагер какъв ще бъде ресурсът му на работа, което ще позволи да се направи съответен график за планово обслужване на машината и да се избегнат нежелани спираня на производството за аварийни ремонти и евентуални инциденти.

От направеното проучване в специализираната литература [1,3,4] се установи, че въпреки все по-широкото използване на търкалящите лагери в съвременната машинопроизводствена практика, липсва методика за определяне на ресурса на работата им, който се явява важен параметър за прогнозиране на поведението на търкалящия лагер по време на експлоатацията му. Предварителните анализи на литературните източници показват, че най-голямо влияние върху износването, респ. ресурса на търкалящите лагери оказва натоварването, при което те работят [2]. В същото време в повечето литературни източници се използва статичното натоварване на търкалящия лагер, без да е изследвано влиянието както на динамичното натоварване, така и на останалите фактори (отклонения от формата, скорост на въртене, мазане и други), което би дало по-пълна картина за ресурса на работа.

Целта на предлаганата статия е да се изследва влиянието на динамичното натоварване върху търкалящия лагер по време на експлоатацията му и създаване на методика за определяне на ресурса му на работа в зависимост от номиналното изчислително динамично натоварване и еквивалентното натоварване при отчитане на конкретните условия.

2. Методика за определяне на ресурса на работа на търкалящ лагер

2.1. Фактори, предизвикващи умора на търкалящ лагер

От направения по-горе анализ на конструкцията на търкалящ лагер може да се направи извода, че контактът между търкалящите елементи и пръстените, които обхващат тези елементи, предполага високо специфично натоварване. В резултат на това в лагера са налице следните явления:
Напрежения на натиск, с максимална стойност по повърхността на пръстените, които достигат до 3500 МПа;
Напрежения на срязване, действащи под повърхността на пръстените и достигащи стойност около 1000 МПа.

Освен това трябва да се добави и че тези високи напрежения, вследствие на въртенето на лагера, се променят циклично. Съчетаването на двата фактора - напрежения и цикличност за един по-кратък или по-дълъг период от време на работа на лагера, води до умора на метала, която се заражда в дълбочина на пръстените и впоследствие се проявява на повърхността им под формата на пукнатини, които провокират отначало микрооткъртвания на материал, а впоследствие и по-големи такива (Фиг. 2).

Фиг. 2. Микрографска снимка на развитието на откъртвания при умора на материала на лагерен пръстен

Феноменът умора на търкалящ лагер, свързан с интензивността и броя на цикличните напрежения, на които е подложен металът във всяка точка на пръстена, може да се използва за дефиниране на понятието ресурс на работа на лагера като брой завъртания, които лагерът може да извърши, преди да се появят първите признаки на умора на материала.

2.2. Номинално изчислително динамично натоварване С
Номиналното изчислително динамично натоварване С е натоварването, при което лагерите имат номинален ресурс на работа L100, от един милион завъртания.

2.2.1. За радиален сачмен едноредов лагер Cр
Номиналното изчислително динамично радиално натоварване за радиален тип лагери се определя по следната зависимост [5]:

\[ C_r = b_m f_c (icosa)^{0.7} Z^{2/3} D_w^{1.8} \]
за \( D_w \leq 25.4 \) mm и

\[ C_r = 3.647 b_m f_c (icosa)^{0.7} Z^{2/3} D_w^{1.8} \]
за \( D_w > 25.4 \) mm,
където:
\( D_w \) – номинален диаметър на сачмата, mm
\( i \) – брой редове на търкалящите елементи (в случай \( i = 1 \)),
\( b_m \) – ресурсен фактор, зависещ от начина на използване на лагера, качеството и термообработката на лагерната стомана и други. За едноредови радиални лагери обикновено \( b_m = 1.3 \).
\( f_c \) – фактор, зависещ от геометрията на лагерните елементи, начина на обработването им и материала,
\( Z \) – брой на търкалящите елементи в ред,
\( \alpha \) – ъгъл на контакт.

2.2.2. За аксиален сачмен едноредов лагер Ca
Зависимостите за номиналното изчислително динамично аксиално натоварване за този тип лагери са следните [5]:

\[ C_a = b_m f_c Z^{2/3} D_w^{1.8} \]
за \( D_w \leq 25.4 \) mm, \( \alpha = 90^\circ \);

\[ C_a = b_m f_c (cos\alpha)^{0.7} \tan \alpha Z^{2/3} D_w^{1.8} \]
за \( D_w \leq 25.4 \) mm, \( \alpha \neq 90^\circ \);

\[ C_a = 3.647 b_m f_c Z^{2/3} D_w^{1.4} \]
за \( D_w > 25.4 \) mm, \( \alpha = 90^\circ \) и

\[ C_a = 3.647 b_m f_c (cos\alpha)^{0.7} \tan \alpha Z^{2/3} D_w^{1.4} \]
за \( D_w > 25.4 \) mm, \( \alpha \neq 90^\circ \).

2.3. Динамично еквивалентно натоварване
2.3.1. За радиален сачмен едноредов лагер
Товарноносимостта на един търкалиц лагер по принцип се дефинира посредством номиналното изчислително динамично натоварване в радиално направление (радиалното натоварване при нулева хлабина), което той може да понесе. В случаи, че лагерът работи в комбинация от аксиална компонента на актуалния \( F_a \) и радиална компонента на актуалния \( F_r \) натоварване, тя трябва да се преобразува в динамично еквивалентно радиално натоварване \( P \). За радиални едноредови сачмени лагери за целта се използват следните формули [5]:

\[ P = \sqrt{F_a^2 + (\frac{F_r}{\sin \alpha})^2} \]
(7) \( P_r = F_r \), ако \( F_r/F_i \leq e \)
(8) \( P_r = X F_r + Y F_a \), ако \( F_r/F_i > e \),
където :
\( X \) – коефициент за радиално натоварване,
\( Y \) – коефициент за аксиално натоварване,
\( e \) – гранична стойност за \( F_r/F_i \) в зависимост от стойностите на коефициентите \( X \) и \( Y \).

Стоиностите на \( X \), \( Y \) и \( e \) са дадени в справочната литература [2,5].

2.3.2. За аксиален сачмен едноредов лагер
(9) \( P_a = F_a \), ако \( \alpha = 90^\circ \),
(10) \( P_a = X F_r + Y F_a \) ако \( \alpha \neq 90^\circ \).

2.4. Уравновесено еквивалентно натоварване
При промяна на актуалното натоварване по линеен закон между две стойности \( F_{\text{min}} \) и \( F_{\text{max}} \) определянето се извършва по формулата :
(11) \( F_e = 1/3(F_{\text{min}} + 2F_{\text{max}}) \)

Когато това натоварване се промения синусоидално между 0 и някаква максимална стойност \( F_{\text{max}} \) тогава
(12) \( F_e = 0,65 F_{\text{max}} \)

Ако натоварването върху лагера се промения по неизвестен закон, зависимостта е
(13) \( F_e = \sqrt{\sum |A_i| P_i} \), където \( \sum |A_i| = 1 \).

2.5. Номинално изчислително статично натоварване \( C_0 \)
В някои случаи функционирането на лагерите може да се извършва в много специфични условия : продължителни престои под натоварване, бавно въртене под натоварване, бавно въртене в противоположна посока и други. При това положение той е подложен на статично натоварване, което предизвиква постоянни локални деформации, оказващи вредно влияние при въртене.

Номиналното статично натоварване \( C_0 \) определя максимално допустимото радиално натоварване да бъде такова, че възникващото в неподвижен лагер напрежение да бъде в нормални стойности за повечето специфични случаи, без да се намалява ресурсът на работа или да се компрометира въртенето на лагера.

2.6. Номинален ресурс на работа на търкалящ лагер \( L_{10} \)
2.6.1. За радиален сачмен едноредов лагер
Когато натоварването върху еднореден лагер е в радиално направление, хлабината е практически нулева и усилията са съсредоточени в средата на търкалящия елемент, номиналният ресурс на работа \( L_{10} \) въз основа функция на натоварването се определя по следната формула [5] :
(14) \( L_{10} = (C_0/P_a)^n \cdot 10^6 \) завъртания,
където :
\( C_r \) – номинално изчислително динамично радиално натоварване, \( N \)
\( P_r \) – динамично еквивалентно радиално натоварване, \( N \)
\( n = 3 \) за сачмени лагери,
\( n = 10/3 \) за ролкови лагери.

2.6.1. За аксиален сачмен едноредов лагер
(15) \( L_{10} = (C_a/P_a)^3 \cdot 10^6 \),
където :
\( C_a \) – номинално изчислително динамично натоварване за радиален лагер, \( N \)
\( P_a \) – динамично еквивалентно натоварване за радиален лагер, \( N \).

Приблизително 30% от изпитваните от един и същ тип лагери достигат ресурс, равен на 5 пъти номиналния \( L_{10} \), а при около 10 % ресурсът е равен на 8 пъти номиналния \( L_{10} \).

3. Влияние на условията на работа върху ресурса на лагера
3.1. Отклонения на формата
Някои отклонения в геометричната форма на вала или отвора като овалност, коничност и други могат да доведат до локално претоварване на търкалящия лагер.

3.2. Хлабина при функциониране на лагера
Повечето производители на търкалящи лагери препоръчват и съответни стойности на хлабината, при които лагерите да работят, тъй като нормалната хлабина при функционирането на лагера оказва слабо влияние върху ресурса му на работа [2]. При по-различни стойности на хлабината може да се получи претоварване, което ще е с тежки последици за този ресурс (Фиг. 3).

Фиг. 3. Влияние на аксиалната хлабина върху ресурса на работа на лагера
Ето защо в повечето случаи, при които не е поставено някакво специално изискване, лагерите се сглобяват с препоръчаната от производителя хлабина, за да се избегнат посочените по-горе рискове и да се улесни регулирането и мазането на лагера.

3.3. Влияние на скоростта
Прекомерно висока скорост на лагера увеличава вероятността от вътрешно прегряване, води до по-високи центробежни сили и вибрации.

3.4. Влияние на температурата
Вътрешните хлабини в търкалящ лагер се изменят във функция на температурата. Приема се, че нормалната температура за функционирането на един лагер е между -20°С и +120°С. Влиянието на температурата, които са извън посочените граници, се изразява в следното:

- Компрометиране на свойствата на смазката;
- Изменения във формата на уплътненията;
- Изменения във формата на сепараторите на лагера, ако са изработени от синтетични материали;
- Промени в структурата на металните части на лагера.

За нормалната работоспособност на лагерите в посочения диапазон от температури те се подлагат на специална термична обработка.

3.5. Мазане на лагерите
Принципното значение на смазката при лагерите е да се създаде маслен филм между търкалящите елементи и техните канали в пръстените със смазката; забавянето на износването от недопустимо високи повърхностни напрежения на вътрешните хлабини в търкалящия лагер се изменят във функция на температурата. Приема се, че нормалната температура за функционирането на един лагер е между -20°С и +120°С. Влиянието на температурата, които са извън посочените граници, се изразява в следното:

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За нормалната работоспособност на лагерите в посочения диапазон от температури те се подлагат на специална термична обработка.

3.5. Мазане на лагерите
Принципното значение на смазката при лагерите е да се създаде маслен филм между търкалящите елементи и техните канали в пръстените със смазката; забавянето на износването от недопустимо високи повърхностни напрежения на вътрешните хлабини в търкалящия лагер се изменят във функция на температурата. Приема се, че нормалната температура за функционирането на един лагер е между -20°С и +120°С. Влиянието на температурата, които са извън посочените граници, се изразява в следното:

- Компрометиране на свойствата на смазката;
- Изменения във формата на уплътненията;
- Изменения във формата на сепараторите на лагера, ако са изработени от синтетични материали;
- Промени в структурата на металните части на лагера.

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- Промени в структурата на металните части на лагера.
Investigation of the dependence of axial force and torque on the geometric parameters of carbide micro-drills with variable slopes of spiral grooves

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Abstract: Micro-drilling (MD or μD) is type of machining (processing) technology used for the drilling of miniaturized parts of small diameter in micro-scale, i.e. diameter in a range of a few microns to several hundred microns. In paper is given the dependence of axial efforts and torque on different modes of depth of drilling in micro-drilling with micro-drills from solid alloy VK60M with standard rake angle ω=30° and fz=0.01 [mm/turn]

KEY WORDS: INDUSTRY 4.0, MICRO-DRILLS, AXIAL FORCE, TORQUE, REGRESSION MODEL.

1. Introduction

The new knowledge society (KS) or knowledge based society (KBS) and "Industry 4.0" condition the accelerated development and use of new technology, materials and production systems in combination with digital technologies: Internet of Services (IoS), Internet of People (IoP), Internet of Things (IoT), Industrial Internet of Things (IIoT), Internet of Everything (IoE), Cloud Computing (CC) and etc. [1-4, 10-11, 13, 17, 19-21, 30-31, 34, 36, 38].

In knowledge society (KS) and "Industry 4.0" and today's fast-paced world with a large number of important applications of one of the most emerging and growing fields of production technologies are micro and nano-machining [22].

Micro- and nano-machining are the most promising technology for the production of miniaturized parts in micro- and nano-scale. Compound micro- and nano-machining is becoming more and more important and popular because of growing demand for industrial products with not only increased number of functions but also of reduced dimensions, higher dimensional accuracy and better surface finish. Micro- and nano-machining are required in a large number of fields like biotechnology, electronics, medicine, optics, aviation’s, automobile and communication and etc. [22].

2. Micro-drilling

Micro-drilling (MD or μD) is type of machining (processing) technology used for the drilling of miniaturized parts of small diameter in micro-scale, i.e. diameter in a range of a few microns to several hundred microns. Micro-drilling using micro drill bits possesses the same features as that of the macro scale drilling but slightly different ones. This uses a special drill geometry, tool holding devices, drilling cycle and speeds of drilling [15, 22-23, 25]. In paper [14] is presented analysis of dynamic characteristics of micro-drills, in papers [16, 18, 24] is presented analysis of stresses in micro-drills, cutting performance of micro-drills is presented in papers [23] optimization of geometric parameters of micro-drills in papers [27-29, 33, 35], wear mechanisms of micro-drills in papers [37] and etc.

On Fig. 1 is given micro-drilling with micro-drills on the CNC machine of the firm DATRON (Web site: https://www.datron.com/).

Micro-drilling is applied in industries such as electronics, aerospace, medicine and automobiles for machining parts with a diameter of several microns, due to a significant uptake in the use of miniaturised products and devices.

Fig. 1. Micro-drilling with micro-drills on the CNC machine of the firm DATRON

A number of different micro-drilling techniques have been developed that can generally be classified into [15]: conventional and non-conventional micro-drilling techniques. Conventional micro drilling makes use of drill bits of different configurations such as: twist, spade, D-shaped, single flute, compound drill and coated micro drill, while non-conventional micro drilling involves electrical, chemical, mechanical and thermal means which include laser, electro discharge machining (EDM), electrochemical machining (ECM), spark assisted chemical engraving (SACE), electron beam (EB), ultrasonic vibration (USV) or combinations of these approaches. These non-conventional micro-drilling techniques include: laser micro-drilling (LMD), electro discharge micro-drilling (EDMD), electrochemical micro-drilling (ECMD), electron beam micro-drilling (EBMD), spark assisted chemical engraving (SACE), ultrasonic vibration micro-drilling (USVMD) and etc. [15, 25]. On Fig. 2 is given overview and classification of laser drilling technologies [12].

Fig. 2. Classification of laser drilling technologies w.r.t. drilling duration and precision [12]
3. Materials and methods

Experiments were conducted with micro-drills from solid alloy VK60M diameter \( d = 0.9 \) [mm] long spiral groove \( l = 10 \) [mm]. Rake angle and spiral angle grooves respectively \( \omega = 30^\circ \), rear angle was \( 18^\circ \). The feed of micro-drilling was: \( f = 0.01 \) [mm/turn].

Material for micro-drilling it was fiberglass [27-29, 33].

All experimental investigation were realized in laboratory precision micro instrumental Department "Industrial Technologies Engineering Mechanics", Georgian Technical University (GTU) from Tbilisi (Georgia) in close cooperation with specialists of the Institute of Manufacturing Technology and Quality Management (IFQ) Magdeburg University Otto-von-Guericke (Germany).

To measure the axial effort was the appliance is made on the basis of known methods and existing analogs, measuring element, which is the system of strain gauges mounted on the elastic casing (Fig. 3) [27-29, 33].

Mathematical dependence between torque (T) from depth of drilling (D) during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \( \omega = 30^\circ \) and \( f = 0.01 \) [mm/turn] can be determined by one of the following regression models in the form:

- linear regression model (LRM):
  \[ T = b_0 + b_1 \cdot D \]  
- quadratic regression model (QRM) or 2nd-degree polynomial regression model (PRM2):
  \[ T = b_0 + b_1 \cdot D + b_2 \cdot D^2 \]  
- cubic regression model (CRM) or 3rd-degree polynomial regression model (PRM3):
  \[ T = b_0 + b_1 \cdot D + b_2 \cdot D^2 + b_3 \cdot D^3 \]  
- power regression model (PRM):
  \[ T = a \cdot D^{b_1} \]  
- exponential regression model (ERM):
  \[ T = a \cdot e^{b_1 \cdot D} \]  
- complex power-exponential regression model (PERM):
  \[ T = a \cdot D^{b_1} \cdot e^{b_2 \cdot D} \]  
- logarithmic regression model (LogRM):
  \[ T = b_0 + b_1 \cdot \ln D \]  

The mathematical processing of the experimental data involves the determination of numerical values of the parameters \( b_0, b_1, b_2, b_3 \) and \( a \) for linear (LRM), quadratic (QRM), cubic (CRM), power (PRM), exponential (ERM), complex power-exponential (PERM) and logarithmic (LogRM) regression models and correlation analysis of the observed regression equations.

Parameter estimation for \( b_0, b_1, b_2, b_3 \) and \( a \) it was determined using the Levenberg-Marquardt (LM) method and a software system using this method. The choice of the regression model is realized on the basis of the values of the coefficient of correlation \((R)\), coefficient of determination \((R^2)\) and adjustment coefficient of determination \((AdjR^2)\), according to the methodology described in scientific monographs [5-6] and papers [7-9, 26-29].

4. Results and discussion

4.1. Determination of dependence between axial efforts \((P)\) from depth of drilling \((D)\) during micro-drilling

Measured values for axial efforts \((P)\) [gr.] on different modes of depth of drilling \((D)\) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \( \omega = 30^\circ \) and \( f = 0.01 \) [mm/turn] are shown in Table 1 and Fig. 4.

### Table 1. Measured values for axial efforts \((P)\) on different modes of depth of drilling \((D)\) during micro-drilling with standard micro-drills \((\omega = 30^\circ)\) and \(f = 0.01\) [mm/turn]

<table>
<thead>
<tr>
<th>n [rpm]</th>
<th>Axial efforts ((P)) [gr.] on different modes of depth of drilling ((D))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>200 290 310 310 310 310 320</td>
</tr>
<tr>
<td>15000</td>
<td>200 180 200 200 200 205 155 220</td>
</tr>
<tr>
<td>20000</td>
<td>120 140 105 160 160 108 170</td>
</tr>
</tbody>
</table>

From Table 1 and Fig. 4, it can be concluded that the values for axial efforts \((P)\) [gr.] on different modes of depth of drilling \((D)\) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \( \omega = 30^\circ \) and \( f = 0.01 \) [mm/turn] range around the indicators of central tendency (Table 2 and Fig. 5).

### Table 2. Indicators of central tendency of axial efforts \((P)\) on different modes of depth of drilling \((D)\) during micro-drilling with standard micro-drills \((\omega = 30^\circ)\) and \(f = 0.01\) [mm/turn]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sign</th>
<th>n=10000</th>
<th>n=15000</th>
<th>n=20000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic mean</td>
<td>AM</td>
<td>272.8571</td>
<td>182.8571</td>
<td>137.5714</td>
</tr>
<tr>
<td>Geometric mean</td>
<td>GM</td>
<td>269.0382</td>
<td>181.2145</td>
<td>135.2789</td>
</tr>
<tr>
<td>Harmonic mean</td>
<td>HM</td>
<td>264.9859</td>
<td>179.5807</td>
<td>132.9747</td>
</tr>
<tr>
<td>Median</td>
<td>Med</td>
<td>290</td>
<td>180</td>
<td>140</td>
</tr>
</tbody>
</table>

Fig. 3. Instrument for measuring axial efforts

Fig. 4. The chart of axial efforts \((P)\) on different modes of depth of drilling \((D)\) during micro-drilling with standard micro-drills \((\omega = 30^\circ)\) and \(f = 0.01\) [mm/turn]

Fig. 5. Graphical representation of indicators of central tendency of axial efforts \((P)\) on different modes of depth of drilling \((D)\) during micro-drilling with standard micro-drills \((\omega = 30^\circ)\) and \(f = 0.01\) [mm/turn]
4.2. Determination of dependence between torque (T) from depth of drilling (D) during micro-drilling

Measured values for torque (T) [gr.sm] depending from depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \(\omega=30^\circ\) and \(f=0.01\) [mm/turn] are shown in Table 3 and Fig. 6.

**Table 3.** Measured values for torque (T) depending from depth of drilling (D) during micro-drilling with standard micro-drills \((\omega=30^\circ)\) and \(f=0.01\) [mm/turn]

<table>
<thead>
<tr>
<th>n [rpm]</th>
<th>Torque (T) [gr.sm] on different modes of depth of drilling (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>13 24 30 34 38 40 43</td>
</tr>
<tr>
<td>15000</td>
<td>12 20 24 25 26 30</td>
</tr>
<tr>
<td>20000</td>
<td>7 16 19 22 23 25</td>
</tr>
</tbody>
</table>

**Fig. 6.** The chart of torque (T) depending from depth of drilling (D) during micro-drilling with standard micro-drills \((\omega=30^\circ)\) and \(f=0.01\) [mm/turn]

Values of indicators of central tendency for torque (T) [gr.sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \(\omega=30^\circ\) and \(f=0.01\) [mm/turn] is given in Table 4 and Fig. 7.

**Table 4.** Indicators of central tendency of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills \((\omega=30^\circ)\) and \(f=0.01\) [mm/turn]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sign</th>
<th>n=10000</th>
<th>n=15000</th>
<th>n=20000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic mean</td>
<td>AM</td>
<td>31.71429</td>
<td>23.14286</td>
<td>19.14286</td>
</tr>
<tr>
<td>Geometric mean</td>
<td>GM</td>
<td>29.78582</td>
<td>22.37541</td>
<td>17.91481</td>
</tr>
<tr>
<td>Harmonic mean</td>
<td>HM</td>
<td>27.35375</td>
<td>21.42016</td>
<td>16.18961</td>
</tr>
<tr>
<td>Median</td>
<td>Med</td>
<td>34</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>

A comparative analysis of different regression equations of torque (T) [gr.sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \(\omega=30^\circ\), \(f=0.01\) [mm/turn] and \(n=10000\) [rpm] is given in Table 5 and Fig. 8.

It can be seen from Table 5 and Fig. 8 that all 7 regression equations represent the experimental data well, since their correlation coefficient \(R\) is greater than 0.92. This is especially true of the 2nd, 3rd, 6th and 7th equations whose correlation coefficients are greater than 0.994.

**Table 5.** Tabular view of analysis of different regression equations of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills \((\omega=30^\circ)\), \(f=0.01\) [mm/turn] and \(n=10000\) [rpm]

<table>
<thead>
<tr>
<th>No.</th>
<th>Title of regression model (RM)</th>
<th>Form of regression equation</th>
<th>(R)</th>
<th>(R^2)</th>
<th>Adj(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Linear (LRM)</td>
<td>(T=13.14286+4.64286D)</td>
<td>0.96109</td>
<td>0.9237</td>
<td>0.90844</td>
</tr>
<tr>
<td>2.</td>
<td>Quadratic (QRM)</td>
<td>(T=4.57143+10.35714D-0.71429D^2)</td>
<td>0.99463</td>
<td>0.98929</td>
<td>0.98393</td>
</tr>
<tr>
<td>3.</td>
<td>Cubic (CRM)</td>
<td>(T=14.2857+17.19048D-2.71429D^2+0.16667D^3)</td>
<td>0.99923</td>
<td>0.99847</td>
<td>0.99694</td>
</tr>
<tr>
<td>4.</td>
<td>Power (PRM)</td>
<td>(T=15.89218D^{0.2222})</td>
<td>0.98728</td>
<td>0.97473</td>
<td>0.96967</td>
</tr>
<tr>
<td>5.</td>
<td>Exponential (ERM)</td>
<td>(T=17.84783e^{0.12542D})</td>
<td>0.92478</td>
<td>0.85522</td>
<td>0.82627</td>
</tr>
<tr>
<td>6.</td>
<td>Power-exponential (PERM)</td>
<td>(T=15.2224D^{0.86997}e^{0.09271D})</td>
<td>0.99748</td>
<td>0.99496</td>
<td>0.99243</td>
</tr>
<tr>
<td>7.</td>
<td>Logarithmic (LogRM)</td>
<td>(T=13.16304+35.07391\ln D)</td>
<td>0.99708</td>
<td>0.99417</td>
<td>0.99200</td>
</tr>
</tbody>
</table>

A similar analysis can be performed for comparative analysis of different regression equations of torque (T) [gr.sm] on different modes of depth of drilling (D) [mm] during micro-drilling with micro-drills from solid alloy VK60M with standard rake angle \(\omega=30^\circ\), \(f=0.01\) [mm/turn] and \(n=15000\) [rpm] and \(n=20000\) [rpm].

5. Conclusion

The methodology of comparative analysis and the choice of the regression equation according to the correlation coefficient \(R\) and the coefficient of determination \(R^2\) is of a general character and can be applied generally for the analysis of similar dependencies and processes and systems.

All 7 regression equations of function \(T=f(D)\) (sequentially: cubic, complex power-exponential, logarithmic, quadratic, power, linear and exponential) represent experimental data well, since their correlation coefficient \(R\) is greater than 0.92.

The experimental data of function \(T=f(D)\) are best represented by cubic (R=0.99923; \(R^2=0.99847\) and Adj\(R^2=0.99694\)), and then complex power-exponential regression equation (R=0.99748; \(R^2=0.99496\) and Adj\(R^2=0.99243\)) and etc.

Acknowledgment

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [PHDF-19-2224, Improving the efficiency of mechatronic systems in order to ensure the reform of "Industry-4.0"].
Fig 8. Graphical representation of analysis of different regression equations of torque (T) on different modes of depth of drilling (D) during micro-drilling with standard micro-drills ($\omega=3^\circ$, $f=0.01$ [mm/turn] and $n=10000$ [rpm]).

References


1. Introduction

Ti6Al4V is a grade-V, α-β titanium alloy where aluminum acts as alpha stabilizer and vanadium as beta stabilizer. Beta phase of titanium having BCC crystal structure is more ductile than Alpha phase of titanium having HCP structure, but the strength of beta structure is higher than alpha structure. The properties of alpha-beta alloy, like Ti6Al4V stays in between of both. Ti6Al4V has some specific properties like high strength low weight, high corrosion resistance etc. Because of these properties, it has got extensive uses in biomedical instruments, automobile engineering, aerospace engineering, marine engineering, etc. The need of machining and shaping this material by conventional machining processes is very hard due to its high strength and higher chemical affinity. That’s why non-contact type unconventional machining process, electro-discharge machining (EDM), has been employed to process this material.

EDM, as shown in Fig.1, is a non-contact type electro thermal non-conventional machining process where spark is generated in between tool and workpiece to machine conductive materials and thus the material is eroded by melting and vaporization. The mechanical properties of materials have no influence in electro-discharge machining as there is no contact in between tool and workpiece, though the thermal properties of the material play an important role. That’s why EDM has been employed to machine high strength materials, like Ti6Al4V.

2. Experimental Set-Up

Though it has several advantages, the EDM process itself is very slow. The accumulated debris in between tool and workpiece, i.e. in the machining zone, deteriorates the quality of machining and also reduces the machining rate.

In recent years, many researches have been carried out to overcome this problem and to improve the machining rate and quality. G.D’Urso et al.[1] observed the effect of different tool materials; like copper, brass and tungsten carbide; on machining micro-hole on workpiece material; like stainless steel, titanium, magnesium and brass. Two types of tool, cylindrical and tubular, were used there and their respective effects were observed. Vijay Verma et al.[2] studied the effects of different process parameters on machining characteristics in drilling through holes on Ti6Al4V. They also studied SEM images of machined surfaces. Dipraj Banik et al [3] observed the machining characteristics on Ti6Al4V and also reduced the machining rate. M.P.Jahan et al.[5] studied the effect of low frequency vibration on EDM. They analyzed the hole accuracy, machining rate and surface quality and described a comparative study. A. M. A. Al-Ahmari et al.[6] combined laser beam machining with EDM to achieve better machining rate and quality. A pilot hole was drilled by LBM firstly; later the hole was finished by EDM. Luciano José Arantes et al.[7] carried out abrasive jet electro-discharge machining to enhance machinability.

The present research has been focused to achieve better machining rate and quality in drilling through holes on Ti6Al4V workpiece by incorporating conical shaped tool and vibration in workpiece. The effect of both, shape of the tool and workpiece vibration, on material removal rate (MRR) and diametrical overcut (DOC) have been studied here and the interaction effects of shape of the tool and workpiece vibration have been analyzed. The paper also includes analysis of the effects of peak-current and pulse-on-time on MRR and DOC. Moreover the qualities of drilled holes have been explored.

2.1 Electro-discharge Machine

In the present research, ZNC electro-discharge machine along with, Ferrolac 3M EDM oil with side-jet flushing arrangement has been used.

2.2 Workpiece Vibration Device

Fig.2 shows the workpiece vibration device with work holding arrangement. The amplitude of vibration (a) = 4μm and the frequency = 400Hz.
2.3 Material

Ti6Al4V has been used as workpiece material here. The workpiece has been sliced in wire-EDM in a square shape of 25mm × 25mm with 1mm thickness.

Two types of specially designed copper tools have been used as shown in Fig.3, one is cylindrical tool and the other one is right circular conical shaped tool with aperture angle of (θ) 50°.

3. Experimental Procedure

First the work piece material was sliced in wire-EDM and the tool was made inform of the conical shape as per the required aperture angle. Then, the workpiece vibration device was fixed at the machine base and the workpiece was fixed properly on the work holding device of the workpiece vibration device. After that, the tool of proper shape was fixed in the machine head and the finally the through hole was drilled on workpiece setting the process parameters properly. Then, the process was repeated for next set of experiments according to the experimental plan. The machining performances were evaluated by value of the response parameters, material removal rate (MRR) & diametric overcut (DOC). Further the hole surfaces were observed by optical microscope.

Material removal rate (MRR):

\[
MRR = \frac{w/p \text{ wt. before machining} - w/p \text{ wt. after machining}}{\text{machining time}}
\]

Diametric Overcut (DOC): The difference between top diameter of the hole (D\(_{\text{top}}\)) (or entry diameter) and tool diameter (D\(_{\text{tool}}\)) (as shown in Fig.4) is defined as diametric over-cut (DOC).

Here, a full factorial set of experiments has been carried out. Table.1 shows the factors selected for experimentation and the levels of each experiment.

<table>
<thead>
<tr>
<th>Process Parameters</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse on time (µs) (T(_{\text{on}}))</td>
<td>10</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Peak current (amp) (I(_{\text{p}}))</td>
<td>5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Aperture angle (degree)</td>
<td>180 (cylindrical)</td>
<td>50 (cone shaped)</td>
<td></td>
</tr>
<tr>
<td>Vibration (f)</td>
<td>Without Vibration(0)</td>
<td>With vibration(1)</td>
<td></td>
</tr>
</tbody>
</table>

4 Results & Discussions

The experimental results based on the planned DOE are tabulated below.

<table>
<thead>
<tr>
<th>Sl No</th>
<th>f</th>
<th>θ</th>
<th>I(_{\text{p}})</th>
<th>T(_{\text{on}})</th>
<th>MRR (mg/min)</th>
<th>DOC (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>0.5002</td>
<td>98.5</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>15</td>
<td>0.7673</td>
<td>109.5</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>30</td>
<td>0.7262</td>
<td>152.1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>10</td>
<td>0.6694</td>
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<td>30</td>
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<td>5</td>
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<tr>
<td>8</td>
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<td>50</td>
<td>5</td>
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<tr>
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<td>10</td>
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<td>87.0</td>
</tr>
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</table>
### 4.1 Analysis of MRR

The ANOVA for MRR is in table 3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F Value</th>
<th>P Value</th>
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<tr>
<td>f</td>
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<td>10.743</td>
<td>10.743</td>
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<tr>
<td>θ</td>
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<tr>
<td>Ip</td>
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<td>1.6097</td>
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<td>T_on</td>
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<td>1.4018</td>
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<td>f x θ</td>
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<td>0.5528</td>
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<tr>
<td>f x Ip</td>
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<td>0.6136</td>
<td>0.6136</td>
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<td>0.000</td>
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<tr>
<td>f x T_on</td>
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<td>0.2752</td>
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<td>0.000</td>
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<tr>
<td>θ x Ip</td>
<td>1</td>
<td>0.0035</td>
<td>0.0035</td>
<td>0.44</td>
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<tr>
<td>θ x T_on</td>
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<td>0.0773</td>
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<tr>
<td>Ip x T_on</td>
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<td>0.0078</td>
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<td>—</td>
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<tr>
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<td>23</td>
<td>20.266</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

R-sq= 99.65%  R-sq(adj)=99.11%  R-sq(pred)=97.53%

Table 3 shows that all the p-values, except in case of interaction between aperture angle & peak-current, are in well below permissible range which is 0.05. Comparing the F-values, it is observed that F-value for vibration is way above than others. That’s why, vibration has the maximum effect on MRR.

Fig. 5 shows the mean effect of process parameters on MRR.

**Fig. 5. Main Effect Plot for MRR**

Fig. 5. shows that by applying work piece vibration the MRR has been almost doubled. In case of vibration, during the period of upward acceleration of workpiece, the debris in between tool & workpiece are pushed out of the machining zone. It makes the machining process more stabilized, the number of secondary spark decreases and thus higher percentage of total energy has been utilized to remove intended material. Also, continuous up-down movement of the workpiece results in the formation of vapor bubbles in a low-pressure region that bursts and finally contributes to material removal due to the cavitation effect.

**Fig. 6. Drilling through hole with (a) Cylindrical tool (b) conical shaped tool**

It has been observed that use of conical tool resulted in higher MRR. In case of conical tool, as shown in fig 6, the tool drills a conical hole first, and then in the 2nd stage the vertical portion of the tool finishes the hole drilling a cylindrical shape through hole. In the 1st stage, during conical hole drilling as the tip of the tool faces the workpiece, the energy density at the tip of the tool is very high and thus the material removal is also high. In the 2nd stage, the dielectric drains out through the hole which created in the 1st stage. This dielectric subsequently clears the debris from the machining zone. Thus, removal of debris from the machining zone makes machining more stabilized and increases the MRR. As in both of the stages the removal rate increases, the overall MRR of the process increases too.

As the peak current increases, the energy input also increases. That’s why, the MRR also increases.

Fig. 5 exhibits that, as the pulse-on-time increases from 10μs to 15μs, MRR increases sharply. As the pulse on time increases the discharge energy per pulse also increases and as the discharge energy increases the MRR increases. But, further as the pulse-on-time increases from 15μs to 30μs the MRR slightly decreases. As the discharge energy increases the size of the debris also increases.
These large sized debris are very difficult to flush out. Thus the debris, accumulated in the machining zone, retard the machining rate.

Figure 7. Surface Plot of MRR vs. aperture angle, vibration

The vibration and the aperture angle are the two parameters mainly emphasized in the research. That’s why, the surface plot for these parameters has been shown in Fig.7. It is observed that, they don’t have any significant interaction effect. The maximum MRR has been achieved when the tool is conical shaped and the workpiece have been vibrated.

4.2 Analysis of DOC

Table.4 shows the ANOVA table for DOC.

Table.4 Analysis of variance for DOC

<table>
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<tr>
<th>Source</th>
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<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
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<tr>
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<tr>
<td>(T_{on})</td>
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<tr>
<td>(f \times \theta)</td>
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<td>112</td>
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<tr>
<td>(f \times I_p)</td>
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<td>562</td>
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</tr>
<tr>
<td>(f \times T_{on})</td>
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<td>(\theta \times I_p)</td>
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<td>1013</td>
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<td>0.001</td>
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| R-sq|=99.68% | R-sq(adj)=99.18% | R-sq(pred)=97.71% |

Table.4 shows that all the p-values, except in case of interaction in between vibration & aperture angle and interaction between vibration & pulse-on-time, are in well below permissible range which is 0.05. Work piece vibration has the maximum effect on DOC, as the F-value for vibration is the highest.

Fig.8 shows the mean effect of different process parameters on DOC

![Main Effects Plot for DOC](image)

Fig.8 shows DOC decreases due to the use of conical shaped tool. In case of cylindrical tool, there is a continuous interaction in between tool and final machined surface as shown in fig.6(a), but in case of conical shaped tool, the tool interacts with final machined surface only during 2nd stage which is very less than in case of cylindrical tool. That’s why, in case of conical shaped tool, the final machined surface is exposed to side sparks for less time than cylindrical tool. Because of that, the DOC is less in case of conical shaped tool.

Fig.8 also shows as the peak current is increased, DOC also increases. As the peak current increases, the energy of the spark increases, simultaneously energy of side spark increases which ultimately increase the size of the hole and thus the DOC increases.

Also, the DOC increases as the pulse-on-time increases in a same way.

4.3 Machined Surface Analysis

Figure 10 & 11 shows the optical microscopic view of the machined surfaces at different parameter settings.

It has been observed from the Fig.10 that hole quality has been improved using the conical tool; as in case of cylindrical tool there is a continual interaction between the tool and machined hole, but in case of conical shaped tool, the tool interacts with final machined
surface only during 2\textsuperscript{nd} stage of machining as shown in Fig.6. It has also been observed from Fig.4 that in case of cylindrical tool the lower diameter is much lower than the upper diameter, i.e., the hole has a severe tapering action in case of cylindrical tool without vibration. It is also significant to observe that in both cases the hole has a substantial recast layer.

5. Conclusions

In the present research Ti6Al4V alloy, has been successfully machined. The effects of both, workpiece vibration and shape of the tool has been analyzed to achieve better machining rate and quality and from the study following conclusions have been drawn:

- The MRR almost has been doubled by the application of workpiece vibration,
- The MRR also has been substantially increased by using conical tool,
- It is also observed that peak current and vibration do not have any interaction effect on MRR. The maximum MRR has been achieved by using conical tool and vibrated workpiece,
- MRR has been increased with the increase of peak current,
- As pulse-on-time increases from 10\mu s to 15\mu s the MRR has been increased, but after that it has been decreased slightly,
- Workpiece vibration has a significant effect on DOC & it has been adversely increased by the application of work piece vibration because of error in vibration. Reduction in the error in vibration challenge to designing the work piece vibration device is to be undertaken.
- DOC has been decreased by using conical tool.
- It is observed that the DOC is minimum when no vibration has been applied and conical tool has been used.

- DOC has been increased with the increase of peak-current and pulse-on-time.
- It is observed that hole quality has improved slightly by using conical tool and the tapering of the machined hole also has been reduced by using conical tool.
- It is also observed that the recast layer almost has been removed by incorporating workpiece vibration.

Acknowledgement

This research has been financially supported by CSIR, GOI

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Modeling of nondestructive testing of materials and structures based on ultrasound tomographic imaging

Моделирование неразрушающего контроля материалов и конструкций на основе ультразвуковых томографических изображений

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Abstract: Non-destructive testing methods are focused on detection of specific defects in materials and equipment. Conventional ultrasound methods provide position and size of such defects. In order to reveal the detailed structure of the targeted defects, the algorithm of that approach is described and numerical modelling results are discussed.

KEYWORDS: NON-DESTRUCTIVE TESTING, ULTRASOUND IMAGING, TOMOGRAPHY, WAVEFORM INVERSION

1. Вступление

Одной из основных задач ультразвуковых (УЗ) методов неразрушающего контроля (НК) является определение наличия или отсутствия внутренних дефектов в материалах, объектах инфраструктуры и оборудовании в различных отраслях промышленности. Среди методов НК, направленных на исследование дефектов, можно выделить [1] эхо-импульсный (отраженные волны), теневой (проходящие волны) и дифракционный (дифрагированные волны). Также заслуживает внимания метод УЗ фазированных решеток, использующий линейки или матрицы пьезопреобразователей. Эти методы позволяют определять положение и оценить размер целевых объектов, но не дают информации об их форме и структуре. По сути методы НК направлены на выявление структуры различных дефектов по зарегистрированному волновому полю, однако решение обратной задачи сводится к сравнению регистрируемых волновых картин с эталонными для такой обратной задачи

Применение методов ультразвуковой томографии (УЗТ) перспективно для НК с точки зрения определения детальной конфигурации и физических свойств искомых дефектов без вмешательства в объект.

При распространении упругих волн в гетерогенных средах возникают различные эффекты, искажающие волновое поле — это многократные отражения волн от внутренних границ, рассеяние, преломление волн в различных материалах, а также эффект дифракции волн на неоднородностях. Устранение артефактов дифракции позволяет более точно определять форму и положение объектов и идентифицировать мелкие объекты на ультразвуковых изображениях [3]. В стандартном варианте медицинского УЗИ применяются аппаратные методы устранения дифракционных эффектов. Реализация теоретических подходов подавления ревербераций и дифракционных искажений использовались в задачах обработки сейсмических данных. Эти методы были популярны, когда вычислительные мощности не хватало для полного численного решения волнового уравнения [4]. В настоящее время подходы к решению обратной задачи методом волновой инверсии в медицинских приложениях [5] и НК [6], хотя и характеризуются повышенной вычислительной сложностью, но являются очень перспективными, поскольку минимизируют все искажающие эффекты, включая поглощение, позволяя получать достоверное пространственное изображение внутренней структуры исследуемого объекта.


Подходы к УЗТ различаются не только по типам используемых волн, но и по методам реконструкции пространственных изображений из зарегистрированного волнового поля. В настоящей работе моделируется метод получения плоского изображения двумерно-непрерывной системы путем регистрации на ее поверхности отраженного волнового поля линейкой трансдьюсеров и его последующей инверсии. Такая схема наблюдения не накладывает ограничений на размер объекта и позволяет построить высокоразрешающие объемные УЗ изображения набором двумерных томографических срезов. В работе приводятся результаты решения прямой и обратной задач построения УЗ изображений методом инверсии поля отраженных волн во временной области для двухмерного случая, и исследуется применимость этого метода в технологии неразрушающего контроля.

2. Решение прямой и обратной задач

2.1. Прямая задача.

В постановке прямой задачи предполагается, что известны акустические параметры гетерогенного упругого полутора, находящегося в начальный момент времени в покое, и на его поверхности располагается линейка из N трансдьюсеров; задача также форма импульса, излучаемого источником. Каждый трансдьюсер s поочередно излучает заданный импульс, а все N трансдьюсеров, включая s, принимают из среды отражённые волны в течение некоторого времени T.

Решение прямой задачи осуществляется путем численного решения волнового дифференциального уравнения в акустическом приближении, имеющего вид:

$$\frac{1}{c(x)^2} \frac{\partial^2 p(x,t;x_0)}{\partial t^2} - \nabla^2 p(x,t;x_0) = s(x,t;x),$$

где $x_0$ — положение источника импульса, $p(x,t;x_0)$ — амплитуда волн в точке $x$ в момент времени $t$, $c(x)$ — скорость звука в точке $x$, $s(x,t;x_0)$ — первоначальный сигнал.

Существуют различные подходы к численному решению такого уравнения, например классический метод конечных разностей, однако более устойчивыми и менее ресурсоемкими является псевдо-спектральный метод [10], в котором пространственные производные аппроксимируются преобразованием Фурье. Такой метод имеет, однако, некоторые сложности в реализации, но большинство из них в данной работе преодоле-
2.2. Обратная задача.

Исходными данными обратной задачи являются данные о волновом поле, полученные в результате решения прямой задачи или экспериментально, в виде $N$ многоканальных записей конечной длительности $T$ каждой. Решение обратной задачи является восстановлением исходного волновому полю пространственное распределение параметров неоднородной среды, через которую прошло большое количество волн под разными углами, в данном случае - значения скорости звука в каждой точке двухмерного пространства.

Основная идея метода волновой инверсии при решении обратной задачи состоит в использовании знаний о математической модели распространения упругих волн для численного моделирования физического процесса и нахождения тех параметров уравнения, которые позволяют наиболее точно симулировать данные, полученные в результате численного или физического эксперимента.

Задача волновой инверсии формулируется в виде задачи минимизации некоторой целевой функции, характеризующей отклонение симулированных данных от экспериментальных.

В качестве целевой функции использовалась [11]:

$$E(c) = \frac{1}{2} \sum_k \sum_t \left( \delta(p(x_t, t; x)) - p_{obs}(x_t, t; x) \right)^2 dt,$$

где $s$ - номер источника сигнала; $r$ - номер приемника сигнала; $t$ - текущий момент времени; $x$ - модель скоростей; $p(x_t, t; x)$ и $p_{obs}(x_t, t; x)$ - модельные и реальные данные, полученные приемником в момент времени $t$ при излучении источником $s$.

Для определения для направления минимизации на каждой итерации вычисляется градиент функции $E$ в аппроксимации $g^{(k)} \approx \nabla E(c^{(k)})$, после чего происходит сдвиг текущей модели скоростей по следующей формуле:

$$c^{(k+1)} = c^{(k)} + \alpha^{(k)} d^{(k)},$$

где $c^{(k)}$ - модель скоростей, построенная на $k$-й итерации; $\alpha^{(k)}$ - шаг минимизации; $d^{(k)}$ - направление минимизации, зависящее от оптимизационной стратегии, и в использованном методе сопряженных градиентов определяется как:

$$d^{(k)} = -g^{(k)} + \beta^{(k)} d^{(k-1)},$$

где $\beta^{(k)}$ - параметр, который выбирается в зависимости от выбранной версии СТ. Метод СТ относится к локально оптимизирующим, т.к. в зависимости от выбора начального приближения модели скоростей $c^{(0)}$ алгоритм может сойтись к экстремуму, не являющемуся глобальным минимальмум целевой функции. Это особенно проявляется при решении нелинейных задач, к которым относится и задача инверсии данных при помощи волнового уравнения. Выполнение каждой итерации алгоритма подразумевает вычисление двух основных параметров: вектора градиента и скалярного значения шага оптимизации.

Одним из способов преодоления неустойчивости оптимизационных задач является регуляризация - добавление некоторого дополнительного слагаемого к условию функции ошибки. Чаще всего регуляризация представляет собой некоторую функцию, зависящую от каких-то априорных данных о модели, в данном случае - начальным распределением скоростей. Для обращения волновых данных важно, чтобы регуляризирующая функция сохраняла край объектов на изображении для большей разрешающей способности. Поэтому построение томографического изображения была использована TV-регуляризация [12].

Как упоминалось ранее, вычисление градиента методом сопряженного состояния осложнено необходимостью считывания и обрабатывание на каждой итерации большие объёмы данных, что, при ограничениях на систему ввода-вывода, существенно увеличивает время на, так называемые, "пакладные расходы". Для ускорения процесса обращения данных использовали метод упорядоченных подмодулей, в результате чего для каждой итерации требуется гораздо меньше объёма данных, что существенно ускоряет процесс без значительного ухудшения качества итогового изображения [13].

3. Численные эксперименты

Для программной реализации рассмотренных ранее методов была выбрана среда MATLAB с библиотекой k-Wave [14], позволяющая моделировать волновой процесс при решении прямой задачи.

Последовательные реализации алгоритмов решения прямой и обратной задачи являются вычислительно затратными: этапы нахождения направления и шага оптимизации суммарно требуют дополнительного решения 4-5 прямых задач. Кроме того, на этапе вычисления градиента методом сопряженного состояния требуется сохранять значения амплитуд не только в местах расположения трансдьюсеров, но и во всей оставшей области, в каждый момент времени. Объём обрабатываемых на каждой итерации данных для упомянутой модели составляет более 100 Гб. Данные такого объёма невозможно хранить в оперативной памяти, поэтому при выполнении необходимых вычислений происходит нагруженный дисковый обмен.

Ресурсоемкий процесс решения прямой задачи был оптимизирован с помощью распараллеливания вычислений на GPU с использованием технологий OpenMP и CUDA, а также MATLAB Parallel Toolbox. В результате такой оптимизации вычислений скорость работы программы увеличилась примерно на порядок.

Из-за ресурсоемкости вычислений тестирование программы проводилось на небольшой, но акустически представительной модели: горизонтальные срезы бетонной опоры (рис.1а) с размерами 128x128 мм с дефектом в виде тонкой внутренней трещины криволинейной формы толщиной 2-3 мм, заполненной воздухом. Модель зондировалась импульсом на центральной частоте 1.4 МГц. На нижней поверхности модели вдоль оси $X$ расположены 32 трансдьюсера.

Для моделируемой области решение одной прямой задачи на типичном персональном компьютере (с характеристиками - 4 ядра, 2,6 ГГц, 8 Гб RAM, 500 Гб HDD) выполняется около одной минуты. Обратная задача для выбранной модели и системы наблюдения решается около 6 минут.

Экспериментально была установлена убывающая зависимость функции ошибки от количества итераций при решении обратной задачи, что подтверждает корректность оптимизирующего алгоритма. При 20 итерациях значение функции ошибки составило 2.2-10^{-7}.

На рис. 1 приведена исходная модель и результат ее восстановления методом волновой инверсии при частоте источника 1.4 МГц. Основные объекты появляются после первой же итерации, а детали проявляются с увеличением количества итераций. Дефект в виде криволинейной трещины хорошо визуализирован, хотя субвертикальные границы отображаются слабее субглобинальных.

Рис.1. Структура исходной (а) и восстановленной (б) моделей в виде пространственного распределения скорости звука (линейка трансдьюсеров обозначена пунктирной линией)
Меньшая контрастность восстановленного изображения объясняется потерями волновой энергии из-за отражений и поглощении, а также из-за отсутствия априорной информации о внутренних акустических свойствах исследуемой среды.

На рис.2 приведены результаты исследования разрешающей способности метода УЗТ на разных частотах зондирующего импульса.

Рис.2. Восстановление исходной модели при частоте зондирующего импульса 200 КГц (а) и 50 КГц (6).

Несмотря на то, что при частоте источника 200 КГц толщина трещины составляет менее четверти длины волны, ее конфигурация хорошо отслеживается на рис. 2а. Однако понижение частоты до 50 КГц приводит к результату, тяготеющему к традиционным методам дефектоскопии, в которых дефект обнаруживается, но его конфигурация неясна, подобные результаты приведены в [2].

Предлагаемый метод довольно устойчив к уровню помех, что продемонстрировано на рис. 3. При повышении уровня аддитивного шума от 1% до 5% конфигурация трещины уверенно прослеживается на частоте источника 200 КГц. При дальнейшем повышении уровня шума качество восстанавливаемых изображений ухудшается, что накладывает определенные требования к разработке контрольно-измерительной аппаратуры для неразрушающего контроля, основанного на томографических изображениях.

Рис.3. Восстановление исходной модели на частоте источника 200 КГц при разном уровне аддитивного шума: 1% (а) и 5% (6).

Качество восстановления исходной модели зависит от количества трансдьюсеров в системе наблюдения. На рис. 4 приводятся результаты восстановления исходной модели с рис. 1а.

Рис. 4. Восстановление исходной модели при использовании разного количества сенсоров: 16 (а) и 8 (6).

Видно, что при уменьшении числа датчиков качество восстановленного изображения ухудшается и возрастает уровень вычислительных шумов, в особенности при предельно малом наборе из 8 датчиков. Тем не менее, форма трещины хорошо прослеживается при 16 сенсорной системе.

4. Заключение

В работе предложен оригинальный алгоритм решения задачи построения плоских томографических ультразвуковых изображений методом волновой инверсии отраженного поля в врененной области. Предложенный алгоритм отличается точностью и производительностью вычислений и более устойчив к шумам по сравнению с конечно-разностными методами, однако не может использоваться для класса реальных шумов на физических моделях. Преимуществом метода отраженных волн, зарегистрированных на поверхности среды, является отсутствие ограничений на размеры изучаемых объектов. Разрешающая способность метода выше, чем у традиционных подходов НК за счет многократного просвечивания целевых объектов волнами под различными углами. При этом для обеспечения хорошего качества изображений исследуемых объектов необходимо выбирать оптимальную частоту зондирования излучаемого импульса. Объемное изображение может быть представлено набором двухмерных срезов. Эти преимущества позволяют применять предлагаемый подход для более широкого круга задач неразрушающего контроля. Недостатком подхода на отраженных волнах может быть отсутствие отражений от вертикальных границ изучаемых объектов, что налагает определенные требования к размерам изображения в системе наблюдения. Разработанный алгоритм программно реализован с параллелизмом вычислений на GPU, что существенно уменьшило время получения восстановленного изображения. Упрощение пространственной модели среды, состоящей из объектов относительно простой формы с условными номинальными параметрами, принципиально не влияет на решение задачи и обусловлено только вычислительными мощностями.

Дальнейший интерес представляет решение задачи в трехмерной постановке для получения объемных высокоразрешающих томографических ультразвуковых изображений при неразрушающем контроле сложных конструкций и оборудования.

5. REFERENCES


"Equal-channel angular pressing-drawing" technology

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Abstract: This article describes the technology of the combined process "equal-channel angular pressing-drawing". The analysis of the influence of this process on the structure and mechanical properties of aluminum, copper and steel wires is given. The results of the study showed that the proposed combined deformation method "equal-channel angular pressing-drawing" has a significant advantage over the existing technology for the production of high-strength wire. This deformation method due to the combination of two deformations: severe plastic deformation in a matrix with parallel channels and the process of deformation through a drawing die, allows to get a wire with an ultra-fine structure and a high level of mechanical properties, the required size and shape of the cross section in a small number of deformation cycles.

Keywords: PRESSING-DRAWING, COMBINED PROCESS, WIRE, MICROSTRUCTURE

1. Introduction

One of the urgent tasks of metallurgy and mechanical engineering is to improve the physical and mechanical properties of products and semi-finished products from metals and alloys. The solution of such problems lies in the creation of highly efficient technologies with the use of modern and advanced methods of metal processing. Therefore, studies aimed at solving the problems of obtaining long materials with properties that combine high strength and ductility at the same time, using relatively simple and inexpensive devices that allow to spend the minimum possible amount of time in the production of products are relevant.

The contemporary level of electronic technology development has led to the appearance of devices that often have moving parts and / or work in difficult conditions. Therefore, interest in the problems of forming physical and mechanical properties of functional conductor materials has recently grown abroad in connection with the need to stabilize the properties of current conductors and increase their reliability, including in heavily loaded cable systems, motor and generators windings and low-current computer networks [1-2]. The increased interest of researchers in such materials has greatly increased in recent decades in connection with the use of severe plastic deformation (SPD) methods to obtain bulk materials with fine grains characterized by high physical and mechanical properties [3-5].

Nowadays, the mechanical properties of bulk nanostructured materials generate particular interest. It is known that they are characterized by an increase in the yield point by 2-5 times compared with the corresponding values on SPD at coarse-cristalline state [6-7]. The paradox of SPD, consisting in the simultaneous growth of strength and plasticity as the degree of SPD increases, low-temperature and highspeed superplasticity, deviations from the Hall-Petch law to the higher values of the yield point [8-10].

The SPD method is free from disadvantages of other methods of obtaining such materials, such as the method of compacting powders obtained previously by various methods, and the method of depositing gas atoms on a substrate or electric deposition of atoms from an electrolyte solution. When the materials are compacted or deposited, impurities and pores flow into the boundaries of their grains, influencing the properties of the obtained materials. Among the SPD methods, the ECAP method is especially noteworthy [11-14].

A polycrystalline sample of a macroscopic volume subjected to ECAP retains its shape after multiple extrusions through a curved channel. As a rule, ultrafine-grained or nanocrystalline materials, obtained at the output, have nonequilibrium grain boundaries and a considerable density of lattice defects [15]. These features of the microstructure formed in the SPD process underlie the mechanical properties of the materials. However, the ECAP has a disadvantage – the impossibility of processing products of relatively large length due to loss of stability by a pressing punch.

2. Prerequisites and means for solving the problem

On the basis of a comprehensive analysis of the existing schemes of plastic structure formation and also taking into account the promising directions of their development [16-20], a new combined "equal-channel angular pressing-drawing" (ECAP-D) process using an equal-channel step matrix (Fig. 1) was proposed.

![Fig. 1 Scheme of the combined process of ECAP-D](image1)

3. Solution of the examined problem

The developed technology will make it possible to obtain in industrial conditions a long wire made of ferrous and non-ferrous metals and alloys with an ultra-fine-grained structure and an increased level of mechanical properties at lower energy and labor costs due to the implementation of the continuity principle [20-22].

To implement the combined "pressing-drawing" process, it is necessary to use additional equipment – an equal-channel step matrix made in accordance with the developed drawing of this matrix (Fig. 2).

![Fig. 2 ECAP matrix drawing](image2)
The matrix is recommended to be made of 5XB2C tool die steel. To increase the hardness and strength, the matrix must be subjected to heat treatment-hardening at a temperature that corresponds to the selected steel grade. The diameter of the channel is selected according to the diameter of the wire to be drawn. The channel lengths and the junction angle are selected in accordance with the drawing in figure 2, since the results of theoretical studies given in [20] show that the proposed channel junction angle and channel lengths provide the most favorable stress-strain state for obtaining an ultra-fine-grained structure and lower values of energy-power parameters.

To implement the combined ECAP-D process, an equal-channel step matrix must be placed in the lubrication container before the hauling. As lubricant in the implementation of the combined process of ECAP-D as a normal drawing, you need to use a shaving soap.

Since this paper has shown the need for multi-cycle deformation, the implementation of this combined process can be carried out according to the scheme proposed in this paper – to replace the matrix after each deformation cycle.

To successfully set the wire in an equal-channel step matrix and avoid breaking the original workpiece during the combined process of ECAP-D, it is necessary to use a setting (pushing) device. When implementing the process, you can use a converted cutting machine from the drawing mill (Fig. 3), in particular, to re-phase this machine, so that the rolls rotate in the direction we need and produce the capture of the wire and due to the active forces of friction, pushing it into an equal-channel step matrix. At the same time, for the successful implementation of the combined ECAP-D process, it is necessary to coordinate the speeds of pushing and pulling the wire.

![Fig. 3 Cutting machine](image)

The technology of wire production according to the proposed technology on the drawing mill is as follows: a cage of bunts of the workpiece prepared for drawing (etched, limed) up to 1000 kg is hung on the bunt holder with the help of shop vehicles.

From the bunt holder, the bunt is placed on one of the figures, and the lower end of the workpiece is pulled up to the sharpener for sharpening. On a cutting machine, the end of the workpiece is sharpened to the desired diameter by a length of 150 ... 180 mm. The pointed end of the billet is fed into a pushing device, with which the billet is pushed through a multi-channel step matrix and a drag set in the fiber holder and is captured by filling tongs, the hook of which is inserted into one of the slots on the drum. The foot pedal pushes the mill to the refueling speed (the pushing device is also started at the same time). After a set of 5-7 turns of wire on the drum, the mill must be stopped. The filling pliers are removed, and the end of the wire is securely attached to one of the drum racks.

Then the mill and the pushing device turn on the speed set by the technology and work until the drum is filled. After filling the drum mill stop, give the drum a reverse in 2-3 turns, the wire between volant, and the drum is cut, and the finished coil grab crane is removed from the drum of the mill on the rack. The finished skein is dumped on the rack for tightening and tipping the ribs, and the grab is installed back in the slots of the drum.

The mill is controlled from the control panel.

In the multi-cycle combined pressing-drawing process, it is recommended that the deformation mode shown in table 1 be changed after the first deformation cycle in the lubricant container to an equal-channel step matrix and a fiber carrier for drawing to a smaller diameter.

### Table 1. Modes of deformation of the wire.

<table>
<thead>
<tr>
<th>Pass</th>
<th>D₀ (mm)</th>
<th>V₀ (m/sect)</th>
<th>F₀ (mm²)</th>
<th>t₀₀ (sec)</th>
<th>E₀ (m)</th>
<th>D₁ (mm)</th>
<th>V₁ (m/sect)</th>
<th>F₁ (mm²)</th>
<th>t₁₀ (sec)</th>
<th>E₁ (m)</th>
<th>D₂ (mm)</th>
<th>V₂ (m/sect)</th>
<th>F₂ (mm²)</th>
<th>t₂₀ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pass</td>
<td>7.0</td>
<td>1.29</td>
<td>35.465</td>
<td>0.65</td>
<td>5.5</td>
<td>0.19</td>
<td>1.5</td>
<td>1.29</td>
<td>0.31</td>
<td>9.465</td>
<td>1.166</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 pass</td>
<td>6.5</td>
<td>1.28</td>
<td>33.166</td>
<td>1.25</td>
<td>6.0</td>
<td>0.11</td>
<td>1.5</td>
<td>1.28</td>
<td>0.47</td>
<td>8.269</td>
<td>1.166</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 pass</td>
<td>5.5</td>
<td>1.26</td>
<td>31.746</td>
<td>1.85</td>
<td>6.0</td>
<td>0.19</td>
<td>1.5</td>
<td>1.26</td>
<td>0.59</td>
<td>8.266</td>
<td>1.346</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 pass</td>
<td>4.0</td>
<td>1.24</td>
<td>29.626</td>
<td>2.45</td>
<td>5.0</td>
<td>0.20</td>
<td>1.5</td>
<td>1.24</td>
<td>0.70</td>
<td>8.246</td>
<td>0.625</td>
<td>0.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Results

This technology of metal processing by pressure can be used for production of high-quality wire from any non-ferrous metals and alloys. This method of deformation when introduced into production does not require significant economic investment and can be implemented at industrial enterprises of the Republic of Kazakhstan for the production of wire, as it does not require re-equipment of existing drawing mills. Since the implementation of this combined process requires only the addition of a specially made equal-channel step matrix to the equipment design, designed for pulling material through it.

To study the effect of the "pressing-drawing" process on the structure and mechanical properties of the wire, laboratory experiments were conducted on copper, aluminum and steel wires.

The selected metals had completely different properties in their nature, which made them ideal model materials for studying the new technology. So the steel of the St.3 brand is a mechanical mixture with a melting point above 1000°C (BCC grid), aluminum of the A0 brand with a melting point of 660°C (HCC grid) and copper of the M1 brand with a melting point of 1083°C (HCC grid). In addition, these materials are characterized by different development of recrystallization processes. In steel, the recrystallization temperature is much higher than in other metals. Copper has a low recrystallization temperature due to the low energy of packaging defects, which facilitates the development of twinning, while aluminum, on the contrary, has a very high energy of packaging defects, which makes it difficult to recrystallize and polygonization develops in the deformed metal.

In the course of the study of the formation of UMP structure and mechanical properties in the wire obtained by the "pressing-drawing" method, the following was established:

- in the "pressing-drawing" process, the structure of all the materials under study is significantly crushed to ultra-fine-grained, so St. 3 steel with an average grain size of 12 microns after deformation was crushed 20 times, the average grain size was 0.6 microns; M1 copper with an average grain size of 50 microns after deformation was crushed 125 times, the average grain size was 0.4 microns; A0 aluminum with an average grain size of 17 microns after deformation was crushed 22 times, the average grain size was 0.8 microns [20-23];
the combination of the rcup method with subsequent drawing allows for high strength characteristics of St.3 steel: the temporary tear resistance increases by 360 MPa, the conditional yield strength increases by 460 MPa, the relative contraction after the break decreases by 8%; but the drop is not as significant as in classical drawing [20];

the values of the temporary break resistance and the conditional yield strength for copper wire after 4 passes of ECAP-B increase from 260 to 570 MPa (absolute increase is 310 MPa) and from 190 to 490 MPa (absolute increase is 300 MPa), respectively [21];

the strength of aluminum wire increases almost 3 times after 4 passes. The temporary break resistance and the conditional yield strength increase from 145 to 400 MPa (absolute increase is 255 MPa) and from 100 to 360 MPa (absolute increase is 260 MPa), respectively; the relative elongation decreases by 7%, the relative contraction by 5% [22-23].

5. References

Abstract: Forging is an experience-oriented technology. The physical phenomena that describe the forging operations are difficult to express with quantitative relationships. In order to avoid the trial-and-error method, we use numerical simulations for studying the forging process. With the help of these simulations, the engineers are able to uncover the potential defects which may happen during the forging process. Concurrent Engineering (CE) helps in making the forging process more effective. In the CE system, each modification of the product with the help of these simulations, the engineers are able to uncover the potential defects which may happen during the forging process. In order to avoid the trial-and-error method, we use numerical simulations for studying the forging process. The resulting shape complexity factor is determined as falling within one of the following categories:

- Group M1: Steel with carbon content not greater than 0.65% and total of specified alloying elements (Mn, Ni, Cr, Mo, V, W) not greater than 5% by mass;
- Group M2: Steel with carbon content above 0.65% or total specified alloying elements (as mentioned above) above 5% by mass;

To determine the category in which a steel belongs, the maximum permitted content of the elements in the steel specification will be used.

Table 1. Chemical composition

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Ni</th>
<th>V</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42–0.50</td>
<td>max 0.37</td>
<td>0.5–0.8</td>
<td>1.3–1.8</td>
<td>0.10–0.18</td>
<td>0.3–0.6</td>
<td>0.2–0.3</td>
</tr>
</tbody>
</table>

The steel 45Х2МФА: ГОСТ 4543 has carbon mass fraction of up to 0.50% and a total mass fraction of its alloying elements of 4.18%. This places the steel in the group M1.

2.1. Category of steel used

The type of steel used takes account of the fact that steels of high carbon and high alloy content are more difficult to deform and cause higher die wear than steels with lower carbon content and lower alloying elements. The category of steel used is determined as being one of the following:

- Group M1: Steel with carbon content not greater than 0.65% and total of specified alloying elements (Mn, Ni, Cr, Mo, V, W) not greater than 5% by mass;
- Group M2: Steel with carbon content above 0.65% or total specified alloying elements (as mentioned above) above 5% by mass;

To determine the category in which a steel belongs, the maximum permitted content of the elements in the steel specification will be used.

Table 1. Chemical composition

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Ni</th>
<th>V</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42–0.50</td>
<td>max 0.37</td>
<td>0.5–0.8</td>
<td>1.3–1.8</td>
<td>0.10–0.18</td>
<td>0.3–0.6</td>
<td>0.2–0.3</td>
</tr>
</tbody>
</table>

The steel 45X2MФА: ГОСТ 4543 has carbon mass fraction of up to 0.50% and a total mass fraction of its alloying elements of 4.18%. This places the steel in the group M1.

2.2. Shape complexity factor

The shape complexity factor takes account of the fact that in forging thin sections and branched components, as compared to components having simple compact shapes, larger dimensional variations occur which are attributable to different rates of shrinkage, higher shaping forces and higher rates of die wear. The shape complexity factor of a forging is the ratio of the mass of the forging to the mass of the enveloping shape necessary to accommodate the maximum dimensions of the forging.

\[
S = \frac{m_{\text{forging}}}{m_{\text{enveloping shape}}} = \frac{\rho V_{\text{forging}}}{V_{\text{enveloping shape}}},
\]

where: \(S\) – complexity factor, \(m_{\text{forging}}\) – mass of forged part, \(m_{\text{enveloping shape}}\) – mass of enveloping shape, \(\rho\) – material density, \(V\) – volume.

The resulting shape complexity factor is determined as falling within one of the following categories:

- S4: up to and including 0.16;
- S3: above 0.16 up to and including 0.32;
- S2: above 0.32 up to and including 0.632;
- S1: above 0.63 up to and including 1;

\[V_{\text{forging}} = V_{\text{part}} \cdot K_F\]
\[ m_{\text{forging}} = m_{\text{part}} \cdot K_p \]

where, \( K_p = 1.5 \div 1.8 \) – shape coefficient for round forged parts (gears, flanges, discs, etc.).

The parts mass and volume can be determined by using any CAD software while using the density of the material in question (Figure 2).

\[ V_{\text{forging}} = V_{\text{part}} \cdot K_p = 1742620.62 \cdot 1.5 = 2613930.93 \text{ mm}^3 \]

\[ m_{\text{forging}} = m_{\text{part}} \cdot K_p = 13679.57 \cdot 1.5 = 2051935.5 \text{ kg} \]

The enveloping shape of a circular forging is the circumscribing cylinder the volume of which is calculated by increasing the maximal width and height of the final part by 5% to accommodate the increased size of the forging.

\[ V_{\text{enveloping shape}} = \frac{(D_{\text{max}} \cdot 1.05)^2 \cdot \pi}{4} \cdot (H_{\text{max}} \cdot 1.05) \]

where, \( D_{\text{max}} \) [mm] – largest diameter; \( H_{\text{max}} \) [max] – largest part height.

\[ V_{\text{enveloping shape}} = \frac{(230.04 \cdot 1.05)^2 \cdot \pi}{4} = 3375836.34 \text{ mm}^3 \]

\[ S = \frac{\rho \cdot V_{\text{forging}}}{\rho \cdot V_{\text{enveloping shape}}} = \frac{2613930.93}{3375836.34} = 0.7743 \]

The complexity factor \( S = 0.7743 \) falls in the S1 category. It is important to emphasize that the initial complexity factor is an estimated value due to the estimation of the forgings and enveloping shapes mass. The estimated degree of complexity should be refined after calculating the exact envelopes and forging mass.

2.3. Parting line configuration

The part has a plain parting line configuration located at the half point of the thickness at the largest diameter (as shown in Figure 3).

2.4. Forging equipment selection

In order to begin the forging design, we must first select a forging machine by doing a control calculation to determine the plausibility of the technological process on the available equipment by estimating the needed machine force.

- For power-drop steam hammers:

\[ G = 10(1 - 0.005D_{f_{\text{max}}})(1.1 + \frac{2}{D_{f_{\text{max}}}})^2(0.75) + 0.001D_{f_{\text{max}}}^2D_{f_{\max}} \cdot \sigma_m \]

- For mechanical presses:

\[ F = 8(1 - 0.001D_{f_{\text{max}}})(1.1 + \frac{20}{D_{f_{\text{max}}}})^2A \cdot \sigma_m \]

where, \( G \) [kg] – hammers falling mass; \( F \) [kg] – mechanical press force needed for forging circular forgings; \( D_{f_{\text{max}}} = D_{\text{max}} \cdot 1.05 \) – largest forging diameter; \( \sigma_m \) [kg/mm\(^2\)] – material strength in the final forging stages; \( A = \frac{D_{f_{\text{max}}}^2 \cdot \pi}{4} \) [mm\(^2\)] – projection of the forging in the horizontal plane.

The steel 45X2МФА: ГОСТ 4543 can be classified in the second type according to table 2. From there we select the values for \( \sigma_m \) for the forging hammers and mechanical presses for the calculations.

Table 2. Steel strength \( \sigma_m \) [kg/mm\(^2\)] in the final forging stages

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Forging hammers</th>
<th>Mechanical presses</th>
<th>Horizontal forging machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Carbon steel with carbon content up to 0.25 %</td>
<td>5,5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>2. Carbon steel with carbon content above 0.25 %, or Alloyed steel with carbon content up to 0.25 % and alloying element content up to 5%</td>
<td>6</td>
<td>6,5</td>
<td>8</td>
</tr>
<tr>
<td>3. Alloyed steel with carbon content above 0.25 % and alloying element content up to 5%</td>
<td>6,5</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>4. All alloyed steel with alloying element content above 5%</td>
<td>7,5</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>5. Alloy tool steel</td>
<td>9 - 10</td>
<td>10 - 12</td>
<td>12 - 14</td>
</tr>
</tbody>
</table>

\[ G = 10(1 - 0.005D_{f_{\text{max}}})(1.1 + \frac{2}{D_{f_{\text{max}}}})^2(0.75) + 0.001D_{f_{\text{max}}}^2D_{f_{\text{max}}} \cdot \sigma_m = 2.4 \text{ t} \]

\[ F = 8(1 - 0.001D_{f_{\text{max}}})(1.1 + \frac{20}{D_{f_{\text{max}}}})^2A \cdot \sigma_m = 13800 \text{ t} = 138 \text{ MN} \]

Since the estimated value for the needed force on the power-drop hammer is reasonable, it is selected as the forging machine used to manufacture the forging of the part. All the tolerances and machining allowances will be selected to suit the forging process on steam hammers.

2.5. Defining the forged part dimensions

All of the tolerances and machining allowances for the forged part were selected from the tables 1 to 6 from the standard DIN EN 10243-1. The standard identifies two grades of tolerances. Forging grade E with tolerances providing adequate standard of accuracy for the majority of applications and capable of being complied with by commonly used forging equipment and production methods. Forging grade F providing closer tolerances to assist in accommodating those instances in which the normal manufacturing standards are inadequate. The forging grades “E” and “F” were allocated to the measures, depending on the particular surface roughness and tolerances designated in the part drawing. The standard also identifies four major types of dimensions and several minor ones and classifies them in 4 groups.

All of the allocated allowances and tolerance grades for the inner and outer forging dimensions are given in table 4. Finally, the resultant dimensions are modified by a factor \( \eta \) that takes into
account the thermal expansion while heating. The outer dimensions are increased and the inner ones are decreased by a specific amount that corresponds to the forging temperature. This way we get the correct hot forging part design with measurements ready for creating the die geometry. \( \eta = 1.025 \) – thermal expansion coefficient for steel alloys at forging temperatures of \( \sim 1200 \) °C.

### 2.6. Forging draft angles

Draft is an angle allowance added to surfaces parallel to the direction of die closure to facilitate release of the part form the die after forging. In general, draft allowances on inside surfaces are greater than those on outside surfaces, because of the tendency of the part to shrink onto projections in the die as cooling takes place [2]. For power drop steam hammers the chosen normative draft angles are as follows: \( \alpha = 7^\circ \) - external draft angle; \( \alpha_1 = 10^\circ \) - internal draft angle.

### 2.7. Forging fillet radii

All edges and corners in the part must have added fillets. These fillets are necessary to aid material flow and ensure good die filling. In addition, sharp corners in dies can lead to premature die failure due to fracture as a result of associated high stress concentrations. In general, larger radii are recommended for the more difficult-to-form materials [2]. The outer radii are selected depending on the mass of the forging and the largest depth of the die impression that is calculated according to the position of the parting line: \( R_{outer} = 2.5 \) mm.

The inner radii are calculated using this formula:

\[
\begin{align*}
R_{inner} &= (2.5 + 3.5)R_{outer} + 0.5 \\
&= 3 \cdot 2.5 + 0.5 = 8 \text{ mm}
\end{align*}
\]

### 2.8. Defining the position, shape and dimensions of the barrier plates for all through holes in the forged part

In the forging process, holes are not punched through because this would make the ejection of the part more difficult. This way the dies are separated by a barrier plate in each hole. The thickness of the part is calculated using the following equation:

\[
s = 0.45\sqrt{d - 0.25h - 5 + 0.6\sqrt{h}}
\]

where, \( s \) [mm] – plate thickness, \( d \) [mm] – diameter of the hole at the topmost surface, \( h \) [mm] – distance from the plate midline to the topmost surface of the forging.

\[
s = 0.45\sqrt{d - 0.25h - 5 + 0.6\sqrt{h}} = 6.87 \rightarrow 7 \text{ mm}
\]

The fillet radii for the plate also have to be calculated. Hence, we use the equation: \( r_1 = R_{inner} + 0.1h + 2 \), where, \( r_1 \) [mm] – fillet radii for the plate edges, \( R_{inner} \) [mm] – inner fillet radii for the forged part.

\[
r_1 = R_{inner} + 0.1h + 2 = 14.37 \rightarrow 14 \text{ mm}
\]

The type of plate depends on the size of the forging part, the diameter and the height of the hole. To determine the type, we need to check the following condition:

\[
d - 1.25r_1 = 57.72 - 1.25 \cdot 14 = 39.75
\]

The condition \( d - 1.25r_1 > 26 \) requires the use of a Type II plate with a shape shown in Figure 288, page 581, Obrada Metala Plasticnom Deformacijom, Binko Musafija.

\[
d_1 = 0.12 \cdot s + 3 = 3.82 \rightarrow 4 \text{ mm}
\]

where, \( d_1 \) [mm] – flat length of the plate, \( S_{max} \) [mm] – minimal plate thickness, \( S_{min} \) [mm] – maximal plate thickness.

### 2.9. Control check for the forging mass and the complexity factor \( S \)

\[
S_{min} = 0.65 \cdot s = 4.4 \rightarrow 4 \text{ mm}
\]

\[
S_{max} = 1.35 \cdot s = 9.2 \rightarrow 8 \text{ mm}
\]

In the forging process, holes are not punched through because this would make the ejection of the part more difficult. This way the dies are separated by a barrier plate in each hole. The thickness of the part is calculated using the following equation:

\[
s = 0.45\sqrt{d - 0.25h - 5 + 0.6\sqrt{h}}
\]

where, \( d \) [mm] – diameter of the hole at the topmost surface, \( h \) [mm] – distance from the plate midline to the topmost surface of the forging.

\[
s = 0.45\sqrt{d - 0.25h - 5 + 0.6\sqrt{h}} = 6.87 \rightarrow 7 \text{ mm}
\]

The fillet radii for the plate also have to be calculated. Hence, we use the equation: \( r_1 = R_{inner} + 0.1h + 2 \), where, \( r_1 \) [mm] – fillet radii for the plate edges, \( R_{inner} \) [mm] – inner fillet radii for the forged part.

\[
r_1 = R_{inner} + 0.1h + 2 = 14.37 \rightarrow 14 \text{ mm}
\]

The type of plate depends on the size of the forging part, the diameter and the height of the hole. To determine the type, we need to check the following condition:

\[
d - 1.25r_1 = 57.72 - 1.25 \cdot 14 = 39.75
\]

The condition \( d - 1.25r_1 > 26 \) requires the use of a Type II plate with a shape shown in Figure 288, page 581, Obrada Metala Plasticnom Deformacijom, Binko Musafija.

\[
d_1 = 0.12 \cdot s + 3 = 3.82 \rightarrow 4 \text{ mm}
\]

The complexity factor \( S = 0.64 \) falls in the S1 category, same as the initially calculated value. Since the mass is within the previously selected range and the refined complexity factor matches the initial calculation, the added allowances are considered correct.

### 2.10. Determining the flash land geometry

The flash produced during closed-die forging is scrap material and may in many cases have a volume that is more than 50% of the final part volume. The amount of flash produced increases with the complexity of the part. However, the production of the flash is a necessary part of the process, and its control is essential to ensure good die filling [2]. The choice of the appropriate width and thickness of the flash land is an important part of the forging design. If the geometry is wrong, the dies may not fill completely or the forging loads may become excessive. In addition, the projected area of the flash in the flash land is usually included in the total projected area of the part for estimation of the forging loads required and therefore is a determining factor in equipment selection for processing. In order for vertical flow to occur in the die, the resistance to flow in the flash gap must be higher than that
required for vertical flow in the die. The material must not flow into the flash gap until the die cavity is completely filled. The resistance to flow in the flash gap depends upon the ratio of flash land width to flash land height. The flash land height can be calculated approximately using the following expression [3]:

\[ c = 0.015\sqrt{\frac{46775.67}{\Delta}} = 3.244 \text{ mm} \]

where, \( c \) [mm] – flash land height, \( A \) [mm^2] – projected area of the forging (including allowances and draft).

\[ c = 0.015\sqrt{46775.67} \]

The flash land width is calculated with the help of a coefficient that takes into account the way the die is filled during the forging process: \( K = 1.5 + 0.3 \frac{\Delta}{\text{avg}} \)

where, \( K \) – coefficient that takes into account the way the die is filled, \( H \) [mm] – largest die depth, \( B_{\text{avg}} \) [mm] – average width of the die at the location of the flash land.

\[ K = 1.5 + 0.3 \times \frac{42.8}{237.24} = 1.55 \]

According to the calculated values for the bridge height \( c \) and the coefficient \( K \) we choose the nearest standard flash land size. All relevant dimensions are given in table 3 below and figure 293, page 596 in Obrada Metala Plasticnom Deformacijom, Binko Musafija [4].

Table 3. Standard flash land and gutter dimensions

<table>
<thead>
<tr>
<th>( c ) [mm]</th>
<th>( c_1 ) [mm]</th>
<th>( h ) [mm]</th>
<th>( P ) [mm]</th>
<th>( h_1 ) [mm]</th>
<th>( A_f ) [mm^2]</th>
<th>( B_1 ) [mm]</th>
<th>( B_2 ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
<td>2</td>
<td>11</td>
<td>30</td>
<td>266</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Finally, we need to determine the flash volume in order to be able to calculate the dimensions of the initial workpiece. The flash volume is calculated by the following expression: \( V_f = \xi \cdot A_f \cdot P \), where, \( V_f \) [mm^3] – flash volume, \( \xi = 0.5 \) – coefficient of gutter fullness for axisymmetric forged parts, \( A_f \) [mm^2] – flash gap cross section area, \( P = D_{\text{max}} \cdot \pi \) [mm] – perimeter of the forging in the parting plane (parting line length).

\[ V_f = \xi \cdot A_f \cdot P = 0.5 \cdot 268 \cdot 237.24 \cdot \pi = 99821.1 \text{ mm}^3 \]

2.11. Determining the initial workpiece dimensions

The volume of the workpiece is the sum of the forging and the flash volume, while taking into account the scale losses that occur during heat treatment processes. Oxide scales discolour the metal surface and hinder subsequent finishing operations and therefore need to be removed from the heated stock, either before or during forging operations.

\[ V_{wp} = (V_{fp} + V_f)(1 + \Delta) \]

where, \( V_{wp} \) [mm^3] – workpiece volume, \( V_{fp} \) [mm^3] – forging volume, \( V_f \) [mm^3] – flash volume, \( \Delta \) - scale loss.

Due to the fact that scale loss cannot be included in the simulation, for the purpose of this report, the scale loss coefficient is not taken into account (\( \Delta = 0 \)).

\[ V_{wp} = (V_{fp} + V_f)(1 + \Delta) = 4252707.32 + 99821.1 \]

\[ = 4352528.42 \text{ mm}^3 \]

Round parts are forged from cylindrical billets and before the dimensions are calculated we need to determine the relation between the height and the diameter of the workpiece.

\[ m = \frac{h_{wp}}{d_{wp}}, \text{ where, } m = 1.5 + 2.8 - \frac{h_{wp}}{d_{wp}} \text{ ratio, } d_{wp} \text{ [mm]} – workpiece diameter, } b_0 \text{ [mm]} – workpiece diameter.

This relation is in the range \( m = 1.5 + 2.8 \). If \( m < 1.5 \) then the shearing of the billet to size is more difficult and is accompanied by the forming of big burr formations. For ratios of \( m > 2.8 \) there is a risk of buckling. The billet dimensions are determined by the volume and the ratio \( m \). The estimated diameter is calculated as follows: \( d_{wp} = 1.01 \frac{V_{wp}}{\sqrt{m}} = 154.04 \text{ mm} \)

The standard dimensions for cylindrical billets are found in Kraut’s Mechanical Engineering Handbook: \( d_{wp} = 155 \text{ mm} \)

The billets height is calculated using the expression:

\[ h_p = \frac{V_{wp}}{A_{wp}} = \frac{4 \cdot V_{wp}}{\pi \cdot d_{wp}^2} \approx 145 \text{ mm} \]

The billet for the part forging has the following dimensions: \( \Phi 155 \times 145 \)

2.12. Determining the die block dimensions

The dimensions selected for the die blocks depend on the depth of the cavity. The minimal thickness and height for each block (table 4) were selected according to the recommendations in Metal Forming Practise Processes, page 135, table 13.11 [3].

Table 4. Selected die block dimensions

<table>
<thead>
<tr>
<th>Upper block</th>
<th>( h ) [mm]</th>
<th>( a ) [mm]</th>
<th>( H ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.76</td>
<td>56</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lower block</th>
<th>( h ) [mm]</th>
<th>( a ) [mm]</th>
<th>( H ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.76</td>
<td>40</td>
<td>160</td>
<td></td>
</tr>
</tbody>
</table>

2.13. Production phases

1. Shearing the initial workpiece with a diameter of \( \Phi 155 \) and height of 145 mm.
2. Heating up the workpiece to the forging temperature of \( \approx 1100 \) °C.
3. Upsetting the workpiece to a height of \( h_1 = 83 \text{ mm} \). The upsetting is carried out on a power-drop steam hammer (5t).
4. Finishing forging done on a power-drop steam hammer to the shape and dimensions given in Figure 5.
5. Flash removal using a trimming die and punching the barrier plate for the hole.

3. Simulation of the forging process

Computer Aided Engineering has many benefits when it comes to saving time and expenses, it gives certain important information about the forging process before the part is approved for production. Information on material flow, stress, deformation, temperature etc. are available to the user at any given moment after the simulation is done. This way potential defects as material overlapping, excess or lack of material etc. After all the calculations are finished, the 3D model and the 2D sketches in the CAD software, everything is set for the simulation to begin.

The numerical analysis for this study is simulated in two operations, upsetting and closed die forging with flash, as well as an additional operation for removing the flash and plate.

The first operation as said is upsetting. It is done with a 5t forging hammer. The initial part is heated to 1100 °C for the recrystallization process to occur. In this phase the initial height of
the part 145 mm is reduced to 83 mm. This allows the following operation to be completed with ease. The reducing of the height is completed with hammer blows. Figure 6. shows the maximum and minimum effective stress of the part in the first blow of the upsetting stage. The maximum stress is 170.83 MPa. Figure 7. shows the maximum and minimum effective stress of the part in the second blow of the upsetting stage. The maximum stress is 216.18 MPa.

Figure 6. Effective stress during the first blow

Figure 7. Effective stress during the second blow

Figure 8. Part temperature after the upsetting phase

Figure 9. Unsuccessful closed die forging simulation

Figure 8. shows the temperature of the part after the upsetting. It is clear that the inside of the part will have its temperature (1116.16 °C) increased due to the deformations.

The second operation, closed die forging with flash, is completed with 5 hammer blows. The part is still heated, and graphite + water is used as a lubricant. In this operation the part gets its final geometry, and this is the phase where the most defects happen. During the simulation, there were a few unsuccessful attempts due to excess material, as it is shown is figure 9.

Figure 10, 11, 12 and 13 show the four needed blows for the operation. The figures show that the cavity fills in the first, second and third blow, and the fourth blow is for filling the flash.

Figure 10. First blow

Figure 11. Second blow

Figure 12. Third blow

Figure 13. Fourth blow

Figure 14. Flash and plate removal

The additional operation, removal of flash and plate, is completed on a mechanical press (6.3 MN). The goal of this operation is to remove the excess material which was necessary during the forging process. This operation is done with one blow, simultaneously removing the flash and plate (Figure 14).

4. Conclusion

Forging simulation offers significant advantages by providing detailed insight into the forging process before tool selection and process decisions are made on the shop floor [5]. Thanks to the numerical simulations, the initial error in the study is avoided, and the simulation was successful. Because of the complexity of metal flow, the friction between the tool and part, the temperature generation, CAE software is needed to analyse the initial idea of how the process should look like. In the process of making a product, it is very important in getting to know the characteristics of certain structures and their behaviour in exploitation.

5. References

4. B. Musafija, Obrada Metala Plascticnom Deformacijom (1979)
Exploration of the possibility for using animal manure as alternative fuel in pig farm

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Abstract: The increasing demand for local products is forcing farmers to expand their production, which also increases the waste generated by the animal husbandry process. The utilization of organic waste from livestock farms is a serious task for farmers, and they need to look for alternative methods of treatment. In this paper, we consider the possibility of applying sludge from a pigs farm for fattening. Samples of dried to room humidity sludge taken from a pig manure metal lagoon were examined. The purpose of the study is to evaluate the prospect of sludge as an alternative fuel for the pig farm. A thermogravimetric (TD) and differential thermal (DTG) analysis method was used to investigate the sediment. These methods of analysis were used because of the wide range of information provided and the possibility of qualitative and quantitative analysis. The types of phase transitions in the processes of heating and cooling, the temperature interval, the time for their flow and the amount of heat absorbed or released are investigated.

Keywords: DUNG, THERMOGRAVIMETRIC, DIFFERENTIAL - THERMAL ANALYSIS, ALTERNATIVE FUEL

1. Introduction

In Bulgaria, pig farming is industry with traditions which, after a long period of decline, are already one of the most promising branches of livestock breeding. At present, domestic production accounts for around 40% of domestic demand, with all prerequisites for this share to exceed 60% in the coming years and to continue to grow [1], [2]. The basis of this upward development, is the strong demand for local products and the relatively high prices of local produce. High investment activity, low production facilities and appropriate conditions can be used to attract new investment in the sector. However, in line with EU legislation, investors face the issue of the generated sludge from livestock farming, creating a new environmental problem that needs to be addressed. Although sludge is traditionally treated as a waste management problem in most EU countries, sludge deposition is gradually declining, as the sludge reuse trend, as a fuel, gains value. The industrialization of pig production comes hand in hand not only with improved efficiency but also with serious environmental challenges. A larger farm also means more bio-waste to be collected, stored safely and utilized. Unfortunately, agricultural land that can be enrichment with livestock manure is constantly decreasing in the world and the management of this waste is becoming more and more problematic [3], [4], [10].

Modern equipment for removal the manure at pig farms in Bulgaria meets the requirements of European legislation (Directive 91/676 / EEC) and usually includes a fertilizer pump and a fertilizer storage lagoon. Dewatering wet the fertilizer, is mechanically via screw presses. To remove the chemically bound water at dewatering of the sludge, takes place processing with organic polymer (floculants). Polymers are supplied in powder form and are prepared in the form of a rare aqueous solution, which is dosed to the slurry at the inlet of the presses. Organic polymers used in mechanical dewatering bind the particles of the sediment with long molecular chains and cause an effect “fluidity” of the dewatered sludge. The obtained mixture with a jelly-like consistency is deposited on dehumidifying fields and although it initially accumulates at “stacks” after one to three days it “slops” to a flat surface [5], [6]. The main purpose of sludge dewatering is to reduce their volume, which facilitates their transportation and, accordingly, recovery or incineration.

2. Materials and experimental procedure

The object of the present study are samples of dried sludge (humidity 7%) taken from a fertilizer metal lagoon in the village of Mechkarevo, municipality Sliven. The pig farm was built in 2014 and has a capacity of 1400 animals. The fertilizer metal lagoon has a capacity of 1100 m³, its capacity being designed in a way that there is no spillage.

The Thermogravimetric (TD) and Differential - Thermal (DTG) method of analysis was used for sludge analysis. Thermogravimetric (TD) method can be used to investigate any process that changes the mass of the sample when heated without melting. The change in mass is used for quantitative analysis and the temperature the change at which occurs for qualitative analysis. The Differential Thermal (DTG) method of analysis is applicable for qualitative and quantitative analysis of all types of materials. The processes of melting, boiling sublimation are investigated.

The type of phase transitions, in the heating and cooling processes, the temperature interval, the time of their flow and the amount of absorbed or separated heat are studied [7]. The aim of the study is to assess the prospect for the sludge as an alternative fuel for the needs of the pig farm.

The general appearance of the laboratory installation is shown in figure 1. Differential thermal analysis is the most commonly used thermal analysis method due to the wide range of information provided [8], [9]. The high temperature analyser is designed to provide maximum calorimetric sensitivity, short time constants, and a non-condensing sampling chamber.

The thermal impact of the samples is from 23°C to 800°C in an atmosphere N₂/O₂/N₂ at heating rate 10°C/min. It is investigated of sludge from the holding’s wastewater was examined, upon entering the fertilizer metal lagoon.

Fig.1. DTA analyzer
3. Results and Discussion

Figure 2 shows (TG) and (DTG) curves for the sample. Stand out are three characteristic stretches.

The first one starts at room temperature and ends at a temperature 225°C. As a result of heating in an inert environment, the (TG) curve shows a loss of mass 7.01%. This is explained by the evaporation of a different in origin moisture. The most intense moisture loss was observed at 72.2°C from 1.23%/min. It can be assumed that the release of moisture ends up 175.9°C, then by the end of the temperature range of mass loss is negligible. Understandably, the dehydration process is accompanied by a pronounced endothermic effect reported on the (TG).

The second region is in the temperature range of 225°C to 550°C. It is characterized by an intense mass loss due to combustion of combustible components. Curve (TG) clearly can be divided into two regions with an inflection point at 381.1°C. Until this temperature is recorded mass loss 29.78% with extreme at 277.9°C by 2.97%/min. There follows a second stretch, at the end of which the loss of mass reaches 58.43% with a maximum of 504.5°C by 3.82%/min. Understandably, incineration is accompanied by a pronounced exothermic effect. The curve of (DT) in this temperature range has two characteristic peaks - one at 339.1°C by 1.95 mW/mg and second at 501.6°C by 13.3 mW/mg, as between the two extreme exothermic values at 390.3°C there is a local minimum of 1.0103 mW/mg. Obviously it is about two parallel processes, the kinetics of which overlap in this temperature range. It seems plausible to explain that the first peak is associated with combustion of the volatiles, while the second, where the exothermic effect is much more pronounced, is related to the burning of the coke residue. It is known that the volatiles burn in a distinct front at a rate determined by molecular diffusion, whereas the burning of the coconut residue proceeds through the significantly slower sorption and adsorption process of the oxidant on the surface of the coke particle. It can be grounded assumed that the endo effect between the two peaks is due to pyrolysis and thermal destruction in the remainder of the material after the burning of the volatiles.

The last stretch of 560°C to 790°C runs at a moderate rate of mass reduction. The explanation is that after 560°C in the sample there is left only a non-combustible mineral mass, the destruction of which proceeds with an endothermic effect. The determined calorific value of the sample is 7557 J/g.

The calorific value of sludge obtained is commensurate with that of lignite coal, but it should be noted that the moisture content of the sludge is 90% and that of coal reaches 40%. The high amount of moisture is a prerequisite for finding another way to utilize them. Extraction of biogas from manure is a good alternative [11]. The introduction of a biogas plant, despite the large initial investment, expands the use of renewable energy sources. The process of processing animal manure is fermentation in an anaerobic environment, in which the incoming organic materials are broken down into their constituent units. The process is carried out in a bioreactor and the final result of the fermentation is the production of biogas and other organic products.

There are several ways to utilize the biogas from pig farms. The easiest way on use the biogas is the burn it directly in boilers to provide hot water for the farm's technological needs, as well as for heating the buildings.

Another way to apply biogas is a cogeneration, based on an internal combustion engine. This type of installation allows farmers to generate on-site electricity and heat that can largely meet their own energy needs. Essential to the technical efficiency of cogeneration systems is the requirement of a constant heating load, which ensures the design operation of the engine and generator. Recently, schemes are being developed to allow the utilization of part of the high-temperature (up to 150 °C) production gases in air-conditioning and industrial installations with absorption, sorption and / or compressor refrigeration machines - the so-called three-generation schemes. They guarantee a constant heat load in the summer and increase the usability of the cogenerators.

Figure 2. TG and DTG curves of the test sample
4. Conclusions

The development of animal husbandry in Bulgaria necessitates the improvement of the systems and methods of treatment of sludge from animal husbandry. The methods of manure treatment considered are applicable, but in carrying out a thorough technical and economic analysis and taking into account the specific features of each livestock farm. The design and construction of the facilities must take into account the capacity of the farm, the way the animals are kept, the amount of litter used.

Based on the results of thermogravimetric (TG) and differential thermal (DTG) analysis, it can be concluded that the use of sludge as an alternative fuel is possible, since their caloric value is commensurate with that of the lignite coal, but it is should be noted that the moisture in the working mass is 90% and for coal it reaches 40%. The dehydration of the sludge will bring additional costs to farmers and it would be more appropriate to use sludge in agriculture as organic fertilizer and to reclaim disturbed land. However, this treatment leads to the accumulation of manure in the holding, as it must remain for 6 months before being introduced into the soil.

The implementation and use of biogas plants for combined heat and power production are of great potential, as they solve several major problems of livestock facilities - the accumulation of manure, meeting the hygiene requirements for animal husbandry, and energy independence and energy efficiency.

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Improving the resolution and accuracy of temperature distribution on the surface of microsystems using thermographic methods

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Abstract: Improvement of thermographic imaging device by using an automatic scanning system as opaque for infrared radiation of a matrix aperture with a window of transparency at the lens of the thermal imaging lens, leads to improvement of the spatial and temporal characteristics of the thermal imager, namely, its separation from the point of view. As a result of the experiments, it was found that the spatial resolution of the improved thermographic method (compared to the standard method of determination) was improved by 15 – 20%, and the spectral resolution by 0.3 – 0.5 μm. According to the results of the analysis of the processed image, the adjusted temperature scale of the thermogram, which, in turn, allowed to increase the accuracy of temperature determination in each accurate image (the temperature distribution error did not exceed 5.5%).

Keywords: THERMOGRAPHIC METHOD, THERMAL IMAGER, TEMPERATURE DISTRIBUTION, RESOLUTION, PRECISION, MICROSYSTEMS

1. Introduction

Today, the development of various components of Microsystems (MST), as well as the products and units and systems built on these components, improves the functional and operational characteristics of these devices, while minimizing them. This increases the specific power and performance of both mechanical and electronic components of the MST. This, in turn, leads to a sharp increase in energy (especially thermal) costs, both in individual parts of the device and in general – throughout the device. Such an increase in heat consumption results in a sharp rise in temperature, which in most cases has a negative impact on the performance of the MST devices. (It should be noted that with a sharp increase in temperature, the mechanical components of the MST devices begin to block the movement of tangent elements due to the thermal expansion of the material, which can reach 15 – 25% of the size of the element itself. At the same time, the temperature decreases (up to 2.5 – 3%) the resistance of semiconductor (then, as the resistance of conductors, on the contrary - increases in 9 – 17%) electronic components of MST devices, which leads to their premature failure) [1 – 4].

To date, there are and are actively applying a number of methods and means to eliminate (at least reduce) the heat load on the MST device and their components. However, in order to take measures to reduce the heat load, there is an urgent need for rapid monitoring and determination of the temperature distribution over the entire surface of the studied objects operating in dynamic mode.

Among the thermal methods for determining the temperature, the most promising is the thermographic method based on the use of a thermal imaging device. The effectiveness of using this thermographic method is confirmed by the work of many scientists from all over the world, among which the following should be mentioned: Vavilov V.P., Ketkovich A.O., Kurtev M.D., Danilin M.S., Dubitsky L.G., Thomson R.D., Holland S., Biron R., Sakagami T., and many others [5 – 10].

However, in spite of the obtained results, the problem of thermography and MST thermography still remains unsolved in the problem of thermography and determination of the surface temperature containing individual trace elements whose temperature is significantly different from the background temperature (for example, separate structural elements on the background the massive body of the device with a temperature higher than the temperature of these elements). Thus, in the thermographic picture, such elements are not observed due to diffraction by the thermal background radiation of these elements, and, accordingly, their thermal profiles, Fig. 1.

Therefore, improving the resolution and accuracy of the surface temperature determination of MST products by thermographic method is a pressing issue.

The aim of the research is to improve the thermographic method by applying an automatic scanning system in the design of the thermal imager, as well as specialized software, which will improve the resolution and accuracy of the temperature distribution on the surfaces of the elements of MST.

2. The experimental technique

Improvement of the method and device of thermographic imaging has the task of improving the space-time characteristics of the thermal imager, namely, its accuracy and resolution by using an automatic scanning system as opaque for infrared radiation of a matrix diaphragm with a window of transparency up to 100 mm in size and up to 1 mm in size the lens of the thermal imager.

In a modified thermal imager containing a series-coupled registration node in the form of a matrix radiometer and an optical
system, which includes an automatic scanning system and an information processing unit. The automatic scanning system gives the possibility of step-by-step movement on a rectangular matrix, which results in obtaining local information of a separate section of the thermal profile of the investigated surface. The optical system also includes a microlens located in front of a transparency window that focuses thermal radiation from an object of observation onto a matrix radiometer [11].

Due to the fact that in the proposed thermal imager there is no multiple reflection of the signal, and there is only a single focusing of the signal when passing through the microlens, the attenuation of multiple reflection of the signal, and there is only a single focusing of the signal onto the object of observation, the correspondence of the maximum value of the position of the transparency window (which corresponds to its maximum position in the lowest line), the maximum value of the position of the transparency window (which is equal to the maximum position of the object of observation) and stop stepper motor 9. After processing by the microprocessor 7, information about the constructed thermographic image, by means of the switching unit 8, may arrive at an external control device, collecting and processing information (eg, PC, industrial computer, etc.).

The imager works as follows. The radiation from the corresponding element of object 1 enters the microlens 2, from which focuses on the conductivity window of the matrix aperture 3 in which focuses on the matrix radiometer 4, which transmits information to the block of synchronous detectors 5. From the block of synchronous detectors 5 information enters the analog-to-digital converter 6, plug-in a microprocessor for controlling the operation of the device 7 and switching unit 8, which provides communication of the thermal imager with external control devices, collecting and processing information (eg, PC, industrial computer, etc.).

The thermal imager consists of a series-connected registration unit in the form of a matrix radiometer 4, an optical scanning system, which includes a matrix aperture 3, made of material that does not transmit infrared radiation with a window for infrared radiation, and microwave radiation conductivity and provides the design of the image on the matrix of the radiometer 4, as well as a processing unit consisting of a block of synchronous detectors 5, analog-to-digital converter 6, plug-in a microprocessor for controlling the operation of the device 7 and switching unit 8, which provides communication of the thermal imager with external control devices, collecting and processing information (eg, PC, industrial computer, etc.).

The use of this technical solution automatically maintains the clarity of the image being obtained and its high resolution by keeping the latter in the focal plane of the recording device.

For the experimental testing of the proposed idea, the article used a device Titanium HD 570M (FLIR Systems ATS) with a spectral range of 3.7–4.8 μm. Thermographic studies were performed with a recording rate of 1 kHz, a resolution of 160×128 pixels, and an integration time of 50 μs. The spatial resolution of the camera in the experiments was 220 μm.

The thermal experiment was conducted by thermal imaging examination in several stages: 1 stage – preparation for the experiment, 2 stage – preparation of control means, 3 stage – conducting the study (external and internal thermal imaging and instrumental measurements), 4 stage – analysis and decoding of the obtained results. Each stage was carried out in a specific sequence [12].

Preparation for conducting a thermal experiment. At this point, it is necessary to evaluate the readiness of the object of study for the thermal experiment. Thermal imaging of objects (MST), for example, when put into service, is usually performed during their test run. Shooting is performed with a dynamically operating device on running tests, as it is necessary that there be a temperature pressure - the difference between the temperature of the MST element and the environment. Typically, this temperature pressure should be at least 10–15 °C. Such temperature pressure will reveal defects in thermal protection, if any. Then a visual inspection of the MST device is performed and its warming is evaluated. It is desirable that the distance from the shooting point to the subject should be 10–30 cm, since at large distances detection of all defects (especially when using thermal imaging with small matrices) is not guaranteed. You also need to snap to the location and navigate to third-party objects. On initial visual inspection, you can make a general idea of the object of study and identify the elements for further detailed thermography. This object evaluation is only preliminary and cannot be independently used to analyze the observations. After visual inspection, reference areas should be selected on the surface of the object. The reference zones are homogenous areas on the surface of protected structures, with constant temperatures being areas with a relatively isothermal surface [13]. The size of the reference area may be 2 – 10 mm (Fig. 3). In these areas, contact measurements will continue to be made.

The result of the works of this stage is the plan (scheme) of thermal imaging examination, where it is necessary to fix the anchor to the elements of the investigated surface, to determine the shooting points (their place and number), here the distance to the object is indicated, the direction of the shooting, the selected reference areas are marked and areas identified by visual inspection of abnormal (or defective) areas - these may be sites with some unusual design solutions or areas with visually visible defects.

After the general idea of the object of study and the control scheme are defined, they proceed to the inspection and preparation of the equipment [14].

Preparation of controls. This step involves selecting controls based on the temperature range of the detection, the sensitivity, the
error of determination, the parameters of the controlled object. Before proceeding directly to thermal imaging control, a series of actions must be taken to reduce errors in temperature detection in the field and to best visualize the thermal image of the object. For this purpose in the thermal imager a number of settings is organized. They can be roughly divided into two classes: settings related to environmental settings and settings that relate directly to the operation of the unit. The settings of the device that set the values of environmental parameters include: ambient temperature; distance to the object of control; air humidity.

Atmospheric conditions in which thermal imaging is controlled affect the passage of infrared radiation from the object to the operator. Therefore, it is desirable to take into account the environmental parameters to reduce errors in determining the actual temperature of the control object. If you set environmental parameters in the corresponding instrument settings menu, the thermal imaging processor will be able to calculate a compensatory correction for external conditions and thus minimize the error in temperature determination associated with attenuation of the IR radiation in the atmosphere. The air temperature and humidity can be determined by a thermogigrometer and the distance by a laser rangefinder. Other settings of the device are already related to the thermal imager and the object of thermal imaging control.

Setting the temperature sub-range of temperature determination. Typically, the thermal imager range (for example, from -40 °C to +100 °C, from -10 °C to +300 °C, from +10 °C to +600 °C). If you ignore these settings of the device, you can see nothing at all on the screen of the thermal imager (if the temperature of the object is lower than the lower limit of the high-temperature range), and to disable the sensitive elements of the matrix (if a hot object falls into the frame when a low temperature sub-band is defined) [15].

Set the radiation factor. Since real bodies give less space to an absolutely black body at the same temperature, it is desirable to indicate, in the instrument settings, the radiation coefficient of the material from which the control object is made in order to calculate it and, accordingly, reduce the error in determining the temperature. The value of the radiation factor is usually taken from reference tables or determined experimentally on the spot. According to regulatory documents, it is not recommended to carry out monitoring of an object having an emission factor less than 0.6. In this case, measures are needed to approximate it to 1.0 by painting the surface of the object or other available paths.

Selecting a working palette. Installation of the appropriate palette is required for better visualization of thermal details of the thermal image of the control object. Set of color palettes is a matter of operator’s habit and tradition in this or that field of use of the thermal imager. So, if a large temperature sub-range (tens of degrees) falls into the frame of the imager, it is advisable to choose a palette with a small number of colors (2 – 3). If an object with a small temperature difference (degrees and tenths of a degree) is considered in the thermal imager, it is better to choose a palette with many colors (up to 8). Specifies the range of displayed temperatures. In most modern thermal imagers this feature is implemented in automatic mode. That is, the upper and lower bounds of the interval itself adjusts depending on the minimum and maximum temperatures of the object that fall into the field of view of the imager. In some cases, you may need to manually adjust the interval, for example, when you need to examine in detail not the entire object with a wide temperature range, but only part of it.

Adjusts focus (sharpness). Sharpening is a very important part of getting a good thermal image. All previous settings discussed can then be corrected in the thermal imaging program (for example, if settings were mistaken at the scene).

To correctly determine the temperature field of the heater with the help of an IR camera, camera calibrations were performed. The resulting calibration curve was approximated by a second degree polynomial. The temperature determination error using a thermocouple was 0.5 °C. The standard deviation was calculated in Altair and was 0.4 °C. The minimum separation temperature difference equivalent to the infrared camera noise is 0.02 °C. Thus, the determined temperature from the test sample corresponded to the surface temperature of the heater directly in contact with the object of study. The relative error in determining the temperature during the calibration step was 3%.

Adjusting the lens image settings. Some models of thermal imagers have the ability to install different lenses with different values of the angles of view. These are the so-called telephoto lenses (narrow-angle) and panoramic (wide-angle). Each time you change the lens, it is recommended that you reflect this in the appropriate settings of the device. Thus, the correction is made to the reading of the device, since the optical system of the imager absorbs IR radiation. Each lens has a construction-dependent absorption correction value. In some devices, this adjustment to the new lens can be implemented automatically. After all the work on preparation for the control and equipment preparation, you can start thermal imaging directly. After the preparation for the control and the devices have been prepared, you can proceed to the stage of thermal control.

Thermal imaging and instrument definitions. At this stage, the geometry of the study object is first determined (the location of the other structural elements of the environment relative to the MCT device is determined) and the distance at which external thermal imaging is taken. It is desirable that this shooting distance remains unchanged. With the help of instruments the temperature and humidity of the environment are fixed. The temperature of the reference zones is then determined, both by the contact method (this is done by means of a contact thermometer) and by the non-contact method (by the thermal imager), and the true coefficient of radiation of the object is established based on these data in the thermal imager menu. Then proceed directly to thermal imaging. External thermal imaging of the object is carried out using the automatic scanning system sequentially left - right and bottom - up, for which the investigated surface is divided into separate sections, arranged in the form of a matrix, Fig. 4.

Start thermal imaging with the coldest area. Each frame that opens the aperture is accompanied by a photograph. The shooting angle is chosen to be minimal, but in any case it should not exceed 60º. If this condition is not met, the control results may be distorted. After the object has been photographed over the entire surface, you can, if necessary, take a closer look at some areas of doubt. For example, we can do a detailed survey of the overlapping zones of individual colder microdistricts against a hotter surface. It is also advisable to carry out a panoramic thermographic survey of each element of the object.

To maintain the necessary detail and quality overall image of a large object (such as a heat unit, car or airplane), it is advisable to perform panoramic shooting from a not too far distance (in any case, the distance should not exceed 1 – 2 m). In this case, you can take a panoramic shot of each element in a few snapshots, and then create a single overall thermal snapshot of the object during computer processing [16]. At the same time, the quality of the thermal image does not deteriorate, no thermal details are lost, and you can make an overall impression of the defects that are characteristic of the whole object. It should be said that the built-in software of many modern thermal imaging cameras allows directly in the program to “stitch” individual thermograms into a single

Fig 4 Scheme of thermal imaging of the device MCT (control unit optical microsystem positioning)
As a result, after thermal imaging, we will have thermograms of all the elements of the object, "detailed" thermograms of the individual sections of the external elements that protect them, as well as thermograms obtained during the internal shooting. Thermograms obtained during thermal imaging are then computer-processed, analyzed and attached to the thermographic report. In order to make instrumental determinations, one or more typical objects, which maintain a relatively uniform temperature regime under the same environmental conditions, are selected. For these objects, reference areas are selected, which are characterized by homogeneous sections of outer walls with relatively isothermal surfaces. Such sites are characterized by conditional (plane) resistance to heat transfer. You need to log the test data automatically or manually after a certain period of time (eg 0.5 – 1 minute) for several minutes.

After the logging time (usually a few minutes) is over, the results of the determination are processed. Thus, after making instrumental determinations, we will have the values of the temperature at the object under study and outside, the values of the temperatures of the surfaces of the structures inside and outside the PC, the amount of humidity in the study zone, and the values of the density of heat fluxes passing through the protecting structures. The resulting quantitative parameters must be recorded and stored. The results are processed using special software that comes with the equipment, as well as with specialized software packages developed with the help of the authors of the article. Then, based on the obtained instrumental definitions, it is possible to calculate the necessary figures of heat consumption.

Analysis and decoding of the obtained thermograms and interpretation of the determination results. Initially, computer processing of thermograms and identify areas of thermal anomalies – that is, the zone of deviation from the predicted temperature distributions on the surface. In computer processing of thermograms, various built-in functions can be used to isolate and refine anomalous areas – for example, you can set points, lines, rectangles, ovals, and the like, indicating temperatures or temperature deviations. Sometimes the analysis and decryption of thermograms also use the functions of histogram construction (Fig. 5).

Thermograms treated in this way give an idea of the presence in the controlled object of anomalous areas (the search for such sites is oriented to the basic idea of work) associated with violations in their manufacture or in operation.

3. Discuss the results of the experiment

According to the results of thermographic studies conducted by the thermographic method before its modification, Fig.6, it is shown that the electronic-mechanical device of micropositioning of the measuring nanosand of the scanning probe nanoscope has an elevated temperature on both its surface, both on mechanical and electronic devices, making it impossible to accurately determine the thermal profile of the individual elements of this device. At the same time, the peripheral mechanical elements of the device had a higher temperature (about 32 °C) compared to the electronic elements located closer to its central part (about 29 °C).

Fig.7 shows the thermograms of the surface of the individual elements of this electronic-mechanical micropositioning device, registered by an advanced thermographic device.

![Fig. 6 Results of thermographic studies (to perfection) electron-mechanical micropositioning device of measuring nanosand of scanning probe nanoscope with specified reference point (mark 1)](image)

![Fig. 7 Results of thermographic studies (after refinement) of the electronic-mechanical micropositioning device of the measuring nano-probe of the scanning probe nanoscope with the specified reference point (mark 1)](image)

As can be seen from Fig. 7, after receiving the thermogram by an improved thermographic device, we have a clearer image of the object under study, whose spatial resolution (compared to the standard method of determination) is improved by 15 – 20%, and the spectral resolution by 0.3 – 0.5 μm. Examining the thermogram visualization (Fig.7), one can see a clear separation of the thermal effect on the piezochips (having a lower temperature) and the mechanical elements of the device (fixed higher temperature heating), which is not observed on the thermogram with Fig.6.

According to the results of thermal imaging diagnostics, the number of high-energy centers of temperature rise was determined. The number of such centers was automatically determined using a software algorithm implemented in the MatLab environment.
According to the results of the analysis of the processed image, the temperature scale of the thermogram was also adjusted, which, in turn, allowed to increase the accuracy of determining the temperature in each accurate image. Thus, the temperature distribution error determined by the authors of the algorithm article did not exceed 5.5%.

At the same time, the high spatial resolution of the proposed advanced thermographic method in the experiments made it possible to trace the evolution of the surface temperature field distribution in certain areas of the surface of individual elements of the MST device. This made it possible to analyze the temporal thermal characteristics and to determine the temperature gradients on the surface of the object under study.

3. Conclusion

It has been proved that the improvement of the thermographic imaging device by using the automatic scanning system as an opaque for infrared radiation of a matrix aperture with a window of size from 100 µm to 1 mm at the inlet of the lens of the imager, leads to the improvement of its spatial and temporal characteristics, namely accuracy and resolution.

Experimental studies have shown the high efficiency of using an advanced thermographic method to obtain a high-precision thermographic image of the investigated high-resolution MST devices.

It was found that the spatial resolution of the improved thermographic method (compared to the standard method of determination) was improved by 15–20%, and the spectral resolution by 0.3 – 0.5 µm. According to the results of the analysis of the processed image, the adjusted temperature scale of the thermogram, which, in turn, allowed to increase the accuracy of temperature determination in each accurate image (the temperature distribution error did not exceed 5.5%).

The data obtained can further be described by semi-empirical dependencies and used to describe the local and integral heat transfer characteristics between the elements of the MST devices.

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Проблемы моделирования ультразвуковой дефектоскопии микродефектов сварных швов

Problems of modeling ultrasonic flaw detection of microdefects of welds

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Annotation. As you know, the goal of many technologies is miniaturization. The miniaturization of technical products has become one of the driving forces for the development of high-tech systems in the late XX and early XXI centuries. The article discusses some of the most famous methods for determining defects in micro-welded joints and joints. The main disadvantages of these methods are established, among which the following: bulkiness, elongation in time, seam destructibility in the process of defect detection, the inability to accurately determine the depth of defects and so on. It is shown that ultrasonic testing of welds allows, without destroying the weld itself, to identify such internal defects as: cracks, gas and slag inclusions, lack of penetration, etc. A dynamic computer model of the propagation of ultrasound in micro-welded seams of metal samples in the presence of defects of various sizes was created on the basis of which a regularity of the sensitivity of the measurement of such microdefects from the parameters of an ultrasonic microdefoscope was revealed.

KEY WORDS: MINIATURIZATION, UNBRAKABLE CONTROL, WELD, MICRODEFECT, ULTRASONIC FLAW DETECTION, MICRODEFECTOSCOPE, DIRECT PIEZOELECTRIC TRANSDUCER, COMPUTER MODELLING.

Введение

Процесс миниатюризации — данная тенденция развития техники, изначально связанная с процессом повышения точности и разрешающей способности создаваемых изделий. Именно последнее является основанием для создания все более малоразмерных изделий.

Впервые миниатюризацию получила распространения среди изделий механизики при развитии технологий, повышающих точность изготовления деталей. Начался этот процесс с производства замков; затем в лидеры вышли часовщики. Именно последние создали первые миниатюрные механические изделия (были созданы арифмометры, интеграторы и т. п.). Однако, развитие сварочных технологий невозможно без использования микрокомпонентов (микроэлектроники), сопряженной уже с интеллектуализацией. Символ этого этапа – множество плат печатного монтажа, в которых достигается субмикронная точность. Наблюдается, что на рубеже XXI столетия начался третий этап миниатюризации на базе 3D микросистемных технологий. Этот этап относится не столько к электронике, сколько к трехмерной электромеханике и позволяет создавать микрокомпоненты (микроэлектромеханические системы [1]).

В тоже время следует отметить, что одним из основных методов соединения для получения целевой готовой металлической конструкции — является сварка [2]. Однако, развитие сварочных технологий невозможно без использования методов неразрушающего контроля (НК), способствующих повышению качества материалов и сварных конструкций ответственного назначения [3]. Это, в свою очередь, привело к развитию фундаментальных основ дефектоскопии, увеличению количества разработок по методам НК. Большое значение для развития и распространения физических методов контроля качества имеет провизительская деятельность. В ИЭС (Институт электросварки) работает Украинское общество неразрушающего контроля и технической диагностики (УО НКТД) — общественная организация, созданная в 1990 г., основной задачей которой является консультация специалистов в пропаганде мер, предотвращающих возможность, комплексное решение проблем оценки качества материалов и надежности промышленных сооружений, расширения знаний и международных контактов [4].

Постановка проблемы

Микроструктура шва и зоны термического влияния в значительной степени определяют свойства сварных соединений и характеризуют их качество. К дефектам микроструктуры относят следующие: повышенное содержание оксидов и различных неметаллических включений, микропоры и микротрецины, крупнозернистость, перегрев, пережог металла и др. [5]

Пергев характеризуется чрезмерным уплотнением зерна и огрублением структуры металла. Более опасен пережог — наличие в структуре металла зерен с окисленными границами. Такой металл имеет повышенную хрупкость и не поддается исправлению. Причиной перегрева является плохая защита сварочной ванны при сварке, а также сварка при большой силе тока.

Как известно, дефекты бывают нескольких видов [6]: - наружные и внутренние; - допустимые и не допустимые. К наружным дефектам относятся нарушения геометрических размеров (подрезы, наплывы), непровары и прожоги, незаваренные кратеры (рис.1).

Рис. 1. Распределение дефектов в сварных соединениях

Основной причиной непроваров является недостаточное сварочный ток, так как он в большей степени влияет на проплавление в металле. Также причиной непроваров может быть большая скорость сварки или недостаточная подготовка кромок сварного соединения. Устранение дефектов этого вида обычно происходит путем повышения мощности сварочной дуги, уменьшением длины дуги и увеличением её динамики.

Подрезом называется дефект в виде канавки в основном металле по краям сварочного шва. Это наиболее распространенный дефект при сварке тонких или налаженных соединений, но может также возникнуть и при сварке стыковых соединений. Этот вид дефекта обычно вызван неправильно подобранными параметрами и устраняется...
регулированием скорости сварки и напряжения сварочной дуги.

Наплав появляется в результате натекания присадочного материала на основной металл без образования сплавления с ним. Обычно причиной этого дефекта является неправильно подобранная скорость сварки и окисление металла. Наплавы могут быть вызваны загрязнением, неправильно подобранными режимами сварки и напряжения дуги. Устранение наплавов:

- ультразвуковым контролем (УЗК) – наплавы могут быть обнаружены по коэффициенту затухания отраженного и прошедших импульсов.
- механическим контролем – наплавы могут быть обнаружены по изменению геометрии поверхности.
- электромагнитным контролем – наплавы могут быть обнаружены по изменению магнитного поля.

Для ультразвукового контроля сварных соединений применяют идентификационные порошки, которые позволяют проводить окончание сварки на месте присадочного материала без образования наплавов.

Суть методики заключается в обработке объекта ультразвуком. При контроле сварных соединений колебания последовательно излучаются в изделие. После этого они воспринимаются в качестве отраженной волны специальным оборудованием (дефектоскопом) [8]. В результате специалист может: детализировать размеры дефекта; определить вид повреждения; установить форму дефекта; выяснить глубину залегания деформации и решить другие задачи.

Основные методы ультразвуковой дефектоскопии [9]:

1. Теневой метод. Данная методика заключается в контроле уменьшении амплитуды колебаний отраженного и прошедшего импульсов.
2. Зеркально-теневой метод. При таком способе дефекты швов обнаруживаются по коэффициенту затухания отраженного ультразвукового колебания.
3. Эхо-зеркальный метод. Данный способ, который также называют "Тандем", заключается в использовании двух ультразвуковых аппаратов. Они работают одновременно и устанавливаются с одной стороны объекта. Сгенерированные колебания отражаются на приемник.
4. Дельта-метод. Основывается на контроле ультразвуковой энергии, которая отражается от дефекта.
5. Эхо-метод. Данная методика основана на регистрации ультразвукового сигнала, который отражается от дефекта.

На сегодняшний день наиболее популярным методом неразрушающего контроля является ультразвуковой контроль (УЗК) сварных соединений. Ультразвуковой контроль представляет собой экспертизу, которая способна в кратчайшие сроки выявить: 
- износ изделий,
- поверхностные или внутренние дефекты металлов и сплавов,
- качество изделия или отдельного сварного шва.

Для моделирования использовалась программа SimNDT. Ультразвуковой симулятор NDT с сердечником двигателя на основе методики эластодинамической конечной интеграции (EFIT) твердых сред предназначен для моделирования процесса распространения ультразвуковых волн в 2D однородной среде для взаимопротивления и штамповочных операций металла.

Рассматривался дефект овальной формы радиусами R=5 мм, 2,5 мм и 0,1 мм в сталином образце 100×100 мм. Координаты расположения дефекта (50 мм: 25 мм),
ультразвуковой контроль проводился на частоте 3 МГц с помощью прямого преобразователя УЗК, рис.2 – 4.

Анализируя результаты компьютерного моделирования УЗД микродефектов сварных швов (рис.2 – 4) установлены следующие закономерности точности определения местоположения микродефектов в зависимости от их размеров.

Так, на рис.2 показана такая закономерность для сферического дефекта радиусом R=5 мм. Как можно увидеть из изображения визуализации процесса распространения ультразвуковых волн (рис.2.а), дефект имеет четко выраженную форму и местоположения (возбуждение В на рисунке). По графику зависимости амплитуды от времени четко наблюдается один сигнал положения которого соответствует 8,2 сек по временной шкале, а амплитуда такого сигнала четко согласуется с размерами самого дефекта (возбуждение А на рисунке).

В тоже время, визуализация процесса распространения ультразвуковых волн (рис.3.а) для меньшего дефекта R=2,5 мм дает кроме основного изображения (соответствует возбужденному сигналу А, рис.3.а) также дополнительное эхо-изображение (рис.3.а справа вверху – соответствует эхо-сигналу B – рис.3.б). Такое эхо-изображение несет неправдивую информацию про характер дефектов при УЗД.

Дальнейшее уменьшение размеров дефекта до 100 – 200 мкм (рис.4) ведет к уменьшению амплитуды, как основного, так и эхо-сигнала (рис.4.6, возбуждение А) до значений близких к значениям белого шума, что исключает возможность точного определения, как размеров, так и местоположения такого микродефекта.

Заключение

Таким образом, показано, что контроль ультразвуком сварных швов позволяет, не разрушая самого шва, выявлять такие внутренние дефекты, как: трещины, газовые и шлаковые включения, непровары и т.п.

Установлены основные недостатки методов поиска микродефектов в сварных соединениях, среди которых громоздкость, растянутость во времени, разрушаемость шва в процессе выявления дефекта, невозможность точного определения глубины залегания дефектов и др.

Создана динамическая компьютерная модель распространения ультразвука в микросварных швах металлических образцов при наличии в них дефектов различного размера, на основе которой выявлены закономерности чувствительности измерения таких микродефектов от параметров ультразвукового микродефектоскопа, показывающие невозможность определения микродефектов размерами менее 100 мкм в сварных швах сплошных материалов. Это доказывает необходимость принципиального усовершенствования метода УЗД, путем интерференции акустических ультразвуковых волн основного и эхо-сигналов на предполагаемых границах дефектов, что позволяет увеличить точность и разрешающую способность определения местоположения формы и размеров микродефектов и в дальнейшем планируется проводиться коллективом авторов.

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A new method for the detection of poor electrical contacts in low-voltage electrical installations characterised by the TN protection system – field validation in residential buildings

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Abstract: The previously developed new method for detecting poor electrical contacts in low-voltage electrical installations characterised by the TN protection system has been validated by field measurements performed in residential buildings. The method was developed by the establishment of a correlation between the measured line to earth and line to neutral short circuit loop resistances and the degree of the contact deterioration, i.e. the increase of its electrical resistance. The correlation was established by analysing the data obtained from a large number of documents related to periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities (issued by the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade), as well as the data obtained through a large number of experiments in which the impact of poor electrical contacts on the occurrence of „hot” spots in low-voltage electrical installations was analysed. In those experiments the influence of an incomplete overlap of the surface of the copper conductor and the contact surface at the electrical component terminal (reduction of the contact surface), a reduced pressure force between the contact surfaces of the copper conductor and the screw of the electrical component terminal (reduction of the torque), and an increased oxide layer at the point of electrical contact (old and/or corrosion-damaged contact) on the electrical and thermal behaviour of electrical contacts was investigated. The developed method for detecting poor electrical contacts was applied to the verification of the quality of low-voltage electrical installations in 6 flats of old (10–60 years) residential buildings and the measurement results are presented and analysed in this paper.

Keywords: POOR ELECTRICAL CONTACT, CONTACT TIGHTENING TORQUE, HOT SPOT, FIRE, CONTACT RESISTANCE, PERIODIC VERIFICATION OF LOW-VOLTAGE ELECTRICAL INSTALLATION

1. Introduction

Failures in electrical installations represent a significant fire safety problem which actively needs to be taken into consideration in many areas of human activities [1–3]. Frequent types of such failures are glowing connections and series arc, which usually occur due to overheating of poor electrical connections characterised by a high electrical resistance [4]. As in many other technical fields [5, 6], there is a constant need for innovations in the development of more efficient methods and devices in the field of electrical installations regarding fire safety. In recent studies, researchers’ efforts were invested in the development of new techniques and algorithms for the detection of the occurrence of the series arc in electrical circuits [7–10], as well as to improve methods for the fault loop impedance measurement in TN low-voltage networks [11]. This paper describes a new method developed for detecting poor electrical contacts in low-voltage electrical installations characterised by the TN protection system.

Poor electrical contact is a failure in low-voltage electrical installations that cannot be detected either by procedures for periodic verification of the quality of low-voltage electrical installations defined in national and international regulations and standards or by any conventional protection device [12–14]. At the same time, it can easily and suddenly cause a hot spot or series electric arc, which are the most common causes of fires caused by failures in low-voltage electrical installations.

In an electrical installation, a poor electrical contact can be considered as characterised by [15]:

- an incomplete overlap of the surface of the copper conductor and the contact surface at the electrical component terminal (reduction of the contact surface),
- a reduced pressure force between the contact surfaces of the copper conductor and the screw of the electrical component terminal (reduction of the torque), or
- an increased oxide layer at the point of electrical contact (old and/or corrosion-damaged contact).

The effects of the reduction of the contact surface, reduction of the torque and the increased oxide layer at the point of electrical contact on the electrical and thermal behaviour of a poor contact were experimentally and theoretically investigated in [16], [17] and [4], respectively. Based on a large number of experiments, as well as on the data obtained from a large number of documents related to periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities (issued by the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade), a new method for detecting poor electrical contacts in low-voltage electrical installations characterised by the TN protection system has been developed and presented in [4] and [15]. The developed method was applied to the verification of the quality of low-voltage electrical installations in 6 flats of old (10–60 years) residential buildings and the measurement results are presented and analysed in this paper.

2. Development of a new method for detecting poor electrical contacts in low-voltage electrical installations characterised by the TN protection system

2.1 The basic idea for the development of a new method for detecting poor electrical contacts

The current standard procedure for the verification of the quality of low-voltage electrical installations [18] is based on the comparison of the measured line to earth resistance with the limit value which enables sufficiently fast tripping of the corresponding protection device (in order to prevent electric shock) [19]. Since the limit values are high, all of the electrical circuits where the measured line to earth resistance is lower than the limit value \( R_{\text{MAX}} \) are declared as in order, although some of them may contain a poor contact.

The idea was to develop a procedure for detecting poor contacts in receptacles, based on measuring both the line to earth and line to neutral short circuit loop resistances during periodic verification of low-voltage electrical installations. The detection of a noticeable increase of the earth fault loop and/or line to neutral short circuit loop impedance indicates the existence of at least one poor contact in the observed electrical circuit.
According to [20], the usually applied (conventional) measuring equipment for verifications of low-voltage electrical installations enables the measurement of both of those impedances. Schematic presentations of the earth fault loop (L-PE) and line to neutral short circuit loop impedance (L-N) measurements using a conventional measuring device are given in Figs. 1 and 2, respectively.

The line to earth resistance \( R_{sL-PE} \) in the TN system consists of the resistance of the power transformer’s secondary winding, phase conductor resistance between the power transformer and the test location, and equipment grounding conductor resistance between the test location and the power transformer. The line to neutral short circuit loop resistance \( R_{sL-N} \) in the TN system consists of the resistance of the power transformer’s secondary winding, phase conductor resistance between the power transformer and the test location, and neutral conductor resistance between the test location and the power transformer.

![Fig. 1 Schematic presentation of measuring \( R_{sL-PE} \) using conventional measuring equipment (\( R_e \) represents the internal electrical resistance of the measuring equipment).](image1)

![Fig. 2 Schematic presentation of measuring \( R_{sL-N} \) using conventional measuring equipment.](image2)

2.2 The data obtained from a large number of documents related to periodic verifications of the quality of low-voltage electrical installations

As reported in [4], the results of periodic verifications of low-voltage electrical installations performed by the Laboratory in public and commercial buildings with a total area of over 150,000 m² were analysed. The measured \( R_{sL-PE} \) values for 11,159 receptacles were statistically analysed and their statistical distribution is given in Fig. 3, which shows the number of receptacles for which the measured \( R_{sL-PE} \) resistances belonged to each of the ranges 0–0.1 Ω, 0.1–0.2 Ω, ..., 1.1–1.2 Ω and 1.2–1.3 Ω. The number of the receptacles for which the \( R_{sL-PE} \) resistance was higher than 1.3 Ω (1.5% of their total number) are not shown in Fig. 3, because their resistances were scattered within the range 1.31–7.68 Ω.

![Fig. 3 Number of receptacles for which \( R_{sL-PE} \) belonged to each of the ranges 0.1 Ω wide. [4]](image3)

It was noticed in [4] that the majority of the measured \( R_{sL-PE} \) resistances belonged to the range 0.3–1 Ω, emphasising that he values lower than 0.3 Ω were measured in cases where the MV/LV transformer station was positioned inside the building or in its vicinity and for electrical circuits on lower floors of the building, while the values higher than 1 Ω were measured for electrical circuits on upper floors, because \( R_{sL-PE} \) increases with the distance between the electrical circuit and the transformer station.

It was also reported in [4] that on 82 receptacles \( R_{sL-PE} \) resistances higher than the corresponding \( R_{sMAX} \) values were measured (in those receptacles the \( R_{sMAX} \) resistances ranged from 1.79 Ω to 7.68 Ω). These circuits were declared as inappropriate for use, because the conditions for the prevention of an electric shock were not met. In addition, apart from the 11,159 receptacles for which \( R_{sL-PE} \) values were measured, there were 84 receptacles where the interruption of the equipment grounding conductor was detected, which were also declared as inappropriate for use. After tightening all electrical contacts in those 166 receptacles (or after replacing the receptacles), as well as tightening all electrical contacts in the supplying distribution boards, the \( R_{sL-PE} \) resistances were measured again and in all cases their values were not only lower than \( R_{sMAX} \), but also lower than 1.3 Ω.

However, as reported in [4], in addition to the 166 receptacles with failures detected by the standard procedure, there were additional 84 receptacles where the \( R_{sL-PE} \) resistances were lower than \( R_{sMAX} \), but high enough to indicate the presence of at least one poor contact (in those receptacles \( R_{sL-PE} \) resistances ranged from 1.3 Ω to 4.38 Ω). According to the standard procedure, although they represent the potential cause of fire, electrical circuits containing those receptacles would have been declared as in order. Nevertheless, the users of the facilities were instructed to make the necessary repairments, and after tightening all electrical contacts, in all of those cases the measured \( R_{sL-PE} \) resistance was lower than 1.3 Ω. Apart from the additional 84 receptacles, the poor contacts were also found in receptacles where \( R_{sL-PE} \) was lower than 1.3 Ω, but over 0.5 Ω higher than the \( R_{sL-PE} \) resistances measured on the surrounding receptacles.

2.3 The data obtained through a large number of experiments

As previously mentioned, the effects of the reduction of the contact surface, reduction of the torque and the increased oxide layer at the point of electrical contact on the electrical and thermal behaviour of a poor contact were experimentally and theoretically investigated in [16], [17] and [4], respectively.

The basic idea for all of the conducted experiments was to create various types of contacts which can be found in low-voltage electrical installations, to establish typical currents (they ranged from 2 A to 25 A in the conducted experiments) in circuits containing the created contacts, and to observe the time-varying
values of the electrical resistance, temperature, dissipated power and voltage of the created contacts. Various types of contacts were
created using various combinations of materials (copper–copper,
copper–brass and copper–stainless steel), solid and stranded wires
with various cross-sections (1.5 mm², 2.5 mm² and 4 mm²), various
percentage of the overlapping area of the electrodes forming the
contact (100%, 50% and 15%) and various adjusted torques on the
other wire screw terminal connection in receptacles and plugs (1
Nm (very good contact), 0.2 Nm (poor contact), or 0.1 Nm (very
poor contact)). In addition, contacts with various types of increased
oxide layer at the point of electrical contact were used in
experiments. Experiments were performed on a receptacle that has
been used for many years (30 years in the analysed case), as well as
on new receptacles, the electrical contacts of which were
intentionally exposed to corrosion prior to the experiments. The
experimental setup and used measuring equipment are shown in
Fig. 4.

Fig. 4 Experimental setup (1 – tested receptacle, 2 – clamp meter FLUKE
323, 3 – digital multimeter PeakTech 3360, 4 – plastic switchboard, 5 –
installation tester instrument FLUKE 1653B, 6 – type-K (Chromel-Alumel)
thermocouple probe, 7 – infrared thermometer Cole-Parmer, 8 – resistance
decade box 230 V, 60 A, 9 – the apparatus providing the adjustment of the
overlapping area of the electrodes, 10 – mechanical torque screwdriver
Wiha TorqueVario-S26462, and 11 – digital torque screwdriver TSD-50).

Analysing the results of the conducted experiments, it was
concluded that copper–stainless steel represents a critical
combination of materials for which a contact most rapidly reaches
the maximum permissible temperature under the same conditions
(the same load, conductor cross-section and contact deterioration
degree in terms of the same percentage reduction of the overlap
surface) [16]. In addition, it was concluded that poor electrical
contacts developed in built-in electrical installations of buildings
(where the copper conductor of the full cross-section is common)
are more unfavourable for the occurrence of a “hot” spot compared
to poor electrical contacts developed in power cables of electric
loads (where the stranded copper conductor is commonly used)
[17]. It was shown in [17] that poor contacts with the electrical
resistance ranging from 80 mΩ to 250 mΩ represent a threat to
safety if the circuit current is high (the current of 16 A, limited by
the applied protection device, generally represents the maximum
rated current in electrical circuits installed in residential,
commercial and public buildings connected to the mains with the
rated voltage of 230 V). Taking into account all data obtained from
periodic verifications of the quality of low-voltage electrical
installations, as well as all data obtained through experiments, it
was concluded in [4] that the limit for the $R_{L-PE}$ resistance
(indicating that there is at least one poor contact in an electrical
circuit) ($R_{lim}$) should be 0.5 Ω higher than the highest $R_{L-PE}$
resistance measured on the surrounding receptacles when doing
periodic verification of low-voltage electrical installations.

3. A new method for detecting poor electrical contacts in low-voltage electrical installations

The measurements of $R_{L-PE}$ and $R_{L-N}$ followed by a
comparison of their values to $R_{lim}$ and the analysis based on
Tables 1–3, represent a new method for detecting poor contacts in
low-voltage electrical installations developed and presented in [4]
and [15].

Tables 1 and 2 contain the maximum line to earth resistances
that ensure effective tripping of the protection device in case of
failure in the TN system ($R_{MAX}$), determined for the most frequently
applied fuse-links (both fast and slow) and miniature circuit
breakers (MCB) of types B and C (with the rated currents ($I_{r}$) of
6–25 A), respectively. In all cases, the value of $R_{MAX}$ was obtained by
dividing the value of the rated mains voltage (230 V) with the
corresponding value of $I_{r}$ (the minimal current for which protection
device operates within 0.4 s (a condition given in [19])). For each of
the considered fuse-links the value of $I_{r}$ was adopted from the
corresponding fuse-link overheating characteristic [21]. According
to [22], the minimal MCB currents ($I_{r}$) for which the fuse-links
react within 0.1 s (and, therefore, within 0.4 s) amount to 5 $I_{r}$ and
10 $I_{r}$ for types B and C, respectively.

Table 3 contains guidelines for potential locations of poor
contacts and possible fire hazards in all situations which can occur
in practice. It should be applied when the measured $R_{L-PE}$ resistance
is lower than $R_{MAX}$ (in the opposite case, the corresponding circuit
should be declared unsafe).

Therefore, by measuring $R_{L-PE}$ and $R_{L-N}$ values in every circuit
followed by a comparison of their values to $R_{lim}$ and the analysis
based on Tables 1–3, it can be determined if there is a poor contact
in the circuit.

Table 1: Values of $I_r$ and $R_{MAX}$ for fast and slow fuse-links ($I_r = 6–25$ A) [4]

<table>
<thead>
<tr>
<th>$I_r$ (A)</th>
<th>Fast</th>
<th>Slow</th>
<th>Fast</th>
<th>Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>16.71</td>
<td>29.65</td>
<td>13.76</td>
<td>7.75</td>
</tr>
<tr>
<td>10</td>
<td>34.08</td>
<td>55.65</td>
<td>6.74</td>
<td>4.13</td>
</tr>
<tr>
<td>16</td>
<td>51.07</td>
<td>86.86</td>
<td>4.50</td>
<td>2.64</td>
</tr>
<tr>
<td>20</td>
<td>67.62</td>
<td>110.01</td>
<td>3.40</td>
<td>2.09</td>
</tr>
<tr>
<td>25</td>
<td>94.69</td>
<td>138.13</td>
<td>2.42</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Table 2: Values of $I_r$ and $R_{MAX}$ for MCB of types B and C ($I_r = 6–25$ A) [4]

<table>
<thead>
<tr>
<th>$I_r$ (A)</th>
<th>Type B</th>
<th>Type C</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>30</td>
<td>60</td>
<td>7.67</td>
<td>3.83</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>80</td>
<td>5.75</td>
<td>2.87</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>100</td>
<td>4.60</td>
<td>2.30</td>
</tr>
<tr>
<td>13</td>
<td>65</td>
<td>130</td>
<td>3.53</td>
<td>1.76</td>
</tr>
<tr>
<td>16</td>
<td>80</td>
<td>160</td>
<td>2.87</td>
<td>1.43</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>200</td>
<td>2.30</td>
<td>1.15</td>
</tr>
<tr>
<td>25</td>
<td>125</td>
<td>250</td>
<td>1.84</td>
<td>0.92</td>
</tr>
</tbody>
</table>
4. Results and discussion

In order to validate the described new method for detecting poor contacts in low-voltage electrical installations, it was applied to the verification of the quality of low-voltage electrical installations in 6 flats of old (10–60 years) residential buildings. All of them were characterised by the TN protection system. In each of the flats 10 receptacles were examined (R_{l,PE} and R_{l,N} values were measured for each of them). The measurement results are given in Table 4.

Note that all of the examined electrical circuits were protected either by slow fuse-links with the rated current of 16 A (R_{MAX} = 4.50 Ω) or by MCBs of type B with the same rated current (R_{MAX} = 2.87 Ω). All measured R_{l,PE} and R_{l,N} values for the 60 examined receptacles were lower than R_{MAX} and, therefore, according to the standard procedure electrical circuits containing those receptacles would have been declared as in order. However, the comparison of the measured R_{l,PE} and R_{l,N} with R_{lim} (the resistance 0.5 Ω higher than the highest R_{l,PE} (R_{l,N}) resistance measured on the surrounding receptacles) showed that there were poor electrical contacts in 4 receptacles representing a potential cause of fire. When the new method was applied, poor electrical contacts were detected on the equipment grounding conductors in receptacles No. 4 in flat No. 2 and No. 1 in flat No. 5, on the neutral conductor in receptacle No. 8 in flat No. 6 and on the phase conductor in receptacle No. 6 in flat No. 4. After the electrician replaced those 4 receptacles with new ones, R_{l,PE} and R_{l,N} were remeasured in those electrical circuits in order to check if their new values met the conditions for safe protection against electric shock in case of failure. The remeasured values showed that in all 4 cases the defects which caused poor electrical contacts were eliminated by the intervention of an electrician, as well as that the replacement of those 4 receptacles with new ones was justified.

5. Conclusion

A new method for detecting poor contacts in low-voltage electrical installations characterised by the TN protection system, based on the measurement of both the R_{l,PE} and R_{l,N} resistances and their comparison to R_{lim} (the resistance 0.5 Ω higher than the highest R_{l,PE} (R_{l,N}) resistance measured on the surrounding receptacles) is presented. The new method was applied to the verification of the quality of low-voltage electrical installations in 6 flats of old (10–60 years) residential buildings and the measurement results are presented and analysed. According to the standard procedure, all of the 60 examined electrical circuits would have been declared as in order. However, the application of the presented method showed that there were poor electrical contacts in 4 receptacles, which represented the potential cause of fire. After the intervention of the electrician the defects which caused poor electrical contacts were successfully eliminated.

The application of the new method when verifying the state of electrical contacts would considerably reduce the probability of the occurrence of dangerous hot spots. This would solve the problem of the inability to detect hot spots by infrared thermography in cases where there is no visual contact. However, it should be emphasised that the application of the new procedure is limited to the TN systems where there is no visual contact. However, it should be noted that the application of the new method is frequently applied system.

6. Acknowledgements

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7. References


The importance of preventive thermographic inspections within periodic verifications of the quality of low-voltage electrical installations

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Abstract: During the lifelong maintenance of low-voltage electrical installations in any facility special attention must be given to fire-causing failures, which cannot be detected by conventional protection devices (miniature circuit breakers, fuse-links, residual current devices, etc.). Such failures are most often caused by poor electrical contacts. International regulations and standards, which define periodic verification of the quality of low-voltage electrical installations, do not contain procedures by which a poor electrical contact would be detected at an early stage. However, one of the techniques used for this purpose today is performing preventive thermographic inspections (a standard covering this area is available only in the USA). By such inspections a poor electrical contact which creates prerequisites for the occurrence of an initial fire in a low-voltage electrical installation can easily and effectively be detected. Detected failures and irregularities can most frequently be eliminated by simple interventions of electricians or facility technical services. Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections. Several practical examples of such failures, detected in low-voltage electrical installations in industrial and administrative facilities during preventive thermographic inspections, are presented and analysed. The procedure of performing preventive thermographic inspections within periodic verifications of the quality of low-voltage electrical installations, as well as the explanation for proper interpretation of the measurement results based on the ΔT and absolute temperature criteria, are also given in this paper.

Keywords: LOW-VOLTAGE ELECTRICAL INSTALLATION, POOR ELECTRICAL CONTACT, HOT SPOT, FIRE, INFRARED THERMOGRAPHY

1. Introduction

In order to prevent fire-causing failures of low-voltage electrical installations in a facility it is important to conduct periodic verifications of their quality using procedures defined in standards [1, 2]. However, there are some dangerous failures, such as poor electrical contact and series electrical arc, which cannot be detected either by conventional protection devices (miniature circuit breakers, fuse-links, residual current devices, etc.) or by inspection procedures defined in standards [3, 4]. In such cases, the application of infrared thermography for predictive/preventive maintenance of thermal defects of electrical components proved to be quite useful and efficient [5, 6]. A thermographic inspection, conducted using infrared thermal imager (infrared camera), enables the identification of “exceptions” – parts of electrical installations where the temperatures of the inspected electrical components deviate significantly from the expected operating ones [7]. Finding such exceptions allows targeted maintenance or elimination of problems before a fire and/or breakdown in an electrical system occurs. Therefore, it is recommended to include thermographic inspection in the procedure for conducting periodic verification of the quality of low-voltage electrical installations [8], although it is not included as a mandatory part of the procedure defined in standard [2] which is valid in almost all countries in Europe. Procedures given in standards covering this area in the USA [7, 9] should be taken into consideration.

2. Infrared thermography and its applications

All objects having a temperature greater than absolute zero (i.e. T > 0K) radiate heat (energy) in form of electromagnetic waves, in general case in continuous frequency spectrum. At room temperature most of that energy is radiated in the infrared spectrum, characterised by wavelengths longer than visible light (a typical human eye responds to electromagnetic waves the wavelengths of which are from about 380 nm to 740 nm). Therefore, that radiated energy cannot be perceived either by the human eye or standard cameras.

Although electromagnetic radiation in the infrared spectrum was investigated since 1800, the first infrared imaging device was introduced in 1947 as a night vision camera for military purposes [10]. Such devices evolved into infrared thermal imagers – non-contact measurement equipment able to detect infrared radiations emitted from an object and, based on gathered information, give a thermal profile of the captured scene as an output.

Infrared thermography is an investigation technique involving thermal image acquiring using an infrared thermal imager followed by processing and analysing the obtained thermal data [10]. Due to the fast advance in the features of infrared thermal imagers, which has come together with their progressive cost reduction, the use of this technique has expanded to many industrial applications [11]. For example, it is used in civil engineering [12], mechanical engineering [13], manufacture of electrical [14] and mechanical [15] components, as well as in the detection of failures in electrical systems [16, 17] and assessment of the condition of electrical equipment [18, 19].

It is emphasised in [20] that poor electrical contact, loose connection, corrosion, rust, accumulation of dust, short circuit and overloading may lead to equipment failure and that most of those defects will generate excessive heat near the area of fault. Such thermal anomalies can easily be captured by an infrared thermal imager and by assessing the condition of the equipment any signs of failure can be identified [20].

3. Thermographic inspections – procedures and evaluation criteria defined in [7, 9]

3.1 Thermographic inspections – significance and procedure

As defined in [7], the purpose of a thermographic inspection is to identify and document exceptions in the electrical installation of the end-user (person or company requesting the thermographic inspection). Exceptions are usually caused by loose or deteriorated connections, short circuits, overloads, load imbalances or faulty, mismatched or improperly installed components. In order to successfully detect them, a thermographer (a person who is trained and qualified to use an infrared thermal imager) must have sufficient knowledge about the components, construction and theory of electrical systems to be able to understand the observed patterns.
of the infrared radiation captured in a thermal image (thermogram). The obligation of the end-user is to provide (or help the development of) an inventory list of the equipment to be inspected in a logical and efficient route through the facility. In addition, the end-user must provide a qualified assistant (a person authorized by the end-user, who is familiar with the operation and history of the equipment to be inspected, as well as trained in all of the safety practices and rules of the end-user) who will accompany the thermographer during the thermographic inspection. The obligations of the qualified assistant are to obtain authorisation necessary to gain access to the equipment to be inspected, notify the operations personnel of the inspection activities, open and/or remove all necessary covers immediately before inspection by the thermographer, close and/or replace the cabinets and enclosure covers immediately after inspection by the thermographer, assure that the equipment to be inspected is under adequate load (ideally – normal operating load), create satisfactory loads when necessary, allow sufficient time for recently-energised equipment to produce stable thermal patterns, measure electric loads when requested by the thermographer, etc.

Thermographic inspections may be qualitative or quantitative in nature. Qualitative inspection implies gathering information about a structure, system, object or process by observing images of infrared radiation, and recording and presenting this information, while quantitative inspection implies precise measuring of temperatures of the observed patterns of infrared radiation. Whenever possible, measured temperatures of similar components under similar load should be compared to each other. Components exhibiting unusual thermal patterns or operating temperatures should be deemed as exceptions and documented with a thermal image and visible light image. If any exception is detected, its severity level should be evaluated, the cause of exception should be inspected and appropriate corrective actions should be taken as soon as possible.

3.2 Documentation for the performed thermographic inspections

The thermographer should provide appropriate documentation for all performed thermographic inspections. Written reports which will be given to the end-users should include the following information [7]:

- the name and any valid certification level(s) and number(s) of the thermographer,
- the name and address of the end-user,
- the name(s) of the qualified assistant(s) accompanying the thermographer during the inspection,
- the manufacturer, model and serial number of the infrared equipment used,
- a list of all the equipment inspected and notations of the equipment not inspected on the inventory list, and
- the date(s) of the inspection and when the report was prepared.

When a thermographer performs a qualitative thermographic inspection, the written reports which will be given to the end-users should include the following information for each exception identified [7]:

- the exact location of the exception,
- a description of the exception such as its significant nameplate data, phase or circuit number, rated voltage, amperage rating and/or rotation speed,
- when significant, the environmental conditions surrounding the exception including the air temperature, wind speed and direction, and the sky conditions,
- hardcopies of a thermal image and corresponding visible-light image of the exception,
- the field-of-view of the infrared imager lens,
- notation of any windows, filters or external optics used,
- if desired, a subjective evaluation rating provided by the qualified assistant and/or end-user representative, of the importance of the exception to the safe and continuous operation of the system, and
- any other information or special conditions that may affect the results, repeatability or interpretation of the exception.

When a thermographer performs a quantitative thermographic inspection, the written reports which will be given to the end-users should include the following information for each exception identified [7]:

- the distance from the infrared imager to the exception,
- whenever possible, the maximum rated load of the exception and its measured load at the time of the inspection,
- the percentage load on the exception, calculated by dividing its measured load by the rated load,
- the emittance, reflected temperature and transmittance values used to calculate the temperature of the exception,
- when using ΔT (temperature difference) criteria, the surface temperature of the exception and of a defined reference and their temperature difference,
- when using absolute criteria, the surface temperature of the exception and the standard temperature(s) referenced,
- if desired, an evaluation of the temperature severity of the exception, and
- if desired, a repair priority rating for the exception based on its subjective rating, temperature severity rating or an average of both.

3.3 ΔT criteria for electrical systems

To evaluate the severity level of a detected exception a thermographer may use the ΔT criteria given in Table 1 [7, 9]. Evaluations by ΔT criteria are based on the value of the measured temperature rise of the exception above the temperature of a defined reference, which is typically the ambient air temperature, a similar component under the same conditions or the maximum permissible temperature of the component. Recommended actions for each defined range of the measured temperature rise are also given in Table 1.

<table>
<thead>
<tr>
<th>Priority</th>
<th>Temperature difference (ΔT) based on comparisons between similar components under similar load</th>
<th>Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures</th>
<th>Recommended action</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1ºC–3ºC</td>
<td>1ºC–10ºC</td>
<td>Possible deficiency; warrants investigation</td>
</tr>
<tr>
<td>3</td>
<td>4ºC–15ºC</td>
<td>11ºC–20ºC</td>
<td>Indicates probable deficiency; repair as time permits</td>
</tr>
<tr>
<td>2</td>
<td>- - - - -</td>
<td>21ºC–40ºC</td>
<td>Monitor until corrective measures can be accomplished</td>
</tr>
<tr>
<td>1</td>
<td>&gt;15ºC</td>
<td>&gt;40ºC</td>
<td>Major discrepancy; repair immediately</td>
</tr>
</tbody>
</table>

3.4 Absolute temperature criteria for electrical systems

To evaluate the severity level of a detected exception the thermographer may also use the absolute temperature criteria defined in [7]. In that case, the thermographer uses the information about the defined maximum permissible temperatures for the inspected electrical components, which are given in various relevant standards. Reference [7] contains a list of relevant ANSI, IEEE and
NEMA standards, as well as relevant information \( T_{\text{amb}} \) – rated ambient temperature, \( T_{\text{rated rise}} \) – rated permissible temperature rise and \( T_{\text{max}} \) – maximum permissible temperature, all in °C (Eq. 1 applies) taken from those standards for the most commonly used electrical components.

\[
T_{\text{amb}} + T_{\text{rated rise}} = T_{\text{max}}. \tag{1}
\]

As an illustration, values \( T_{\text{amb}}, T_{\text{rated rise}} \) and \( T_{\max} \) are given in Table 2 for some electrical components.

<table>
<thead>
<tr>
<th>Electrical component</th>
<th>( T_{\text{amb}} )</th>
<th>( T_{\text{rated rise}} )</th>
<th>( T_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>THW (PVC), polyethylene, XHHW or RH-RW conductor insulation</td>
<td>30°C</td>
<td>45°C</td>
<td>75°C</td>
</tr>
<tr>
<td>Silicone rubber conductor insulation</td>
<td>30°C</td>
<td>95°C</td>
<td>125°C</td>
</tr>
<tr>
<td>Connectors and terminations (copper, copper alloy or aluminum)</td>
<td>40°C</td>
<td>50°C</td>
<td>90°C</td>
</tr>
<tr>
<td>Disconnects and switches</td>
<td>40°C</td>
<td>30°C</td>
<td>70°C</td>
</tr>
<tr>
<td>Miniature circuit breakers</td>
<td>40°C</td>
<td>30°C</td>
<td>70°C</td>
</tr>
<tr>
<td>Fuses with fuse links</td>
<td>40°C</td>
<td>30°C</td>
<td>70°C</td>
</tr>
<tr>
<td>Coils and relays (Class 90)</td>
<td>40°C</td>
<td>50°C</td>
<td>90°C</td>
</tr>
</tbody>
</table>

The thermographer measures temperatures across a given surface and compares measured temperature values of electrical components to the temperature values given in Table 2 (as well as to other relevant temperature values given in [7] and other relevant standards) and after detecting an exception evaluates the severity of its level and recommends corrective action. When the detected exception is composed of several adjacent components, the evaluation should be based on the \( T_{\text{amb}}, T_{\text{rated rise}} \) and \( T_{\text{max}} \) values of the component for which those values are the lowest. In addition, when several different \( T_{\text{amb}}, T_{\text{rated rise}} \) and \( T_{\text{max}} \) values for similar equipment are given in the relevant standards, the lowest temperatures (most conservative) should be used for the evaluation. In cases when the thermographer is unable to determine the class of insulation or equipment being inspected, the lowest \( T_{\text{amb}}, T_{\text{rated rise}} \) and \( T_{\text{max}} \) values (most conservative) within the component group should be used for the evaluation.

Unless noted otherwise, \( T_{\text{rated rise}} \) and \( T_{\max} \) values are valid for equipment operating at the stated \( T_{\text{amb}} \), and at 100% of their rated load \( I_{\text{rated}} \), in A. In many cases when the thermographer performs infrared inspections the ambient temperatures are lower than the stated \( T_{\text{amb}} \), and equipment operates at less than 100% \( I_{\text{rated}} \). Which is why the electrical component that possesses a potential problem may cause its overheating does not reach the actual operating temperature (which would be reached at the stated \( T_{\text{amb}} \) and at 100% \( I_{\text{rated}} \)) during thermographic inspection. In such cases, the comparison of the measured temperature values of electrical components to the stated \( T_{\max} \) values can mislead the thermographer to a conclusion that a potential problem does not exist and that corrective actions are not required. Therefore, in such cases it is necessary to compare the measured temperature values of electrical components to the corrected maximum permissible temperature \( T_{\max \text{ corr}} \) in order to detect an exception, evaluate the severity of its level and recommend appropriate corrective action.

Value \( T_{\max \text{ corr}} \), for the measured reduced operating load \( I_{\text{meas}} \) in A of the inspected electrical component and measured ambient temperature \( T_{\text{amb \ text{ meas}}} \) in °C, lower than stated \( T_{\text{amb}} \) can be calculated using Eq. 2 [7]:

\[
T_{\text{max \ corr}} = \left( \left( \frac{I_{\text{meas}}}{I_{\text{rated}}} \right)^2 + T_{\text{rated rise}} \right) + T_{\text{amb \ text{ meas}}}. \tag{2}
\]

4. Results and discussion

Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by the personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections [21]. Five practical examples of such failures, detected in low-voltage electrical installations in industrial and administrative facilities during preventive thermographic inspections, are presented and analysed. In each of them the measured temperatures of the electrical components showed that according to ΔT criteria given in Table 1 priority for corrective action was the highest (1). Major discrepancy was ascertained and immediate repair was recommended because in each of them the temperature difference between similar components under similar load was far above 15°C and the temperature difference between the component and ambient air temperatures was far above 40°C. In addition, in each of the presented examples the measured temperatures of electrical components were far above \( T_{\max} \) values defined for those components by the absolute temperature criteria. In some cases, danger can be eliminated by tightening the screws on the terminals of electrical components. However, in all of the presented cases poor electrical contact could not be eliminated this way, so the old components with permanently damaged contacts had to be replaced with new ones.

4.1 Practical example No. 1

This practical example represents the result of a thermographic inspection of a main switch of a switchboard feeding three floodlights, each with the rated power of 1200 W (Fig. 1).

![Fig. 1 Thermal image (left) and corresponding visible-light image (right) of the detected exception (hot spot on one of the active phase terminals). [21, 22]](Image 306x281 to 433x451)

The detected exception (hot spot on one of the active phase terminals) can clearly be seen (the maximum temperature measured during thermographic inspection was 107°C). According to the measured temperature of the terminal, using ΔT criteria given in Table 1, it was concluded that the priority for corrective action was the highest (1), major discrepancy was ascertained and immediate repair was recommended, because temperatures of adjacent terminals did not reach more than 30°C (the temperature difference between similar components under similar load was more than 77°C – far above 15°C) and ambient air temperature did not reach more than 25°C (the temperature difference between the component and ambient air temperature was more than 82°C – far above 40°C). A similar conclusion was obtained using the absolute temperature criteria because the maximum temperature of the terminal measured during the thermographic inspection was 107°C, which was significantly above \( T_{\max} \) value defined for connectors and terminations in Table 2 (90°C) and far above \( T_{\max} \) value defined for
PVC conductor insulation in Table 2 (75°C). However, in standard [23] it is stated that the maximum allowed temperature for PVC insulation is 70°C, and therefore, following the rules that when the detected exception is composed of several adjacent components, evaluation should be based on the $T_{\text{max}}$ values of the component for which those values are lowest and when several different $T_{\text{max}}$ values for similar equipment are given in the relevant standards, the lowest temperatures (most conservative) should be used for the evaluation, in this case $T_{\text{max}} = 70°C$ is used, which is far below measured 107°C. By functional check of the condition of the terminal, it was found that it was mechanically damaged, so it had to be replaced with the new one.

4.2 Practical example No. 2

During a thermographic inspection of the switchboard from which the ovens were fed in a bakery, overheating of the contacts on the main switch was detected (Fig. 2). The maximum temperature measured during the inspection was 114°C. The interpretation of the measurement results based on the $\Delta T$ and absolute temperature criteria is the same as the one given for the practical example No. 1.

4.3 Practical example No. 3

This example was observed during a thermographic inspection of a ventilation cabinet in a heating substation. The contact temperature of one of the contactors in the cabinet was found to reach 107°C (Fig. 3). It was established that the contactors were very old and worn out. As the situation did not significantly change after the contacts were tightened, the replacement of the worn-out contactor with a suitable new one was recommended.

4.4 Practical example No. 4

A dangerous hot spot of temperature over 100°C was detected inside a distribution cabinet containing a poor electrical contact on the phase conductor terminal block (Fig. 4). The thermally damaged terminal block was immediately replaced.

4.5 Practical example No. 5

This is an example where a defective lamp was detected. The thermographic inspection showed that the lamp electromagnetic ballasts had temperatures exceeding 106°C (see Fig. 5). According to the information given in Table 2, $T_{\text{max}}$ value for class 90 coils is 90°C. Also, according to [24] the maximum ballast case operating temperature specified by standards is 90°C.

5. Conclusion

Experience from a large number of periodic verifications of the quality of low-voltage electrical installations in industrial and administrative facilities, conducted by the personnel of the Laboratory for testing low-voltage electrical and lightning protection installations at the School of Electrical Engineering in Belgrade, showed that many dangerous failures would not be detected without performing preventive thermographic inspections. In order to successfully detect them, a thermographer must have sufficient knowledge about the components, construction and theory of electrical systems to be able to understand the observed patterns captured in a thermal image. Finding such failures allows targeted maintenance or elimination of problems before a fire and/or breakdown in an electrical system occurs. Therefore, it is recommended to include thermographic inspection in the procedure for conducting periodic verification of the quality of low-voltage electrical installations, although it is not included in standards valid in countries in Europe. The procedure of performing thermographic inspections, as well as the explanation for proper interpretation of measurement results based on the $\Delta T$ and absolute temperature criteria, defined in standards covering this area in the USA, are also given in this paper.
6. Acknowledgements

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Improving the wear resistance of the meat comminutor knives by using the method of pulse-plasma hardening

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Abstract: The paper presents experimental results of hardening of the meat comminutor knives by using the pulse-plasma method. A search for existing methods for increasing the wear resistance of knives of meat-cutting machines has been carried out. The determination of the increase in wear resistance of the meat comminutor knives has been carried out according to the following stages: knives hardening; knives testing on the meat comminutor with the simultaneous execution of control prints; determination of the radius of blade curvature using an optical microscope and processing of research results. It is experimentally established that the use of the proposed method allows to increase the wear resistance of the meat comminutor knives by 4 times. Also, during the study, the optimal hardening modes of the meat comminutor knives are determined. The graphical dependence of the amount of knives wear on the presence and regime of hardening treatment is presented.

KEYWORDS: MEAT COMMINUATOR AND CUTTER KNIVES; INCREASE OF WEAR RESISTANCE, PULSE-PLASMA HARDENING

Introduction
Due to the widespread use of meat comminutors and cutters in meat processing, the considerable cost and insufficient durability of their knives, as well as their high metal consumption, the task of increasing their durability continues to be relevant. Numerous studies on the choice of the method of surface hardening of the cutting edges of meat comminutor and cutter knives are known, but they have a limitation on practical use, provide insufficient increase in durability and require significant investment or energy consumption. It is advisable to search for a more effective method of surface hardening of the cutting edges of knives of these meat-cutting machines [1-4].

A significant number of scientific papers [5] is devoted to the study of increasing the durability of meat comminutor and cutter knives. Chemical-thermal treatment is the most widely used in the study of increasing the durability of a meat-cutting tool. So, according to [5], to increase the durability of the cutting tool of meat-cutting machines, the chromium plating method, after processing by which the wear resistance of the cutter knives increases by 2-3 times, and that of the meat comminutor knives – up to 1.5 times, is recommended. Nitriding the cutting edges of the cutter knives leads to an increase in their wear resistance by 1.7 times. Insufficient increase in the durability of the meat-cutting tool can be considered the disadvantage of such methods of hardening.

Single-phase borating of the meat comminutor grids allows to increase their mean time between failures (MTBF) by 4-5 times. However, it should be noted that despite the advantages of chemical-thermal treatment (the simplicity of technical equipment), these methods have significant drawbacks – high energy and time costs. Also, as is known, borating leads to a significant increase in the fragility of the metal surface, which is not a significant drawback for meat comminutor grids, while for the cutting edges of the meat comminutor and cutter knives this leads to their increased chipping.

The effect of cryogenic reinforcement on the wear resistance of a cutting tool is investigated. An increase in durability of up to 2 times has been noted. However, the implementation of this method requires complex technical equipment, which has significant cost. Positive effect is not observed in all cases, which impedes the wide industrial use of the method.

Electrospark alloying of the surface layers of the cutting edge is another known method. Saturation of the knife material with alloying elements (W, Ti, Mo) allows to increase durability by 1.5-2 times [5, 6]. The disadvantages of this method include its insufficient effectiveness, which is caused by the absence of a complex effect (of heat treatment, surface plastic deformation, alloying).

A constructive method for increasing the durability of the meat comminutor knives, which consists in using the effect of selective transfer in a friction pair knife-grid due to the use of bronze inserts, is known [6]. Due to this, an increase in durability up to 2.5 times is achieved. But it should be noted that for the application of such a solution it is necessary to manufacture special designs of knives, which creates a limitation in practical use.

An increase in durability of the cutter knives by 1.2-1.4 times is achieved after surface plastic deformation. Despite the simplicity of technical implementation of such an impact, an increase in durability up to 1.4 times cannot be considered significant.

Other methods of increasing wear resistance are also known [7-9].

Known technologies to increase the wear resistance of parts by pulse-plasma processing have been developed [10, 11]. The pulsed action is ensured by the use of explosives (gas) and the amplification of detonation waves by an electromagnetic field between symmetrically located electrode nodes. Also during processing, the surface alloying with metal electrode erosion products (molybdenum, tungsten) and gas (propane, nitrogen) occurs. As a result of this treatment, the wear resistance of machine parts increases by 3-5 times.

This technology has high efficiency (as with pulsed laser hardening), high productivity (0.5 m²/hour), significantly higher heating efficiency (0.8 versus 0.05), and an order of magnitude lower cost of technological equipment compared to laser hardening.

We can conclude that the known methods for increasing the durability of the meat comminutor and cutter knives have insufficient efficiency and high energy intensity. The application of the method of pulse-plasma hardening for this purpose is promising. However, in the well-known literature there are no quantitative data on increasing the wear resistance of knives of these meat-cutting machines after pulse-plasma processing.

The experiments results and their discussion
The aim of this work is to experimentally determine the increase in durability of the meat comminutor and cutter knives by means of hardening their cutting edges by pulse-plasma processing.

The determination of the increase in wear resistance of the meat comminutor knives was carried out according to the following stages: knives hardening; knives testing on the meat comminutor with the simultaneous execution of control prints; determination of the radius of blade curvature using an optical microscope and processing of research results.

For experimental studies, the WS-180 meat comminutor model was chosen. We have studied the wear resistance of four-blade single-sided knives with a right angle of sharpening of the cutting edge, which were made of steel 60C2 and passed the standard heat treatment for such knives.

Pulse-plasma hardening was carried out on the installation "IMPULSE" of the laboratory of the E. O. Paton Electric Welding Institute of the NAS of Ukraine. The operation diagram of the installation is shown in Fig. 1.

The detonation plasma generator consists of a detonation chamber 1, where the formation of a combustible gas mixture and...
the initiation of its combustion in detonation mode are carried out; coaxial electrodes 2 and 3; power sources 4. In the process of accelerating the plasma formation, gas-dynamic and electromagnetic forces take part [7, 8]. As a result of detonation, partially ionized combustion products enter the interelectrode gap 5 from the detonation chamber and close the R–L–C circuit of the power source. The capacitor bank is discharging.

Between coaxial electrodes 2 and 3, a current flows through the leading volume of gas 6, the degree of ionization of which increases. The resulting plasma jet 7 acts on the treated surface 8. When the plasma pulse interacts with the surface of the product, the electric circuit between the central electrode and the surface of the product 8 closes, and in the contact zone, an area of shock-compressed plasma layer is formed.

The heat flux to the surface of the workpiece is controlled by the parameters of the R–L–C power source circuit, the distance H, and electrode recesses (Fig. 1). The recessing of the electrode mainly affects the diameter of the processing zone, thereby playing the role of focusing. This, in turn, allows to adjust the density of the heat flux at the same pulse energy. The maximum heat flux to the surface layers occurs when the product is an anode, and the minimum one – when the product is insulated. During pulse-plasma processing of an isolated product, a decrease in heat flow occurs.

Pulse-plasma processing allows to combine complex cyclic (1-10 Hz) pulses (t_{imp} = 0.2...0.6 ms) effect on the surface of a solid: thermal (up to 10^8 W/cm²) and electromagnetic (current density up to 10^12 A/m²) effects and plastic deformation. In this case, the plasma parameters are as follows: the plasma flow velocity is up to 6 km/s; the temperature is up to 20000 K.

![Fig. 1. The diagram of the installation "IMPULSE" for pulse-plasma processing](image)

As a result of pulse-plasma treatment, fast heating (heating time is 10^{-3}...10^{-5} s) of the metal surface layer occurs, followed by its intensive cooling by removing heat into the metal volume. The high heating and cooling rate (up to 10^7 K/s) promotes phase hardening, the deformation of the surface layer and, as a consequence, the formation of a finely dispersed crystalline structure (for example, for carbon steel, the structure is represented by dispersed martensite needles of 160...300 nm), as well as high dislocation density (~10^{12} cm^{-2}). The resulting hardened layers have a characteristic size of up to 50 microns. It is also possible to introduce alloying elements (C, N, W, Mo, Cr, Ti, V, Al, etc.) into the plasma in the form of a vapor-droplet phase from a metal electrode (rod), fixed along the axis of the central electrode that erodes, and with the help of plasma-forming gas, which creates the conditions for chemical influence on the surface and plasma-chemical synthesis.

In this case, the hardening of the meat comminutor knives (Fig. 2) was carried out with the following parameters: the capacitance of a capacitor bank of the discharge circuit C = 800 mF; voltage on the covers of the capacitor bank U = 3.2 kV; discharge circuit inductance L = 30 mF; pulse initiation frequency v = 2.5 Hz; the electrode material used is W. The duration of the interaction pulse was about 0.5 ns, and the heat flux density was ~1.2·10^7 W/cm². In order to ensure the functioning of the hardened layer of the blade during the entire life of the knife, hardening was carried out with four-fold overlap on the front surface of the cutting edge, which during operation of the knife could not be re-sharpened (ensuring the effect of self-sharpening).

Three processing modes were used: No. 1 – 2 pulses per point, the part was grounded; No. 2 – 4 pulses per point, the part was grounded; No. 3 – 8 pulses per point, the part was grounded.

Fig. 2 shows a comparison of the bluntness of the cutting edge 1 and cutting edge 2, respectively, of the conventional and hardened meat comminutor knives of the WS-180 model, which are paired with a grid with an external diameter of 180 mm. It can be seen that the cutting edge 2 has a much less blunting.

After hardening, the knives were mounted on the meat comminutor and tested in operation before the first re-sharpening within 10 hours of machine time. Knives were tested at the production sites of the meat processing company LLC “Cherkassy Food Company”. Meat raw materials for half-smoked sausages of the 1st grade were crushed; the meat comminutor of WS-180 model was used with a blade rotation speed of 5 s⁻¹.

The determination of the amount of wear was carried out by determining the radius of curvature of the cutting edge of the blades. The radius of curvature was determined by the method of control prints [6]. To this end, during the operation of the knife, the imprints of the blades on lead washers were carried out. The point of measurement of the radius of curvature was chosen in the middle of the working length of the blade. An MBS-9 optical microscope with the magnification – × 56, scale division value – 0.014 mm was used.

In Fig. 3 a graphical dependence of the amount of knives wear on the presence and modes of hardening treatment is shown.

It is established that pulse-plasma treatment of the meat comminutor knives has led to such an increase in their durability: knives hardened in mode 1 – 1.8 times; knives hardened in mode 2 – 3.2 times; knives hardened in mode 3 – 4 times.
Conclusion

The effect of pulse-plasma hardening on increasing the durability of knives of meat-cutting comminutors has been experimentally studied. It is established that when using the processing modes of the grounded part of 2, 4 and 8 pulses to the point, the increase in durability of the meat comminutor knives occurs 1.8, 3.2 and 4 times, respectively. Such a significant increase in the wear resistance of knives is due to the complex hardening effect of pulse-plasma treatment (thermal, electromagnetic effect and plastic deformation).

The experimental determination of structural changes in the material of knives as a result of pulse-plasma hardening with the aim of further optimization of processing conditions may be the direction of subsequent studies.

Literature

CAD/CAM-system module for the design of automatic production

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Abstract: Automated production becomes a new reality of the industry, one of the important points in the construction of such production is a more accurate and quick design of technological processes for processing and assembly of parts. Analysis of computer-aided design systems shows the inadequacy of their capabilities to achieve this result. Significant improvement of CAD/CAM systems is required, for which it is necessary to establish close relationships between the part, tool, machine tool, technology, as well as digitize world experience and build an advanced algorithm that independently takes many different decisions, such as grouping part elements into operations and grouping transitions for their processing.

Keywords: CAD/CAM-SYSTEM, AUTOMATED PRODUCTION, AUTOMATION TECHNOLOGICAL PROCESS.

1. Introduction

A production site with an automatic production cycle of parts and the complete absence of people is the new reality of modern industry. All enterprises engaged in serial production go to this model of organization of production.

Automated production includes complex mechanical equipment with built-in electronic devices, such a combination creates electromechanical components that operate under the control of microcontrollers and a personal computer. These mechatronic modules have gained wide popularity in all fields, and by combining them whole mechatronic systems are created, for example, automatic production lines.

An automatic line may include CNC machines, robots, conveyors, manipulators, unmanned carts and many other devices. Since all components are interconnected through digital communication and controlled by a computer, they can work without people. This gives the most accurate, high-quality and high-performance result, excluding the human factor, which in turn leads to favorable economic indicators of production costs, and high competitiveness in the market.

Almost all automakers can serve as an example of such automated production; the car body moves along the line from one robot to another, which carry out welding and further assembly of the car without people.

Any production begins with its design, and the more thoroughly it is completed, the more efficient the production itself will be. Since automated production requires maximum debugging of all devices, the design of automated production is a more difficult task and is carried out using various CAD/CAM systems.

2. Design Automated Production

The scheme of automated production for each nomenclature of parts can be completely different, therefore its development is still a more creative process, however, production indicators, such as productivity, efficiency, profitability and others are more tangible and are expressed as specific numbers. The calculation of these numbers is very important and quite amenable to automation.

A lot of things determine the technological process of processing a part or a group of parts, since at the stage of development of the technological process the necessary metalworking equipment, devices, tools and many other equipment and accessories are selected, as well as processing strategies. From how rationally all the details of the technological process are thought out in many respects, they will determine the production indicators.

A lot of factors are involved in the development of the technological process that need to be taken into account; not taking into account the slightest action can lead to inconsistency and downtime of expensive equipment, and as a result, to obtaining not maximum production indices.

Therefore, it is necessary to design the processing of each element of the part separately as efficiently as possible, accurately calculate all the processing parameters, and also form a sequence of their processing in each operation. This is a rather time-consuming process that requires a lot of knowledge, experience and time, and it is often necessary to optimize the process for various requirements, which takes additional time.

After the development of the technological process for processing the part, it is possible to develop the automated production scheme itself. At this stage, the composition of the equipment, their rational arrangement, the general sequence of moving parts play an important role, since a small inaccuracy in the location of only one element can lead to significant losses of time and other resources. To find the best production indicators, different schemes are compared, while the most accurate calculation gives a virtual simulation of the production process in real time, i.e. virtual modeling of different schemes.

An example of a computer-aided design system with precise detailing and visualization of all production processes is the Siemens Technomatix system (see Fig. 1). Two-dimensional or three-dimensional virtual production is created in the system, object-oriented programming is implemented, with the help of which it is possible to create any non-standard processes, for example, moving a part by a person along a given trajectory at a given speed or assembling a node with hard-to-reach places by a robot. In the database of the system there are many elements of automated production and thus the organization of production with any degree of automation is possible.

![Fig. 1 Automated Production](image-url)
automation of production, which will bring the maximum possible performance.

3. Automation Technological Process

The main trend in computer-aided design of technological processes for processing parts is the recognition of structural elements of parts, with automatic selection of the processing route and the necessary tools in accordance with a given logic or rules (see Fig. 2).

Fig. 2 Recognition of elements in the CAD/CAM-system

Automatic selection of the processing strategy with the selection of tools was implemented in the «CAD TPP CNC» for designing the processing of complex, precise holes, the processing of which requires more than 6 ... 10 transitions. Manually designing the processing of such holes takes a lot of time, this method made it possible to design the processing of complex holes in a matter of seconds using the one-button method, with all the necessary tools in the database [1].

Modern CAD / CAM systems implement similar capabilities for processing typical structural elements, taking into account the accuracy and roughness indices specified in the 3d model, as practice has shown, this significantly reduces the time of technological design. This possibility so far concerns only simple elements, and for non-typical and frequently encountered elements, it is possible to set individual logic.

However, the task of logic is often required for many typical elements, since the same element can be processed with different strategies, transitions and tools, it is necessary to teach systems to choose the most efficient processing method for a particular case, taking into account the characteristics of the machine, the processed material and other data.

To improve the method of recognition of elements, it is necessary to use more complex algorithms and a more developed database. Such improvement must be carried out taking into account modern requirements of production.

Recognition of elements is a big step in the automation of technological processes, but still insufficient, since modern automated production requires a higher degree of automation of design work. This requires not only recognition of the structural elements of the part, but also their grouping in operations, as well as the effective grouping of all transitions for processing grouped elements. Effective recognition in combination with a progressive grouping of operations will give a tremendous synergistic effect, which can significantly reduce the time and complexity of design.

Automating such a grouping of elements and technological transitions is a difficult task, since it is influenced by a huge number of factors. In addition to scientific research, account must be taken of practical tests and many other data. It is necessary to unite and consolidate world experience. Digitization of this experience will provide a developed database, for which it is necessary to create a complex algorithm that can make decisions and self-learn. Thus, it is possible to create automation of the design of technological processes of a completely new level, the level of artificial intelligence.

The possibility of manual editing of the technology should be implemented very carefully, it should be as simple and quick as possible, for example, by highlighting a particular structural element in a 3D model and moving it to another operation, then the system itself will integrate the processing of the new element into the operation. And also the system should check all human actions for the possibility of this change, and exclude the human factor. Frequent the same manual changes to the technology, the system should fix and offer to adapt to them.

During the design of technological processes for automated production, a solution of many non-standard problems is required. For example, the selection of grippers for moving parts, the calculation of gripping forces, storage of parts, their correct positioning during movement, installation in the device, etc. For each detail, these tasks are solved individually.

Part of these tasks is difficult to automate, therefore it is necessary to create auxiliary modules that help technologists make the right decisions, as well as select or find new ideas for specific production conditions. Similar tasks must be solved in conjunction with a new approach to the automation of technological processes - recognition of structural elements with grouping of operations and transitions.

So the technologist will be able to quickly design a progressive technological process, select all the necessary devices for capturing and moving workpieces, calculate more accurate technological parameters for processing and movements, i.e. to get the exact necessary numbers with which you can create a scheme of automated production.

4. New Module of CAD/CAM-System for Automated Production

4.1. Technological Process

As has already been established in the automation of the design of technological processes in modern CAD / CAM systems, there are many bottlenecks, many tasks are solved manually or in a semi-automated mode, which is a laborious and inefficient design process.

The trend of automatic recognition of structural elements of a part plays an important role, but this is not enough, higher-order automation is necessary, namely, automatic grouping of operations and transitions. Also, many additional modules are needed to solve auxiliary problems of technological design.

In this connection, a new module of the CAD / CAM system is needed, which will link the solutions of these problems into a single whole. And also adapt the module in the CAD / CAM system, replacing existing recognition modules.

An analysis of the problems discussed above leads to the fact that in CAD / CAM systems there are no close links between the part, the processed material, the technology, the control program, the tool and the equipment (see Fig. 3).

Having established these close ties, as well as creating a developed database summarizing world experience, it becomes possible to automate such complex tasks as automatic selection of tools, machining strategies, calculation of cutting modes, grouping of transitions and many others, which will significantly reduce the time and complexity of design.
Fig. 3 The relationship of CNC-program with design elements

For example, setting the characteristics of the material to be processed, the rigidity of the part, machine tool, fixture, you can automatically select the strategy for processing the part and the corresponding tools, as well as calculate the cutting conditions, and then group transitions.

In this case, it is necessary to take into account various recognition and grouping filters, for example, recognition of elements located on certain sides of a part or grouping transitions with minimal tool changes or minimal part rotations, etc.

In the algorithm of the new module, it is necessary to take into account the rigidity of the technological system, the capabilities of the machine, otherwise the design result will be far from reality, and accordingly, performance indicators, including economic indicators, will be distorted.

In the «CAD TPP CNC», a relationship was realized between the parameters of each element of a complex hole and the methods of processing it, the processing routes, which in turn are associated with tools, and all this data is contextually related to each other [2].

This way of organizing data is also called a semantic model, i.e. different processing properties are inherited from each other, for example, when processing a hole, the processed material and equipment are already predetermined at the stage of tool selection; therefore, a drill compatible with this data is searched. So after recognizing the hole, the system, knowing about the machine, the material being processed, as well as other data, will independently select the necessary tools, and there is no need to set many additional filters. This also applies to the selection of processing routes and other technical data [3].

However, linking is not enough to group processing transitions for complex holes. To do this, it is necessary to give the system additional logic, for which a special algorithm has been developed that allows, based on the obtained interconnected data, as well as technological knowledge, to compose the necessary sequence of transitions for processing a complex hole of arbitrary shape.

Many complex holes can be present on one part, for the processing of which the same tools are used, in this case the system should group the processing transitions of the entire part in the most optimal way without unnecessary turns and tool changes.

4.2. Technical and economic indicators of automated production in the new CAD / CAM system module

According to the theory of productivity, technical production indicators are mathematically related to economic indicators. By asking in this mathematical model technical data on technology, processing time, cutting conditions, productivity, composition of automated production, we can find out the cost of production, production costs, payback period, economic efficiency, profitability, etc. Thus, we can quickly draw a conclusion on the economic possibilities of building this production.

On the other hand, this theory works in the opposite direction, i.e. by setting the desired values of the cost of production, economic efficiency, it is possible to obtain technical indicators of automated production, such as the composition of equipment, degree of automation, number of jobs, design dates, etc.

Thus, using this mathematical model and the parameters of the new CAD / CAM system module, you can quickly work out several options for automated production and find the most optimal one for a particular enterprise. For example, for one plant, production will be 100% automated using the most productive equipment, for the second 70% with partial use of human labor, and for the third it will be necessary to develop special multi-spindle equipment, etc.[4]

To study this mathematical model, it is necessary to describe the elements of production: types of automated equipment, auxiliary equipment, drives, transport, warehouse, etc., including establishing links between them, as well as criteria for their effectiveness. In addition, it is necessary to establish links between typical technological processes, routes and elements of automated production [5].

The construction of this mathematical model is a difficult task, because it requires a lot of different studies, in addition, it is necessary to take into account a number of parameters that are difficult to automate, for example, the parameter of production flexibility. Production can be fully automated, but it may be absolutely not adapted to change the manufactured parts. And in the world with a frequent change of products, the task of automating production requires taking into account the requirements of flexibility.

4.3. Digitalization of production

The passing Fourth Industrial Revolution aims to combine industrial and digital technologies, during which the construction of virtual production, digital doubles, robotic production and many other changes.

These opportunities show rapid development and already today demonstrate a positive effect, and will soon become the main criteria for the competitiveness of enterprises.

The introduction of various technical equipment is now tested in a virtual environment and only after that is their production and implementation carried out. Many physical tests are not required, which significantly reduces the cost and speeds up the process of introducing new equipment into production.

When simulating, several hundred calculations are carried out that determine the scheme and composition of automated production equipment, the manual method of carrying out these calculations takes a lot of time, which is unacceptable in modern conditions.

The new CAD / CAM system module is designed not only to design the most advanced technological processes in the most automated way, but also to build effective automated production of parts on their basis, determine the number of equipment, the number of jobs, and find the optimal technical and economic performance indicators that can be used to virtually real-time test production. If parts are changed, you can also quickly adapt their processing in this production.

Digitalization involves the conversion of all information into a digital form, thus creating databases, visualizing processes, automating calculations, developing high-order algorithms, introducing industrial networks, common industrial sites, digital
services and many other features. All this creates new requirements for the construction of automated systems.

For example, as the initial information, it is not the drawing of the part, but the 3d model, thus new requirements for the construction of the design 3d model appear, in which all the data indicated in the drawing should be reflected. According to this model, it is possible to carry out automatic recognition of elements and solve many other problems in an automated mode.

In this regard, in some cases, the design of drawings and technological processes becomes an unnecessary task, in the presence of a detailed 3d-model, or rather a digital double of the part, the designed technologies and control programs for CNC machines, documentation is no longer necessary, all these data are transmitted to the machine in paperless form. Thus, a number of enterprises today have already refused to issue design and technological documentation. However, for enterprises where complex products are manufactured, technological processes are still required, but if detailed digital data are available, generating it is a possible automation task.

4.4. Design of mechatronic modules

In the construction of automated production, the share of electronics involvement is steadily increasing, there is a transition from mechanics to mechatronics. In fact, mahatronics unites many different areas: mechanics, electrical engineering, microelectronics, information technology, power electronics and many others. As a result of this association, a new technique is created that implements any actions, for example, moving parts between machines. It is impossible to create such a technique on the basis of only one field of science; therefore, mechatronics products are very complex and are implemented by many specialists.

The mechatronic module is an independent product for the implementation of movements, and the mechatronic system is a collection of mechatronic modules that are synergistically connected to each other to perform a specific functional task, for example, an automated part production line.

The design of such mechatronic modules and systems is the team work of many specialists in mechanics, electronics, programming and many others - this creates the requirement of a single space in which all specialists will be interconnected when working on one project.

In the new module, we will consider only the mechanical part of the design process of automated production, but with the possibility of integrating modules for other specialists. Therefore, in the framework of the new module, it is necessary to solve the following problems: a more detailed selection of gripper and other manipulator nodes, and calculations for loading equipment. With a detailed drawing of all the components of the mechatronic modules, it becomes possible to more accurately calculate whether they will cope with the flow or not, based on the designed technological process.

Thus, at the design stage, it is possible to track that one machine or robot cannot cope with the flow, thus a number of solutions are applied to eliminate bottlenecks at the design stage. It is possible to add a robot, and it is possible to move the robot on its guides, or to take other measures.

4.5. Implementation of a new CAD / CAM system module for automated production

Summing up all of the above, for the design of automated production it is necessary: development of an optimal technological process, calculation of technical and economic indicators, digital representation and simulation, design of mechatronic modules, creation of a single space, as well as the solution of many related tasks. Automation of a very large number of tasks, but all of them must be solved interconnected, supplementing each other with data, with a possible return to the initial data for their correction and new tests. This requires the creation of a large software module for the CAD / CAM system.

However, in the framework of the study on the creation of such a module, it is important to understand the relationship between various design data both within a separate task, for example, the tasks of computer-aided design of technological processes, and between data of different tasks, for example, data on the technological process and determining the composition of the equipment of an automated complex. Between the technological process and the calculation of technical and economic indicators.

The work of such relationships has confirmed its relevance in conjunction with the algorithm for grouping technological transitions for processing complex holes. This makes it possible to implement a higher order algorithm, namely the grouping of structural elements of a part in an operation, as well as the construction of automated complexes for processing these parts [6].

Such algorithms will endow the CAD / CAM system with the property of independent decision-making, which people today still decide.

5. Conclusion

The most important for the construction of automated production is the establishment of an effective technological process with the accurate calculation of all technological parameters: productivity, efficiency, etc. For this, a new module of CAD / CAM systems is needed, which allows solving this problem more automatically.

The establishment of close relationships between the part, tools, machine tool makes it possible to create high-order algorithms to achieve this goal, as well as the design of automated production.

In the context of the rapid development of digital technologies, automation of production, this task becomes one of the most important for the quick launch of new products on the market and ensuring its low and competitive cost.

6. References


Features of solving identification problems in transport technologies

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Abstract: The peculiarities of carrying out the basic methods of solving the problems of identification, which have become widespread in transport technologies, are considered. Three approaches were tested: a deterministic approach based on the method of selected points, a statistical approach that includes the least-squares method, and an inductive approach - a method of group accounting of arguments. A number of experiments have been conducted, which is based on structural optimization of the model. In the process of analysis of the obtained models, a rational model of setting and solving identification problems in transport technologies of optimal complexity was obtained. This systematic flow diagram can be successfully applied to solve complex analytical tasks.

Keywords: INFORMATION TECHNOLOGY, IDENTIFICATION, TRANSPORT TECHNOLOGIES

1. Introduction.

The basis for building models of modern automation objects is most often the use of the concept of “function” (in the broadest sense of the word). This is based on the definition of a function as a law according to which the function value argument is matched. Apply the following methods and algorithms that form the basis of model-building information technology (search for the laws of operation in the broadest sense of the word): the method of selected points, the method of regression analysis (least squares), the algorithm of continuous determination of the static characteristics of the control object (Gabor filter), method of extrapolation (prediction), group method of accounting of arguments (GMAA) for construction of complex models and systems and others [1 – 3]. According to the author of the method of group account of arguments A.G.Ivakhnenko: “There is a deliberate search of many contender models of different complexity according to a number of criteria. The result is a model of optimal structure in the form of a single equation or system of equations. The minimum of the selection criterion is determined by the model of the optimal structure” [4, 5]. Therefore, according to system-wide approaches, there are two schemes of activity [8]:

Engineering approach

<concept development> → <concept analysis> → <order> → <existing condition> → <definition of need> → <validation of hypotheses> → <evidence> → <validation> → <scientific community>

Thus, the right choice of the optimal method of solving the problems of identification is very relevant and necessary, especially in modern transport technologies.

The purpose of the study is to identify a control entity that is an element of transportation technology and is influenced by several input quantities.

2. The methodology of scientific research.

The deterministic approach – the method of selected points [9] is one of the simplest methods of determining a formal expression. For example, the static characteristics of the system is the method of selected points. This method corresponds to a Lagrange or Newton polynomial. Static characteristics of the system can be set as a curve of any order, such as 2nd order:

\[ \Phi = a_0 + a_1 \lambda + a_2 \lambda^2 + a_3 \lambda^3, \]

but if the attempt is unsuccessful then the order of the equation must be increased. Yes, entering new variables:

\[ x_1 = \mu, x_2 = \lambda, x_3 = \mu^2, x_4 = \lambda^2, x_5 = \mu \lambda, \]

we obtain the equation of the static characteristic in a linear form:

\[ \Phi = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5. \]

The algorithm for solving the problem of identification using the method of selected points is shown in Fig. 1.

![Fig. 1 Structural diagram of the method of selected points](image-url)

Substituting a value to a given equation, we obtain a system of equations (4):

\[
\begin{align*}
  a_{11} x_1 + a_{12} x_2 + \cdots + a_{1m} x_n &= b_1, \\
  a_{21} x_1 + a_{22} x_2 + \cdots + a_{2m} x_n &= b_2, \\
  &\vdots \\
  a_{m1} x_1 + a_{m2} x_2 + \cdots + a_{mn} x_n &= b_m
\end{align*}
\]

or in matrix form: \( Ax = b, \)

where

\[
A = \begin{bmatrix}
  a_{11} & a_{12} & \cdots & a_{1m} \\
  a_{21} & a_{22} & \cdots & a_{2m} \\
  \vdots & \vdots & \ddots & \vdots \\
  a_{m1} & a_{m2} & \cdots & a_{mn}
\end{bmatrix}
\]

\( A \) – the matrix of coefficients of the system; \( b = [b_1, b_2, \ldots, b_m] \) – the vector of free terms; \( x = [x_1, x_2, \ldots, x_n] \) – vector of unknowns.

The numerical solution of the SLAR by the Gauss method is based on the reduction of the matrix of coefficients of system \( A \) to a triangular form, which is achieved by sequential removal of unknown equations from the system. Consider the scheme of a single division. Initially, the first equation removes the unknown \( x_1 \) from all the following equations. Why is the first equation divided by the principal element \( a_{11} \) (provided that \( a_{11} \neq 0 \)), and then the equation multiplied by the corresponding coefficient at \( x_1 = a_{12} \) subtracted from the last equations of the system. An intermediate matrix \( A^{(1)} \) is obtained. Then the second equation removes the unknown \( x_2 \), the intermediate matrix \( A^{(2)} \) is obtained, and so on, until only one unknown \( xn \) remains in the last equation. The equivalent system is thus obtained:
The method of least squares allows to determine the parameters of models of static and dynamic systems, based on the criterion of the minimum standard error.

The static system is defined by the system of functions of many variables, which are represented in the form of power expansions up to 9th degree, including:

\[ f_i(x_1, x_2, \ldots, x_n) = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_m x_m, \quad i = 1, \ldots, n. \]  \hspace{1cm} (6)

The statistical characteristic of a system with one perturbing effect and one regulating effect can be represented as a second-order curve:

\[ \Phi = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + \lambda^2 + \mu. \]  \hspace{1cm} (7)

If the sum of the squares of the deviations of the experimental values from the calculated values is greater than some predetermined number, then the order of the equation must be increased. The problem of determining the coefficients of the equation is a problem of parametric optimization \[10\]. If it is necessary to determine the form of an equation, then this identification is structural. Equation coefficients are determined using the least-squares method, by minimizing the function:

\[ \Omega = \sum_{i=1}^{n} (\Phi_{\text{calc}}^i - \Phi_{\text{exp}}^i)^2, \]  \hspace{1cm} (8)

where \( \Phi_{\text{calc}}^i \) – calculated values of the function \( \Omega \), \( \Phi_{\text{exp}}^i \) – experimental (a priori) values.

The “IDENT” program \[11, 12\], which is a part of the “FACTOR +” PMC, finds the best RMS approximation of the function of several variables of a given polynomial. The least-squares problem we consider here is called differently in different scientific disciplines. For example, mathematicians may approach it as a search task for a given point of the functional space of the closest point in a given subspace. Statistics introduce probabilistic distributions in their formulation and use terms such as regression analysis to describe this area. Engineers come to this task with subjects such as parameter estimation or filtering.

The main point is that when these tasks (formulated in any of these contexts) reach the stage of specific calculations, they have the same central problem, namely the sequence of linear least-squares problems.

This basic linear least-squares problem can be formulated as follows: let the data be a valid \( m \times n \)-matrix \( A \) of rank \( k \), \( k < m \), and a real \( m \)-vector \( b \). Find the true \( n \)-vector \( x \) that minimizes the Euclidean length of the vector \( Ax - b \).

Consider as an important example the case where a linear least-squares problem originates from a nonlinear problem and the solution vector should be used as an amendment to the current nominal solution of the nonlinear problem. A linearized task will be a useful approximation to a nonlinear one in only a limited neighborhood. If there are different vectors, a sufficiently small non-inferiority giving in a linear problem, then one may prefer that it has the smallest length. This increases the likelihood of staying in a neighborhood with a reasonable linear approximation.

**Group Method of Data Handling (GMDH) [13]** is a method of generating and selecting regression models of optimal complexity, the block diagram of which is shown in Fig. 2.

![Flowchart of the GMDH algorithm](image)

The complexity of the model in GMDH means the number of parameters. To generate, we use a basic model whose subset of elements must be included in the desired model. External criteria, special model quality functionals calculated on the test sample, are used to select models.

GMDH is recommended for use when the sample contains several items. Then, when constructing regression models, it is impossible to use statistical hypotheses about the density of distribution, such as the Gaussian distribution hypothesis. Therefore, an inductive approach is used to consistently generate models of increasing complexity until at least some quality criterion of the model is found. This quality criterion is referred to as the external criterion because different data is used when setting up models and evaluating model quality. Achieving a global minimum of the external criterion when generating models means that a model that has reached such a minimum is in demand.

### Table 1: Input data sampling

<table>
<thead>
<tr>
<th>x</th>
<th>0.1</th>
<th>0.3</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>0.2</td>
<td>0.6</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2 shows the results of the program for four variants of polynomial structures that are consistently complicated.
Table 2: The results of the study of sequential complication of the polynomial structure (function of one variable)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Polynomial coefficients: $c(0)=3.971429$</th>
<th>Polynomial coefficients: $c(0)=2.000000$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: $\text{error}=3.7$</td>
<td>$y=3.971429$</td>
<td>The polynomial value in points: $ff(0)=3.971429$</td>
</tr>
<tr>
<td>The polynomial value in points: $ff(1)=3.971429$</td>
<td>$ff(1)=3.971429$</td>
<td>$ff(2)=3.971429$</td>
</tr>
<tr>
<td>$ff(3)=3.971429$</td>
<td>$ff(4)=3.971429$</td>
<td>$ff(5)=3.971429$</td>
</tr>
<tr>
<td>Obtained polynomial: $y=3.971429$</td>
<td>$ff(6)=3.971429$</td>
<td>$ff(6)=3.971429$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 3. $y = C_0 x^2$</th>
<th>Polynomial coefficients: $c(0)=0.450960$</th>
<th>Polynomial coefficients: $c(0)=0.094183$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: $\text{error}=1.2$</td>
<td>$y=0.450960 x^2$</td>
<td>The polynomial value in points: $ff(0)=0.450960$</td>
</tr>
<tr>
<td>The polynomial value in points: $ff(1)=0.450960$</td>
<td>$ff(1)=0.450960$</td>
<td>$ff(2)=0.450960$</td>
</tr>
<tr>
<td>$ff(3)=0.450960$</td>
<td>$ff(4)=0.450960$</td>
<td>$ff(5)=0.450960$</td>
</tr>
<tr>
<td>Obtained polynomial: $y=0.450960 x^2$</td>
<td>$ff(6)=0.450960$</td>
<td>$ff(6)=0.450960$</td>
</tr>
</tbody>
</table>

Table 3 shows the data for the two-variable function experiments.

Table 3: Input data sampling

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>0.1</th>
<th>0.3</th>
<th>0.8</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_2$</td>
<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>$y$</td>
<td>0.02</td>
<td>0.18</td>
<td>0.64</td>
<td>2</td>
<td>6</td>
<td>20</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 4: The results of the study of sequential complication of the polynomial structure (a function of two variables)

<table>
<thead>
<tr>
<th>Experiment 1. $y = C_0$</th>
<th>Polynomial coefficients: $c(0)=6.120000$</th>
<th>Polynomial coefficients: $c(0)=1.865445$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: $\text{error}=7.3$</td>
<td>$y=6.120000$</td>
<td>The polynomial value in points: $ff(0)=6.120000$</td>
</tr>
<tr>
<td>The polynomial value in points: $ff(1)=6.120000$</td>
<td>$ff(1)=6.120000$</td>
<td>$ff(2)=6.120000$</td>
</tr>
<tr>
<td>$ff(3)=6.120000$</td>
<td>$ff(4)=6.120000$</td>
<td>$ff(5)=6.120000$</td>
</tr>
<tr>
<td>Obtained polynomial: $y=3.971429$</td>
<td>$ff(6)=6.120000$</td>
<td>$ff(6)=6.120000$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2. $y = C_0 + C_1 x + C_2 x^2$</th>
<th>Polynomial coefficients: $c(0)=1.489670$</th>
<th>Polynomial coefficients: $c(0)=1.489670$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: $\text{error}=2.5$</td>
<td>$y=1.489670 + 1.48967 x + 0.094183 x^2$</td>
<td>The polynomial value in points: $ff(0)=1.453435$</td>
</tr>
<tr>
<td>The polynomial value in points: $ff(1)=1.453435$</td>
<td>$ff(1)=1.453435$</td>
<td>$ff(2)=1.453435$</td>
</tr>
<tr>
<td>$ff(3)=1.453435$</td>
<td>$ff(4)=1.453435$</td>
<td>$ff(5)=1.453435$</td>
</tr>
<tr>
<td>Obtained polynomial: $y=3.971429$</td>
<td>$ff(6)=1.453435$</td>
<td>$ff(6)=1.453435$</td>
</tr>
</tbody>
</table>

Table 4 shows the program results for five consecutively complicated polynomial structure variants.

In Fig.3 a) it is shown how, when complicating a function from one variable in the second experiment, the polynomial that most closely corresponds to a given set of points was found, with further complication of the polynomial the error started to increase, which led to the deterioration of the result. The graph of Fig.3 b) for a function with two variables. For this case, the polynomial with the smallest magnitude error was found in the third experiment.
Experiment 3. \( y = C_0 x_1 x_2 \)

Polynomial coefficients: \( c(0)=1.000000 \)

Error: \( \text{error}=4.2 \times 10^{-17} \)

The polynomial value in points:

<table>
<thead>
<tr>
<th>( f(x) )</th>
<th>( f(0) )</th>
<th>( f(1) )</th>
<th>( f(2) )</th>
<th>( f(3) )</th>
<th>( f(4) )</th>
<th>( f(5) )</th>
<th>( f(6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f(0) )</td>
<td>0.020000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(1) )</td>
<td>0.180000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(2) )</td>
<td>0.640000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(3) )</td>
<td>2.000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(4) )</td>
<td>6.000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(5) )</td>
<td>20.000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(6) )</td>
<td>14.000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Obtained polynomial: \( y = x_1 x_2 \)

Experiment 4. \( y = C_0 x_1^2 x_2^2 \)

Polynomial coefficients: \( c(0)=0.054916 \)

Error: \( \text{error}=2.2 \times 10^{-8} \)

The polynomial value in points:

<table>
<thead>
<tr>
<th>( f(x) )</th>
<th>( f(0) )</th>
<th>( f(1) )</th>
<th>( f(2) )</th>
<th>( f(3) )</th>
<th>( f(4) )</th>
<th>( f(5) )</th>
<th>( f(6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f(0) )</td>
<td>0.000022</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(1) )</td>
<td>0.001779</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(2) )</td>
<td>0.022494</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(3) )</td>
<td>0.111990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(4) )</td>
<td>1.511870</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(5) )</td>
<td>22.398077</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(6) )</td>
<td>5.487529</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Obtained polynomial: \( y = 0.054916 x_1^2 x_2^2 \)

Experiment 5. \( y = C_0 x_1^3 x_2^3 \)

Polynomial coefficients: \( c(0)=0.013999 \)

Error: \( \text{error}=3.8 \times 10^{-8} \)

The polynomial value in points:

<table>
<thead>
<tr>
<th>( f(x) )</th>
<th>( f(0) )</th>
<th>( f(1) )</th>
<th>( f(2) )</th>
<th>( f(3) )</th>
<th>( f(4) )</th>
<th>( f(5) )</th>
<th>( f(6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f(0) )</td>
<td>0.000001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(1) )</td>
<td>0.000272</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(2) )</td>
<td>0.004587</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(3) )</td>
<td>0.111990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(4) )</td>
<td>1.511870</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(5) )</td>
<td>22.398077</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f(6) )</td>
<td>5.487529</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Obtained polynomial: \( y = 0.013999 x_1^3 x_2^3 \)

---

**Fig. 3.** Functional dependence of change of magnitude of error at complicated structure of a polynomial:

- **a)** for one variable;
- **b)** for two variables.

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Fig. 4 depicts a generic block diagram showing the interaction of the identified identification tasks. Structural optimization depicted in the graph fully incorporates parametric optimization, i.e. the least-squares method, and also shows the functional interaction of structural optimization with the group argument method.
4. Conclusion

As a result of scientific researches the peculiarities of realization of the basic methods of solving the problems of identification, which have become widespread in transport technologies, are considered. To do this, we analyzed and compared three methods for solving identification problems: a deterministic approach based on the method of selected points, a statistical approach that includes the least squares method, and inductive approach – a method of group accounting of arguments.

Based on the considered methods, an extended flowchart is constructed, which gives a generalized characteristic of the interaction of the described tasks. As a central element of the flowchart is structural optimization, on the basis of which experimental studies were conducted on the complexity of the polynomial structure and finding the model with the smallest amount of error.

A number of experiments have been conducted, based on structural optimization of the model. In the process of analysis of the obtained models, a rational model of setting and solving identification problems in transport technologies of optimal complexity was obtained. This systematic flow diagram can be successfully applied to solve complex analytical problems in transportation technologies.

5. Literature

1. S. Matthew, Using computers in the law office (Clayton State University, Clayton, USA, 2015).


Квалиметрический анализ качества микроструктуры стали 08Х18Н10Т, подвергнутой радиально-сдвиговой прокатке

Qualimetric analysis of the microstructure quality of 08X18N10T steel subjected to radial shear rolling

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MACHINES, TECHNOLOGIES, MATERIALS. 2020

Abstract: Qualimetric analysis of the microstructure quality of 08X18N10T steel subjected to radial shear rolling was performed. Bars of 08X18N10T stainless austenitic steel were used, rolled on the SVP-08 radial-shear rolling mill from a diameter of 30 mm to 21 mm in 3 passes with a compression of 3 mm per pass at a temperature of 800°C. For qualimetric assessment of the microstructure quality, we used such methods as determining the average grain size, grain area, and degree of grain misalignment. The free JMicr0Vision v1.2.7 program was used to analyze the structure images. Data analysis shows that the central area of the bar experiences the greatest improvement, with a change in the quality index from 0.13 to 0.43, that is, more than 3 times. At the same time, the growth in the quality of the peripheral region is low (only 1.29 times) and tends to slow down. After the third pass, the quality of the microstructure of the central and peripheral parts is almost compared. The difference is 0.1, or 19 % compared to the difference of 0.28 (68 %) after the first pass.

Keywords: MICROSTRUCTURE QUALITY, QUALIMETRIC ANALYSIS, QUALITY INDEX, RADIAL-SHEAR ROLLING, STAINLESS AUSTENITIC STEEL.

1. Введение

В нынешних условиях дефицита энергетических и сырьевых ресурсов весьма актуальна проблема энергосберегающих технологий, в том числе и при получении материалов со свойствами, сочетающими одновременно высокую прочность и пластичность.

Подобное уникальное сочетание свойств характерно для субультра- и ультрамелкозернистой ( СУМЗ и УМЗ) формы структурного состояния материалов с преобладанием большеграновых межзеренных границ. Известные результаты применения субультрамелкозернистой материалов в машиностроительной и медицинской отраслях, показывают их большое будущее и спрос на изделия из таких материалов.

Однако рост спроса существенно ограничивается высокой стоимостью производства изделий из таких материалов, обусловленной высокой энерго- и трудоемкостью их производства. Наиболее распространенный и изученный метод получения СУМЗ и УМЗ – равноканальное угловое срезание (РКУ) [1], однако недостаток этого и многих других известных процессов состоит в их дискретности, т.е. невозможности обработки изделий относительно большой длины и в необходимости проведения большого числа циклов обработки, что значительно ужесточает его промышленное применение.

Решить проблему по получению длиномерных заготовок с УМЗ-структурой возможно путем использования радиально-сдвиговой прокатки (РСП) [2-3]. Отличие данного способа прокатки от обычной поперечно-витовой прокатки, состоит в том, что в данном случае прокатывается целый крутой пруток по трехвальковой схеме с увеличенными углами подачи валков, что способствует интенсификации деформации сдвига и немононотонности течения металла в условиях преобладания схемы гидростатического сжатия. Такие условия благоприятны для формирования УМЗ структуры, особенно при пониженных температурах деформации [4]. Поэтому этот способ деформирования имеет большой потенциал для получения длиномерных металлических изделий с УМЗ структурой, поскольку в отличие от других способов максимально прост, эффективен и технологичен.

Целью данной работы было исследование влияния радиально-сдвиговой прокатки на эволюцию микроструктуры нержавеющей аустенитной стали.

2. Анализ микроструктуры

Для решения поставленной цели был проведен натурный эксперимент, который заключался в деформировании прутков из нержавеющей стали аустенитного класса марки 08Х18Н10Т (0,08 % С; 17-19 % Cr; 9-11 % Ni; 2 % Mn; 0,8 % Si; 0,5-0,7 % Ti) диаметром 30 мм на стане радиально-сдвиговой прокатки СВП-08 до диаметра 21 мм за 3 прохода с обжатием 3 мм в каждом, при температуре 800°С со штатной скоростью вращения валков 50 об/мин. После достижения требуемого диаметра, производилось интенсивное охлаждение прутка водой. Подобный температурный режим для получения УМЗ структуры нержавеющих сталей был использован в работе [5].

Далее было проведено исследование микроструктуры прокатанных образцов. В отечественной и зарубежной практике для анализа и контроля микроструктуры применяются технологии, основанные на сравнении наблюдаемой структуры с эталонами, а также различные методы количественного металлографического анализа, такие как средний размер зерен, средняя площадь зерна, средние квадратичные отклонения этих величин, удельная поверхность продеформированной стали.

Для квалиметрической оценки качества микроструктуры стали 08X18H10T мы использовали квалиметрический анализ качества микроструктуры. Для квалиметрической оценки качества микроструктуры стали 08X18H10T, в качестве базовых, применялись такие методы количественного металлографического анализа, как определение степени неравноосности зерен, соотношения фаз, доля и характер распределения неметаллических включений в сплавах и другие показатели [6, 7]. Важно отметить, что эти методы не однозначны и не полностью соответствуют друг другу, что затрудняет объективную и точную комплексную оценку. Поэтому в нашем случае для исследования микроструктуры прокатанных образцов мы использовали квалиметрический анализ качества микроструктуры.

Для квалиметрической оценки качества микроструктуры стали 08X18H10T, в качестве базовых, применялись такие методы количественного металлографического анализа, как определение среднего размера зерна, площади зерен, степени неравноосности зерен [6].

Для анализа изображений структуры была использована бесплатная программа JMicr0Vision v1.2.7 от Nicolas Roduit [8-9], которая позволяет автоматизировать процесс измерения геометрических характеристик зерна. Для этого нужно выделить границы зерен в автоматическом или ручном режиме. В нашем случае мы использовали ручной режим, поскольку границы зерен не на всех участках всех снимков были достаточно контрастны для автоматического распознавания, а
это могло повлечь ошибки. После ручного обозначения границ зерен, получившиеся фигуры были автоматически пронумерованы (рисунок 1) и для них вычислены вышеупомянутые геометрические характеристики. При желании измеряемые величины можно визуализировать, выбрав через инструмент Data Viewer, команду Label и выбрав в появившемся меню требуемую для отображения характеристику. Так, на рисунке 2 показаны значения площадей некоторых зерен для той же пары изображений структуры после деформирования.

Для работы с геометрическими характеристиками открываем инструмент Data Viewer, оставляем в таблице только нужные характеристики и копируем их для дальнейшей работы в MS Excel. Программа автоматически определяет наибольший и наименьший линейные размеры получившейся фигуры, которые обозначаются как длина (Length) и ширина (Width). На рисунке 3 показан скриншот окна инструмента Data Viewer с таблицей геометрических характеристик зерен.

Для вычисления комплексного показателя качества используем главные геометрические свойства микроструктуры, которые будут составлять дерево свойств и назначаем им коэффициенты весомости. Затем определяем границы диапазонов нормирования. Нижние границы принимаем равными нулю, а верхние округленно будут соответствовать максимальному значению соответствующего значения данного свойства в генеральной совокупности всех трех проходов. После чего для каждого свойства определяем тип функции нормирования и ее форму посредством выбора параметра Δ - основание степени, влияющего на форму функции. Для оценки качества и нормирования выбранных свойств лучше всего подходят односторонние границы и функции Z и S типа [10].

Такие свойства как площадь зерна и средний размер зерна стремительно набирают значимость по мере уменьшения натуральных показателей этих свойств. Чем меньше размер и площадь зерна – тем лучше. Степень неравноосности зерна изменяется в пределах [0;1]. Значение 1 соответствует равноосному зерну, поэтому, в нашем случае выбираем функцию Z-типа, значимость которой стремительно растет по мере приближения натурального значения к 1. Форма функций нормирования соответствует изображенной на рисунке 4. Коэффициенты весомости распределяем поровну и все данные сводим в таблицу 1.
Используя полученные свойства зерна, формулу (1) из работы [10] и данные таблицы 1 вычисляем единичный показатель качества по площади зерна, по среднему размеру зерна и по степени неравноосности зерна для каждого распознанной программы зерна.

\[ k_i = \begin{cases} 
1 - \frac{1}{1 - \Delta} \cdot \frac{Z}{Z_{min}} & , \quad \Delta = 0,05 \\
1 - \Delta & , \quad r < r_{min}, \quad r > r_{max},
\end{cases} \]

где \( r \) – натуральное значение квалиметрической оценки, полученное по данным измерений.

Далее рассчитанные значения объединяются в комплексный показатель качества, так же для каждого каждого распознанной программы зерна. После чего результаты сводятся в таблицу и для столбцов показателей качества находятся средние, минимальные и максимальные значения, а также среднее квадратическое отклонение (СКО), как меру изотропности микроструктуры. Использовать СКО для комплексного показателя качества намного удобнее, чем для рекомендуемых в классической работе [6] площадей зерна, потому что появляется возможность сравнивать уровень разброса различных по размеру структур. Полученные значения были сгруппированы по проходам, и результаты приведены на рисунке 5 в виде гистограмм.

4. Заключение

Таким образом проведенный анализ комплексных показателей качества стали 08X18H10T, подвергнутой 3-м проходам деформирования на стане радиально-сдвиговой прокатки, показывает, что наибольшее улучшение испытывает центральная зона прутка, с 0,13 до 0,43, то есть более чем в 3 раза. При этом, рост качества периферийной области невысок (всего в 1,29 раза) и имеет тенденцию к замедлению. Это связано с тем, что при данной температуре при увеличении степени деформации не происходит дальнейшего измельчения структуры, а только улучшается ее форма, становясь более равномерной, о чем тоже свидетельствуют значения СКО, показывающие минимальный разброс значений.

После третьего прохода качество микроструктуры центральной и периферийной части почти сравнивается. Разница составляет 0,1, или 19 % по сравнению с разницей 0,28 (68 %) после первого прохода. Зерна становятся более равноосными, но при этом остаются отдельные фрагменты прежней полосчатой структуры, как это видно из рисунка 1 (б), чья неправильная форма влияет на оценку. При этом, количество таких фрагментов постепенно уменьшается, улучшая структуру.

Рис. 4 Показательные функции нормирования Z типа при \( \Delta = 0,05 \) [10]

Таблица 1 – Свойства микроструктуры и коэффициенты их весомости

<table>
<thead>
<tr>
<th>№</th>
<th>Свойство</th>
<th>Единица измерения</th>
<th>Диапазон для ( \Delta = 0,05 )</th>
<th>Тип функции</th>
<th>( \Delta )</th>
<th>Коэф. весомости</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Площадь зерна</td>
<td>нм²</td>
<td>0 – 3-10⁶</td>
<td>S</td>
<td>0,05</td>
<td>0,33</td>
</tr>
<tr>
<td>2</td>
<td>Средний размер зерна</td>
<td>нм</td>
<td>0 – 3000</td>
<td>S</td>
<td>0,05</td>
<td>0,33</td>
</tr>
<tr>
<td>3</td>
<td>Степень неравноосности зерна</td>
<td>-</td>
<td>0 – 1</td>
<td>Z</td>
<td>0,05</td>
<td>0,34</td>
</tr>
</tbody>
</table>

Рис. 5 Средние значения комплексного показателя качества микроструктуры стали 08X18H10T по проходам (а) и его СКО (б)

Примечание: Данная работа выполнена в рамках выполнения темы № АР05131382 «Разработка и исследование технологий получения ультрамелкозернистых материалов с улучшенными механическими свойствами и повышенной радиационной стойкостью для использования их в качестве материалов первой стенки термоядерных реакторов и в ядерной энергетике» по программе грантового финансирования по научным и (или) научно-техническим проектам на 2018-2020 годы в Республики Казахстан.

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7. ГОСТ 5639-82. Стали и сплавы. Методы выявления и определения величины зерна.


РЕЗЮМЕ: Технологичното развитие на човешкостта след откриването на електромагнитното поле (EMF), което е в основата на биолого-компютърните технологии, доведе до непреоксиснато излагане на човека на електромагнитното поле на живите организми. Основната цел на този технологичен разрез е да продължи и броят на генераторите на електромагнитното поле (EMF) да се увеличава, което ще доведе до все по-голямо облъчване на хората от електромагнитните вълни в широк честотен диапазон. С развитието на смарт технологии и частност интернет на нещата (IoT), което представлява мрежа от устройства, използвани за възможността за намаляване на електромагнитните замърсявания около нас.

Създаването на умни градове, умни домове и интелигентни фабрики повлиява редица въпроси за негативните въздействия на електромагнитните вълни. Ето защо в настоящата статия се разглежда и анализират възможните ефекти върху човешкото здраве на човека и възможните мерки за намаляване на електромагнитните вълни, генерирани от електромагнитните вълни. Ето защо в настоящата статия се разглежда и анализират възможните ефекти върху човешкото здраве на човека и възможните мерки за намаляване на електромагнитните вълни, генерирани от електромагнитните вълни.
увеличение на скоростта на трансфер на данни се използват все по-високи честотни диапазони. Както е известно, високочестотните сигнали захватат по-бързо в пространството и в необходими базови станции да бъдат по-близо една до друга, което ще доведе до тяхното увеличаване. В процес на изграждане е спътничка комуникационна система за бежичен трансфер на големи обеми от данни със сигнал. Федералната комисия по комуникации на САЩ е разрешила на компанията СпейсХ, която да покрие цялото земно кълбо със сигнал. В настоящата статия ще бъде предложен метод за вторично използване на безжичните технологии като вариант за намаляване на електромагнитните загрявания и подобряване на начина на живот на хората. Вторичното използване на бежичните технологии – SAWT (secondary applications of wireless technologies) е технология, използваща съществуващите в пространството EMF не по предназначение, а за решаване на нови задачи [11, 12]. Например, съществуващият в ефира телевизионен сигнал да не се използва за гледане на телевизия, а с подходяща сигнална обработка да се използва за създаване на радио бария, което може да служи за охрана на граници или обекти, да се използва за откриване и преброяване на подвижни източници на ултразвука с цел управление на светофоиния уред или чрез измерване на времетраене на сигнала от няколко статични предаватели да се реши навигационната задача и др.

Статията е организирана в увод, източници на изкуствени електромагнитни полета, ефекти на EMF върху физиологията на човека, технология за вторично използване на бежичните технологии, заключение, литературни източници.

2. Източници на изкуствени електромагнитни полета

Електромагнитните вълни се разпространяват в пространството със скоростта на светлината, като се характеризират с определена дължина на вълната \( \lambda \), имат съответна честота \( f \) и енергия на фотона \( E \). Затова електромагнитният спектър може да се опише еднako добре като функция на кои d с е от тези три величини. Връзката между енергията на фотона и честотата на вълната e:

\[
E = hf
\]

където \( h \) е константата на Планк и \( h = 4.14 \text{ eV/VGHz} \).

В зависимост от големината на енергията на фотона электромагнитните излъчвания се делят на йонизиращи и нейонизиращи лъчения. Нейонизиращото лъчение се характеризира с енергия на фотона \( E < 10 \text{ eV} \). Йонизиращото лъчение е с енергия на фотона \( E \geq 10 \text{ eV} \) и се асоциира с рентгеновите лъчи и гама-лъчения и техните биологични ефекти върху хората. При тях енергията на фотона на съответното лъчение се оказва по-висока от енергията на най-слабите молекулни връзки и те могат да разрушат молекулите в биологичните тъкани, като йонизират молекулите и атомите на клетките. Йонизиращото лъчение предизвиква прекъсване на мономолекулните връзки на веществото в тъканиите, което от своя страна води до разрушаване на ДНК-молекулите в клетките и промяна на генетичния материал.

Електромагнитното лъчение като видимата светлина, микроълвите и радиовълните са нискоенергетични и при тях не се наблюдават йонизиращи ефекти. Действието на този вид вълни се свързва основно с възбуждането на индуциращи токове в проводници среди, включително биологични тъкани.

Националната агенция за радио изследвания в США в процеса на използването на RF-EMF може да се обясни с принципа на затопляне при използването на RF-EMF. Тази възможност за затопляне на органи, включително на мозъка, е обект на съответните изследвания. Електромагнитните вълни се характеризират с определена дължина на вълната, като функция на честотата на вълната (фиг. 1). Крайно ниските честоти ELF, върху ниските SLF и инфраниските честоти ILF се характеризират с честоти в диапазона 3-3kHz и се генерират от електрониката и електрическите проводници, използвани в домовете и работните места. ELF-EMF също се излъчва от линиите на високо напрежение, които пренасят електроенергия от електроцентралилни до домовете ни.

Радиовълните са в обхвата от 3 KHz до 300 GHz и се разпространяват в пространството, когато радио сигналът се излъчва от антената с подходящи размери. RF-EMF се излъчва от устройства като мобилни телефони, Wi-Fi системи, сателитни комуникационни системи, радио- и TV станции и интерактивни радиостанции. Например, могат да се изолят за защита на радио- и рентгенови излъчвания. Преди използването на радио сигнал, тези устройства работят на принципа на излъчване на електромагнитни вълни.
3. Ефекти на EMF върху физиологията на човека

Физиологията на човека зависи от нормального протичане на биохимични процеси в организма, тъканите и клетките. Облъчването с мощни EMF за по-дълъг период от време представлява риск за здравето на човека (фиг. 2). Безспорен е ефектът от облъчване с микровълни, водещ до напрежаване на биологичните тъкани, но нетипичните ефекти представят голем интерес за изследователите. RF-EMF се класифицира като вероятно канцерогенно за хората [10-12] при продължително подлагане на EMF. С развитието на IoT се предполага хората да живеят в т. нар. умни къщи и умни градове и да работят в умители фабрики, в които голма част от обектите, включително автомобилите и машините, ще комуникират по безжичен път с помощта на електромагнитни сигнали. Това означава, че хората ще са заобиколени от радио замърсяване в целия възможен честотен диапазон. Резултати за влиянието на тези технологии върху здравето на човека ще се появят след време, но за тях може да се съди от резултати за ефектите на мобилните технологии върху човека.

Фиг. 2 Източници на EMF

Съществуват много научни изследвания за влиянието на GSM технологиите върху човека, като част от тях смятат, че могат да се появят различни неврологични ефекти поради близостта на черепната нервна система и мобилния телефон до главата. Тези неврологични отклонения включват главоболие, загуба на концентрация и нарушение на съня поради токсична експозиция на тъканите в човешкото тяло. Роговицата на човешкото око може да бъде опасно повредена поради отсъствие на кръвоносните съдове в нея и свързаната с това терморегулаторна система чрез кръвообращение.

Фиг. 3 Термо снимка преди и след 20-мин. разговор с GSM

4. Вторично използване на безжичните технологии

Под вторично използване на безжичните технологии се разбира използване на налични EMF в пространството за нетрадиционно решение на практически-полезни задачи. Например, използване на радио-, TV или GSM сигнали за подаване на радио бариери с цел откриване на подвижни обекти, оценка на техните параметри, класификация на обектите и др. Тази информация може да се използва за управление на пътен трафик в умните градове след време, без да се налага създаването на нови радио бариери с мониторирането на допълнителни предаватели на радио сигнали. По подобен начин е възможно създаване на различни охранителни системи както в помещения с наличен WiFi, така и на открито с използване на наличните радио-,TV, GSM или GPS сигнали (фиг. 4).

Използването на GPS като система за вторично приложение на безжичните технологии е много удобно за имплементиране както в населени места, така и извън тях, включително по цялото земно кълбо [12-18]. Знаяки местонахождението на предавателите (стационарни GSM BS, TV- и радио предаватели, различни сензори, използвани от IoT) и измервайки времезакъснението на сигнала, е възможно да бъдат създадени различни навигационни системи. През последните години се предлагат алтернативни решения за навигационни системи, използвайки естествени източници на EMF като GPS, GLONASS, BeiDou, Galileo и др. През последните години се предлагат различни технологии, използвайки информацията от радио съобщенията, получена от даден обект. Създаването на подобна технология ще обезпечи подобряване на изкуствените навигационни системи като GPS, GLONASS, Beidou, Galileo и др.
ориентиране в пространството или определяне на часовото време. С наличната в момента апаратура е възможно да се открие радио сянка от различни обекти, да се оценят параметрите и да се решат полезни задачи като подобряване на навигацията, откриване и класификация на обекти и др. [19-21]. Създаването на система за вторично използване на бежичните технологии ще доведе до намаляване на радиочестотните замърсявания, като в същото време ще бъде полезно за практиката. За получаването на тези приложения е необходимо да се използват специфични познания от различни професионални области и разработването на специализирани софтуерни решения.

5. Заключение

Прекомерното излагане на EMF води до измерими физиологични ефекти върху човешкия организъм като изменение на електрическата полярност на клетъчната мембрана, промени в белтъчните молекули, разрушаване на водната молекула, промени в междумембранината, в стойността на pH и хормоналния баланс. Повишението стойности на EMF въздействат върху имунната система, като намалява нейната функционалност [22]. Влиянието върху човешкото, в частност детското здраве, може да бъде свързано с три нива на въздействие: клетъчно, физиологично и свързано с продуктивността и ефективността на лечебния процес. Всички те са съотносими към качеството на околната среда и с продължителността и ефективността на лечебния процес. Влиянието върху човешкото здраве, като намалява нейната функционалност, ефективност на лечебния процес, се очаква да бъде най-значимо при борбата с инфекциите, като в същото време ще бъде използвано специфични познания от различни професионални области и разработването на специализирани софтуерни решения.

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Copper (i) bromide thin films deposited by thermal vacuum evaporation for application in solar cells

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1. Introduction

Transparent conductive materials have been vastly investigated due to their important application in optoelectronic devices. Most of the commercially available materials are transparent metal oxides of the n-type conductivity, whereas there are only a few candidates for transparent materials of p-type conductivity. Copper halides like CuBr, CuI and CuCl are transparent p-type semiconductors and have been highly reconsidered for optoelectronic applications recently. Out of these compounds the most studied material is copper (I) iodide which has been largely investigated for its application in next generation photovoltaic technologies. In this work we have investigated the properties of CuBr for its potential application as a hole transport material (HTM) in perovskite solar cells.

2. Problem discussion

Organic-inorganic perovskite solar cells (PSC) have reached efficiencies up to 22 %. In state-of-the-art perovskite solar cells, the planar (n-i-p) architecture was mainly used. For most of the efficient solar cells with planar configuration, 2,2′,7,7′-Tetrakis(N,N-di-p-methoxyphenylamine) 9,9′-spirobifluorene (spiro-OMeTAD) is dominantly used as the hole transport material. However, its synthesis is complex and requires extensive purification, which results in rather expensive material that compromises the commercialization of PSCs as a cost competitive photovoltaic technology solution. Copper (I) bromide is a promising candidate to replace the expensive spiro-OMeTAD and can be easily deposited by thermal vacuum evaporation with high deposition rates. Thermal evaporators are usually used for the deposition of the back contact of the solar cell and for this purpose are normally integrated with the glovebox setup in order not to expose the device to ambient environment, which makes them suitable for the integration of other inorganic materials in the device structure. In addition, thermal evaporation also provides superior uniformity of the layers in comparison to RF sputtering, mainly used for deposition of CuBr thin films.

3. Objective and research methodologies

The main purpose of this work is to investigate the process of direct thermal evaporation of Cu(I)Br thin films and their properties related to their potential application as HTM in solar cells. The studied films were deposited out of commercial CuBr powder on top of glass substrates. The film thickness could be increased by repetition of the process and was controlled by varying the amount of the material in the boat while the other parameters were kept constant. The boats were covered during evaporation to eliminate the effects of thermal dissipation of powder during glowing.

The optical properties of CuBr were studied by optical absorption spectroscopy at room temperature. The optical transmission shows high transparency up to the absorption edge. The optical band-gap was estimated from the Tauc plot to be 2.98 eV (figure 2). The absorption spectrum is plotted in the inset, showing the characteristic Z12 and Z3 excitons for CuBr.

X-ray diffraction (XRD) analysis was carried out (Bruker D8, θ–2θ configuration) to determine the crystal structure of the CuBr films. The X-ray diffraction pattern exhibits several CuBr peaks, indicating polycrystalline structure with a preferred orientation (111). The preferential growth direction on glass substrates is (111). It is evident from the diffractogram that the material is polycrystalline with preferential orientation along the (111) direction. The X-ray diffraction pattern indicates Bragg peaks for (111), (220), (311), and (331) reflections and is in agreement with the literature data for γ-CuBr phase. The average crystallite size was estimated by the Scherrer equation. For samples with various thicknesses the crystallite size was between 98 ± 2 nm for the thinnest and 128 ± 3 nm for the thickest samples.

Figure 1. Optical transmission spectrum of CuBr.

Figure 2. Tauc plot and typical absorption spectrum of CuBr.

Figure 3. X-ray diffraction pattern of CuBr.
The surface chemical composition was examined by X-ray photoelectron spectroscopy in Kratos Axis Supra spectrometer. The position of Cu2p photoelectron line and CuLMM Auger line indicate that the copper is in Cu and Cu1+ states (figure 4 and figure 5, respectively). The Br3p line appears at 182.8 eV and the Br3d peak at 69.3 eV, which are the proof for the CuBr compound. In addition, the Cu shake-up satellite feature which is characteristic for Cu(II)Br is not present at 934.7 eV. These results indicate that the evaporated layers are stoichiometric.

Figure 4. High resolution XPS spectrum of Cu 2p photoelectron line.

Figure 5. High resolution XPS spectrum of CuLMM Auger line.

Scanning electron microscopy (SEM) micrograph presented in figure 6 reveals that the direct thermal evaporation results in the formation of homogeneous and dense films that follow columnar growth. In the inset of figure 6 is presented a cross-section of a 4 μm thick CuBr film. The film was grown in two separate runs with equal amount of material in the boat and the rest of parameters were kept constant. Although there is no clearly visible interface between the two CuBr layers grown one on top of the other, it can be seen that the columnar structure continues to grow with the same density following the growth direction.

Figure 6. SEM surface image and cross-section of two layers deposited one on top of the other.

Thin films were evaporated on top of sputtered ITO electrodes on glass substrates and I-V scans were taken in the interval from -2 V to +4 V. Straight line indicates the formation of Ohmic contact between the ITO electrode and CuBr which is a proof that the material can be successfully implemented in the solar cell structure.

Figure 7. J-V characteristic of CuBr deposited on ITO planar electrodes.

4. Conclusion
The work presents a process for formation of CuBr thin films by direct thermal vacuum evaporation. The XPS investigations have shown formation of stoichiometric compound CuBr. The obtained CuBr films are highly transparent, over 80% in the visible range with onset of strong absorption before 420 nm. The estimated optical band gap for direct transitions was 2.98 eV . The X-ray diffraction pattern indicated typical reflections for the γ – phase CuBr with random orientation and grain size about 100 nm. Scanning Electron Microscopy has shown formation of dense and uniform layers with column structure. The volt-ampereometric measurements of thin films structures with planar electrodes presented straight linear dependence and formation of Ohmic contact between CuBr and ITO back electrode.

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Abstract: The objective of this report is to review the key characteristics and principles of Postmodernism in graphic design. Researched are the works of some of the leading postmodernist authors. This served as a basis for identifying the Postmodernism-characteristic elements and compositional techniques. The impact of Postmodernism on the web design has been analyzed. Shown are examples of current web design employing Postmodernism-typical compositional techniques and visual details.

Keywords: POSTMODERNISM, DECONSTRUCTION, DISORDER, GRAPHIC DESIGN, WEB DESIGN, WEB TYPOGRAPHY, ILLEGIBILITY.

1. Увод

Цел на настоящият доклад е да бъдат разгледани ключовите характеристики и принципи на Постмодернизма в графичния дизайн. Проучени са произведенията на един от водещите постмодерни автори. На тази база са определени елементите и композиционните способи характерни за постмодернизма. Анализирано е въздействието на Постмодернизма върху оформлението на уеб дизайн. Направен е опит да се посочат примери от съвремения уеб дизайн, които използват композиционни похвати и визуални елементи характерни за Постмодернизма.

Постмодернизът е едно от най-аморфните течения в изкуството и графичния дизайн. Характерно за Постмодернизма е, че бележи явно отхвърляне на Международния типографски стиль, реда на школата Баухаус, традиционната употреба на типографията и модулната мрежа. Освен това се изоставя и принципът за подреждане на елементите на дизайна и текста под прави ъгли за сметка на използване на произволни ъгли. Част от влиянията върху Постмодернизма могат да се проследят до футуризма и дадаизма. Постмодерният дизайн отразява отрицание на реда и установеното статукво в дизайна. В действителност някои от първите типографски експерименти на футуристите могат да бъдат приети за постмодерен дизайн.

2. Изложение

Едни от първите работи в духа на Постмодернизма са създадени през 60-те г. на XX в. в Швейцария. През 1964 г. Розмари Тиси създава рекламен плакат за печатарската фирма E. Lutz & Company (фиг. 1а). Елементите на тази реклама не са подравнени по строга модулна мрежа, а изглеждат интуитивно и произволно поставени на листа. През 1966 г. Зигфрид Одермат прави дизайн на търговската марка на Union Safe Company, която е антитеза на Швейцарския дизайн – буквите в думата са прекалено близки една до друга и образуват компактно единство, но се губи четливост на думата (фиг. 1б). В реклама за цяла страница на вестника Одермат третира логотипа на Union, като чиста форма, която манипулира визуално създавайки динамична композиция на страницата във вестника. През 1968 г. заедно с Розмари Тиси създават студиото за графичен дизайн – Odermatt & Tissi [1].

През 70-те години на XX век голяма част от дизайнерите в световен мащаб започват да се дистанцират от шестващия дотогава Модернизъм, а заедно с това от рационализма и функционализма – на преден план започват да излизат проявите на постмодерното движение характеризиращо се с голямо вътрешно разнообразие и експресивност. Сред дизайнерите постмодернисти представители на „Новата вълна” в типографията можем да открием Волфганг Вайнгарт (фиг. 2а), Дан Фридман (фиг. 2б), Вили Кунц (фиг. 3а) и Ейприл Грейман (фиг. 3б) [1].

През 1981 г. Дан Фридман нарисува плакат за изложба, която посветена е на темата „Машини. Технологии. Материали” [1].
Важно значение за развитието на Постмодернизма има появлата на персонални компютри. С навлизането на настолните издателски системи и графични програми се налагат и нови професионални възможности за експерименти срещу типографската традиция. Широката достъпност на графичния софтуер и популяризацията на типографията като и бързото развитие на глобалната мрежа водят до появлата на разнообразни творчески решения както при разработката на нови шрифтове така и в дизайна на печатни продукти [2]. Един от най-известните постмодерни графични дизайnerи от по-младото поколение са американецът Дейвид Карсън и англичанина Невил Брууди.

Дейвид Карсън е един от популярните съвременни графични дизайнери. Невконвенционалният му и експериментален графичен стил революционизира сцената на графичния дизайн в Америка през 90-те години на миналия век. През 1989 г. започва работа като арт директор в списанието Beach Culture (фиг. 4). След публикуването само на шест броя списанието спира да излиза. По-късно започва работа в алтернативно музикално списание Ray Gun. Като арт директор на списанието Карсън разработва отчетливи оформления с иновативна употреба на типографията. Той е считан за създател на „гръндж типографията“ – подходът му към типографията е анархистичен и нарушава всички типографски правила [3, 4].

Фиг. 3 Вили Кунц, плакат за уъркшо по типография, 1974 г. (а). Ейприл Грейман, покана за China Club, 1980 г. (б)

Фиг. 5 Невил Брууди, реклама за NIKE, 1988 г.

Основните изразни средства и ключови принципи на постмодерната страница са:
- Постмодерните страници, използват текст навсякъде на страницата – понякога дори застъпващ се текст един върху друг.
- Постмодерните дизайнери употребяват различни шрифтове – безсерифни, серифни, четливи или нечетливи. Целта на страницата на Постмодернизма е да интерпретира текста и да се предизвика читателя. Водещо става въздействието на текста, а не неговата четливост.
- Много често се използват контрастите на пространство, текстура, форма и размер за да се създаде акцент.
- Някои постмодерни типографи деконструират и разпадат текста, за да покажат на читателя различни визуални интерпретации.
- В постмодерните страници не се използват модулни мрежи, а оформлението е свободно и експериментално [7]. Канадската фирма за уеб дизайн Reflektor Digital разработва сайта 36 Days of Type (фиг. 6). Дизайнерите на компанията за разработка създават анимирани версии на различни букви, използвайки редица техники за кодиране. На началната страница са използвани анимирани букви и цифри в различни кегли и начертания на шрифта, които създават усещане за текстура и привличат вниманието на потребителите на сайта.

Фиг. 4 Дейвид Карсън, оформление за сп. Beach Culture, 1998 г.

Фиг. 6 Уеб сайт 36 Days of Type (https://36days.reflektor.digital/) 2019 г. на канадската компания Reflektor Digital – пример за влиянието на Постмодернизма върху уеб дизайн

Руското студио за дизайн SLAVA създава сайта за съвременната арт организация Baibakov Art Projects (фиг. 7). Основната мисия на организацията е да утвърждава изкуството чрез различни кураторски, редакторски, стратегически и филантропски инициативи. Дизайна на сайта е минималистичен в монохромна светлока и е с ключов акцент към типографската иерархия на страницата. Характерно
за уеб сайтът е употребата на интересен анимиран фон напомнящ на разлети петна мастило.

Друг сайт, който използва характерни композиционни прийоми на Постмодернизма е страницата на испанското студио за дизайн REVELÈ (фиг. 8). За дизайн на уеб страницата не е използвана строга модулна мрежа, а елементите на сайта са оформени асиметрично и свободно. В оформлението на уеб сайтът са използвани кръгове, които закриват текста в сайта – но благодарение на интерактивността в уеб страницата при разместването им с мишката текста се открива и става четлив. Друга водеща характеристика на сайта е умелата употреба на типографията като ключов елемент на дизайна.

На фиг. 9 е представен уеб сайта на френската компания ARCHE68. Основаният акцент на уеб сайтът е насочен към неговото текстово съдържание. Експерименталното оформление на типографията прилича визуално потребителите на сайта, но и насочва фокусът към текста на страницата. Уеб сайта прави впечатление и със своята необичайна анимирана навигация.

3. Заключение

Като извод от направеното изследване може да се заключи, че Постмодернизма въздейства върху съвременния уеб дизайн. В някои от настоящите уеб сайтове се засилва употребата на типични елементи използвани в постмодерния дизайн. Все повече се експериментира с различни шрифтове и текстури – това води до по-голямо разнообразие в графичното оформление на актуалните уеб сайтове.

4. Литература

Innovation activity of wine industry enterprises
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Abstract: The sector of wine production is traditional for the Bulgarian economy and thus the innovation activity in the sector can contribute to the overall development of the economic processes. The object of the survey is enterprises from wine industry, located in Bulgaria. The subject of the study is the innovation activity of wine producers and the possibilities to optimize their innovation potential. As a result, methodological approaches and empirical results are presented according the approbation of innovation in enterprises. The results show that the wine producers in Bulgaria make slow steps towards more contemporary development of the sector, but the more significant results are yet to come.

KEYWORDS: INNOVATION, WINE INDUSTRY, COMPETITIVENESS

Инновационна активност на предприятия от винарската-industry

1. Въведение
Инновативните предприятия в България и възможностите за увеличаване на техния брой са предпоставки за дългосрочната конкурентоспособност на икономиката. Внедряването на иновации и повишаването на иновационния потенциал на организацияте изисква особено внимание в контекста на все по-бързо увеличаващата се скорост на промените в глобален план. В непрекъснатия променящия се глобална околната среда стратегическото преимущество може да дойде само от лидери на промяната, а единственият начин за това е чрез иновации.

Изследването по отношение на винарската индустрия в страната ни е повече от необходимо, предвид нарастващата конкуренция на световния пазар на вино и цялостна структурна трансформация на винената индустрия, отразяващи се и на българското винопроизводство. Съвременните предприятия трябва да се про-активни, ориентирани към бъдещето, предвиждайки промените, а не реактивни. Това от своя страна предполага да се търсят и формират нови способи на конкурентно поведение, стратегически поставени и способни да се адаптират върху лозаро-конкурентните пазари и със способността да се различават от съперници, обърквайки им устойчиво развитието на предприятието. Способността да се определят адекватно позицията на дадена организация в най-важния среда, т.е. по отношение на други субекти в сектора, е от съществено значение за вземането на стратегически решения (Т. Димитрова, 2017). Тя помага на организацииите да интегрират своите ресурси и дейности и определя успеха и устойчивостта на бизнеса.

Възможностите за използване на иновационни продукти в предприятията зависят от много фактори като равнище на обезпечението на фирмата, способността на висшите мениджъри да развиват и внедряват нови продукти и технологии и други. С устойчивия растеж на икономиката продължава и тенденцията на подобряване на средата за предприемачество и бизнес в България. Изключително важно е да се определи точно видът на нововъведение, което би довело до увеличаване на производството или намаляване себестойността на продукцията. За предприемачеството е необходимо специфична иновация, която да съответства на нуждите на служителите и на възможностите за развитие.

Всички извършени на човешка промени, на които светът става свидетел, са резултат от тенденцията да се търси нещо ново и различно. Новите идеи в света нямат край, но когато тези идеи създават стойност, удовлетворяват съществуващи или създават нови потребности, се получава иновация. Добрите идеи са безполезни, докато не се реализират. А за да се реализират, трябва да се намери предприемач, който чрез своята визия, проектираност и способност за премерен риск може да направи добрата идея в готов полезен продукт (Angelova et. al, 2019).

Понякога иновации се извършват чрез използване на съществуваща идея, концепция или продукт и неговото усъвършенстване. Обаче по-забележителното е да се мисли отвъд вече съществуващото и да се излезе със съвсем нова концепция.

Научната литература изобилства от определения за иновации, но според утвърдената дефиниция на Организацията за икономическо сътрудничество и развитие (OECD, Oslo...
2.1. Според обекта, в който се реализира новостта, иновациите биват продуктови, процесни, пазарни (маркетингови) и организационно-управленски иновации. Видовете иновации са показани на схема 1.

Схема 1. Видове иновации, според обекта, в който се реализира новостта

2.2. Според степента на радикалност, дълбочината на промените и отдалечеността във времето между идеята и практическото приложението, иновациите биват основни, подобриeni и псевдоновации.

2.3. Според източника, иновациите биват иновации от изследване и развитие, собствени фирми и иновации от други източници. Основната идея на тази систематизация е да покаже, че не всички иновационни процеси във фирмите трябва да бъдат развити или и въведени в съответствие с R&D (Research and Development) институции (университети, изследователски институти и т.н.). Освен това, бързото и отговорното във един такъв вид развитие на бизнес процесите или краткосрочната реализация на идеята, развойна дейност (псевдоновация) не бива да се свържат с R&D институции. Много от тях имат собствени R&D отделени (вътрешно R&D), докато други създават иновации благодарение на собствени предприемачки идеи.

2.4. Според фирмената стратегия, иновациите биват отворени и затворени. Отворената иновация се състои от стратегия, чрез която фирмите могат да получат технологиите, от които се нуждаят, и да експлоатират технологиите, които създадоха. Затворената иновация е използвана стратегията на наемането на технически най-подготвените хора в дадена област. Тя приема, че фирмата трябва сама да развива своите нови продукти и услуги и да бъде първата компания, която ги представя на пазара.

2.5. Според сферата, в която се реализират, иновациите биват производствени и управленски.


2.7. Според източника на идея възникването на иновациите може да се предизвика от конкретни потребители, от ново откритие или от собствени потребности на предприятието.

2.8. С по-голямо практическо значение е класификацията на иновациите по признания, свързани със стратегическите цели и конкурентната позиция на фирмата. Такъв е признатът новост – съответно за фирмата, за пазара и за конкретния потребител. По този признак се разграничитват пет вида продукти: нови продукти в световен мащаб; коренно нов продукт за фирмата, с която се навлиза на нов за нея пазар; нов продукт, с която се допълва съществуващата стокова гама на фирмата; усъвършенстван продукт; репозициониран продукт.

2.9. Според влиянието на иновациите върху потребителските навици те биват: иновации, непрекъсващи потребителските навици; иновации, променящи съществено потребителските навици, и иновации, създаващи нови потребителски навици.

Разглежданите класификации потвърждават извода, че групираният на иновациите е важно само при осъществяването на конкретни цели и дейности, свързани с разработването на иновационна стратегия на фирмата. От съществено значение за видовете иновации е макросредата, а така също и икономическото състояние на фирмата.

В ръководството на Осло 2018 (4-то издание) Организацията за икономическо сътрудничество и развитие дава нова класификация на иновациите. Утвърдени са две основни групи - иновация на продуктите и иновации в бизнес процесите. Иновациите в продуктите могат да бъдат иновации на стоки и услуги. Иновациите в бизнес процесите включват иновации в производството на стоки или услуги, дистрибуция и логистика, маркетинг и продажби, информационни и комуникационни системи, администрация и управление и развитие на продукти и бизнес процеси.

Иновацията може да се характеризира като иновационен процес, когато се разглежда като комплекс от взаимосвързани, но обособени по фази възникващи. Те имат определена степен на завършеност, която включва времетраене, получени междинни резултати или крайни резултати. Независимо от голямото разнообразие на тези фази, класическите модели на иновационната активност на предприятията включва следните основни фази:

Схема 2. Класически модел на иновационна активност

3. Методика за изследване на иновационната активност

Концептуалният модел за изследване на иновационната активност на предприятията е част от проект № КП-06-М25/5/17.12.18 г., финансиран от фонд „Научни изследвания“ към МОН. Включени са широка гама от изследователски методи за успешно постигане на целите и задачите на изследването. Дейността на всяка организация е въз основа на взаимосвързаности процеси - от маркетинг и планиране до продажби и следпродажбено обслужване. Желаният резултат се постига по-ефективно, когато дейността и съответните ресурси се управляват като процес. Тази постановка се основава на факта, че управлението на ефективността е непрекъсната поредица от взаимосвързани действия или функции, които се представят...
като процеси. Разработването на методологични положения се основава на методологията, т.е. интегриране на ключовите условия и процеси в работата на специалистите, определяне на компетенции за инновационен въпрос от бизнес процесите и диагностичен анализ на тяхното състояние.

Изследователският подход използва количествен метод, а именно структурирано интервю - анкета, който има за цел да получи обратна информация от специалистите на компанията за иновативните решения в организациите. Използва се методът на експертна оценка и се провежда с подкрепата на учени от икономическите университети като консултанти. Обработката на информацията се извършва със специализирани софтуерни продукти.

Схема 3. Методически положения

4. Резултати и дискусия

Настоящото проучване е проведено сред малки и средни предприятия от сектор Винопроизводство, позиционирани в България. Резултатите сочат, че в анкетирането са участни 57 винарски изби, като разпределението според броя на заетите е 27 чов. Изследваните предприятия са само от групата техните организации.

Половината от анкетираните посочват положителната си нагласа във връзка с очакваните резултати в следствие прилагането на иновации. Голяма част от тях смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите, т.е. те са на мнение, че знай за иновациите и биха приложили в момента или вече прилагат в организацията.

В анкетната карта е включена секция Иновации, в която те са обобщени в групи според различните видове. След анализ на данните най-често срещаните отговор на анкетираните е Неприложимо при нас за възможността за иновации в предприятието. Анализът на фиг. 5 насочва вниманието към високата мотивация и търсенето на конкурентоспособността на предприятията от страна на висшата управление и специалистите, защо в тях.

В група 1 - Иновации по отношение на суровината, анкетираните категорично заявяват, че биха приложили или вече прилагат в предприятията. Под 5% от отговорите са посочили възможност 1 - Неприложимо при нас или 2 - Знаем за тази възможност, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието.

В група 2 - Иновации по отношение на суровината, анкетираните категорично заявяват, че биха приложили или вече прилагат в предприятията. Под 5% от отговорите са посочили възможност 1 - Неприложимо при нас или 2 - Знаем за тази възможност, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието.

Фиг. 3. Приложение на ин. стратегии

Респондентите посочват положителната си нагласа във връзка с очакваните резултати в следствие прилагането на иновации. Голяма част от тях смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите и смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите и смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите и смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите и смятат, че този процес ще доведе до повишаване удовлетвореността на клиентитите. Анализът на фиг. 5 насочва вниманието към високата мотивация и търсенето на конкурентоспособността на предприятията. Анализът на фиг. 5 насочва вниманието към високата мотивация и търсенето на конкурентоспособността на предприятията. Анализът на фиг. 5 насочва вниманието към високата мотивация и търсенето на конкурентоспособността на предприятията.

Фиг. 4. Етап на изпълн. на инов. стр.

В група 1 - Иновации по отношение на суровината, анкетираните категорично заявяват, че биха приложили или вече прилагат в предприятията. Под 5% от отговорите са посочили възможност 1 - Неприложимо при нас или 2 - Знаем за тази възможност, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили. Това се отнася за възможността за възможността за иновации в предприятието, но не бихме приложили.

Половината от анкетираните посочват, че прилагат иновативни стратегии в организациите или планират да започнат. Това е индикация, че темата за иновациите е водеща част от корпоративната култура. В по-голямата част от предприятията иновационната стратегия е в процес на разработване (фиг.4).
представляват интерес и могат да бъдат приложени с цел анкетна карта, представя над 30 различни възможности, които иновационната активност на предприятията. Изграждането на концептуален модел за изследване на телекомуникационни възможности, като всички те са част от политическата обстановка в страната, информационните и на база разработената методика ще имат конкурентната среда, биопроизводството. От съвкупността още не прилагат много иновации по отношение на служителите. Те са следвани от удовлетвореността на клиентите и продуктивността, които са свързани със самото предприятие. Повишаване конкурентоспособността, ефективността и - винопроизводителите виждат най-разработка. Прави впечатление, че в иновациите иновационни стратегии или се прилагат, или са в процес на планират да го направят. Освен това при 1/3 от анкетираните резултата, че повечето от тях вече прилагат такива или иновационни стратегии. Това заключение се обосновава на България полага усилия по изграждане и внедряване на получени от респондентите, сочи, че винопроизводството в реализира в рамките на проект КП БЛАГОДАРНОСТ


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1. Въведение

1.1 Литературен обзор на разрушителните иновации

През 1995 година професора по Бизнес Клейтън Кристенсен от Бизнес Факултета на Университета Харвард за първ път представи теорията си за Разрушителните Иновации. Теорията е публикувана в *Harvard Business Review* в статията „Разрушителни технологии: Улавяне на вълната“ (Disruptive Technologies: Catching the Wave) със съавтор Джоуесъф Л. Бауер. Авторите представят ново виждане за същността на технологията и така се въвежда нов термин в бизнес науката - „разрушителна технология“. Кристенсен определя разрушителната иновация като продукт или услуга, предназначена за нов набор от клиенти.


Първа Дефиниция

Първоначално Кристенсен описва разрушителните иновации като: ... процес, чрез който даден продукт или услуга се вкоренява първоначално като просто приложение на дъното на пазара, характеризиран с най-малкото количество потребители, и след това безмилостно се придвижва нагоре към най-върховното ниво на пазара, характеризиран с най-добър предмет. Наличие на потребители, и след това безмилостно се придвижва нагоре към най-върховното ниво на пазара, характеризиран с най-добър предмет. Разрушителната технология е нов термин, който възприема по различен начин в зависимост от нуждите на клиентите. "Първа Дефиниция" (1997)

Тази дефиниция показва модел, при който ново-стартрашеният млад бизнес успява да навлезе в долната част на пазара и започва да се възползва от съществуващата стойностна стража преди да се премести в по-горното ниво на пазара и да атакува, така нареченият „утвърдени оператори“. Кристенсен и Рейнор (2003) дават подобни примери със стоманената индустрия и търговията на дребно, по-точно с търговиците, които продават с малък бизнес успява да навлезе в долната част на пазара и конкуренти. (1)


Втора дефиниция

Второто определение на разрушителните иновации се свързва с тезата, че разрушителните иновации променят потребителските жадствата за ефективност или очакванията на потребите на пазара (Даниелс 2004, Маркидес 2006, Телис 2006). Тази дефиниция се осла на наличието на някаква относителна характеристика, което съществено променя начин на действие на потребители, като първите потребители започват да гледат на новопредлаганите продукти/услуги. Очакванията им са свързани с нова функционалност, технически стандарти или нов цени. Тъй като потребителите се обръщат към новите фирми, които предоставят достъп до тези нови предпочитания, като по този начин нарушават съществуващата пазарна структура (2).


Приемането на тази теория на минимуми на бизнес организация може да доведе до успеха и просперитета й.

2. Същност на разрушителните иновации

2.1 Теория на Разрушителните Иновации

При прегледа на различната литература може да се направи следният анализ. Когато Кристенсен описва за първи път какъв представляват разрушителните иновации, той ги определя като продукти с конкурентни цени и по-ниско качество от съществуващи подобни продукти на пазара. Но това не представлява много подходящ начин за класифициране на новите технологии. Тъй като различие в цената представлява бизнес стратегия. А качеството е характеристика, която се възприема по различен начин в зависимост от нуждите на клиентите. Обяснението е, че дефиницията се фокусира върху бизнес стратегиите по отношение на начина за навлизане на пазара.

Може също да отбележим, че не се засягат други иновационни характеристики, като по-късно наречение от Маркидес „вторични атрибути“ (3), които предизвикват интерес в нов сегмент клиенти поради което те започват да купуват новият продукт или услуга. Както и не се разискват условията довели до създаването на нови пазари. Примери за вторични характеристики са уголемяване на паметта при смартфоните, запазване на информация в облак и други.
С развитието на теориата за разрушителните иновации и нарастването на броя автори, занимаващи се с тази теория, се наблюдава усъвършенстване на теорията и опознаване на необходимите условия за зараждането на този вид иновации. А също и разпознаване на някои от основни характеристики, по които да се категоризират иновациите (4).

През 1995 – 1997, Кристиенсен говори за „разрушителна технология“. Но по-късно, при написването на втората си книга („Решението на иноватора“ (2003)) самият той разбира, че понятието е по-общирно и обхваща много повече неща, от които първоначално са били описани. Професор Кристиенсен заменя термина „разрушителна технология“ с „разрушителна иновация“. Той объяснява това с фактът, че е разбрал че възможност на много малко на брой технологии е присъща да са разрушителни. По-скоро бизнес моделът, спомагател на новата технология, създава разрушителното въздействие (5). Тази еволюция не само в терминологията, но и в насочване на вниманието на мениджърите от технологията към бизнес модела, обосновава и неговото разбране за развитието на бизнесите както на пазарно така и на индустриално ниво. Въвеждането на термина „бизнес модел“ е от голямо значение, тъй като в денонощието повечето от разрушителни иновации са свързани точно със смяната на съществуващ бизнес модел.


2.2 Анализ на същността на разрушителните иновации

Аналитичното разглеждане на теориата води до няколко извода. Разрушителните иновации се фокусират върху функционалното качество и цената на продукт/услуга. Теоретично, въведените иновации са с по-ниско качество и по-ниски цени от широко употребяваните. Постепенно фирмата производител подобрява качеството като по първични, така и по вторични характеристики. Пример за това е камера на първата смартфон. Първият телефон с камера (J) имаше вторични характеристики. Пример за това е камера в уохмен, които първоначално са били описани. Професор Кристенсен върху функционалното качество и цената на разрушителните иновации се свързани точно със смяната на съществуващ бизнес модел.

Ето защо говорим за дилемата на доминиращите на пазара фирми (7). Този феномен е описан от двама автори. Според Маркидес (2006) това е дилемата, пред които се изправят съществуващите доминиращи на пазара, които конкурират за клиенти, които ако не е бил създаден такъв пазар, не са могли да знайт за съществуването на такъв продукт или услуга и поради това никога не са били използвани. Джоузел Фуслер и Делмер Нажи обясняват, че такива разрушения, които са свързани с поява на нов пазар „се конкурират с не-конкурация“. (2)

Доминиращите на пазара фирмии са създалени за да задоволяват клиентската си база. По-голяма част от фирмите са със строго обособени дългосрочни и краткосрочни стратегии и съответстващи инвестиции. Ето защо първоначално те или игнорират напълно или даже и не разбират за поява на нова конкуренция. Също така, узурпирани от вторите теорията са нямат голяма стимули да се адаптират или да отворят на предизвикателствата от разрушенията. Като пример на такъв вид разрушителни иновации са създаването на пазар за лаптопи, смартфоните, стрийминг услуги (5) и др.

С течение на времето, новият бизнес модел, който е взел начало в употребата успява да спомогне на фирмата за развитие и подобря продукта по изключителен начин по второстепенните характеристики, които са били приоритизирани от долна част на пазара. Ниската цена на Форд T и преносимост с големи пътна памет при iPod. Същевременно с това обаче бизнесът подобрява параметрите и на първостепенните атрибути, или на характеристиките, които са били предпочитани от клиентите на доминиращите на пазара, като производителност, дизайн, цвет и др. По това време досегашните клиенти на доминиращите на пазара фирми започват да се интересуват от предложения на новия бизнес модел (3). По този начин се достига до един момент, в който доминиращите фирмии трябва да оценият, че е навлязъл нов начин за частичен подобряване на клиентите.

С развитието на теорията за разрушителните иновации и нарастването на броя автори, занимаващи се с тази теория, се наблюдава усъвършенстване на теорията и опознаване на необходимите условия за зараждането на този вид иновации. А също и разпознаване на някои от основни характеристики, по които да се категоризират иновациите.
MACHINES. TECHNOLOGIES. MATERIALS. 2020

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Приятно! Я подготовил текст на английский язык из вашего изображения. Пожалуйста, проверьте его на наличие ошибок и уточните, если необходимо.

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Гореописаните компоненти предоставят основа, върху която се гради теорията за проява на разрушителните иновации. Това може да помогне за изграждане на един вид правила, които да помогнат на менежмънта на компаниите да се справят с трудностите, предизвикани от разрушителните иновации.

3.2 Въвеждане на разрушителни иновации в практиката

Нека да определим няколко фактора, които могат да помогнат при въвеждане на разрушителни иновации в практиката:

- наличие на проблем: незадоволен купувач или създаване на ново появил се малки пазари, които нямат много (или вторични) части или услуги, които техните съществуващи клиенти не желаят да получават.
- Превръщане на проблема във възможност. Да се разработват атрибути, които вече нямат (или изобщо нямат) клиенти и се радват на по-новите, които се радват на по-ново появил се малки фирми, които нямат много (или вторични) части или услуги, които техните съществуващи клиенти не желаят да получават.
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- Превръщане на проблема във възможност. Да се разработват атрибути, които вече нямат (или изобщо нямат) клиенти и се радват на по-ново появил се малки фирми, които нямат много (или вторични) части или услуги, които техните съществуващи клиенти не желаят да получават.

- Използване на нова технология или откритие, което да доведе до промяна в структурата на пазара. Пример за това е използване на нова технология във възможност. Пример за това е възможност. Пример за това е възможност. Пример за това е възможност.

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Нека да приложим тези фактори, за да обясним поява на МРЗ на пазара. Проблемът, който е бил налице е, че ако човек иска да пътува и да слуша музика е било необходимо да се носи и голям брой CD-та. Появява се възможност за изясняване на атрибути, които са необходими за задоволяване на нужди на уред за слушане на музика, мъжък, преносим, с голяма памет. Откритието, което се използва е, че въпреки че CD са също дигитални, но използват по-стар формат (аналов сигнал). Докато МРЗ използва нова технология за дигитална музика – цифрата. Ето как започва използването на нов уред, а продажбите в най-спиралните периоди на iPod 2008 и 2009 са били
по 54 милиона/година (16). Продажбите след това намаляват заради широкото навлизане в употреба на смартфона.

4. Заключение

Запознаването ни със същността на разрушителните иновации и анализ на възможностите за тяхното разпознаване и въвеждане в практиката води до определени изводи. Последствието от тях е определение на някои основни действия необходими да се извършат от менджмънта на фирмата: като идентифициране на клиенти и конкуренти, техните ценности и поведение, разбиране на технологията, както и определяне на силните и слабите страни на компанията. Ето някои стъпки, които да се предприемат за по-успешно усвояване на разрушителните иновации:

1. Правене на периодичен одит.
2. Мониторинг на околната среда на фирмата.
3. Проактивно действие, а също и бързо отреагиране към евентуални промени.
4. Разпознаване на различните видове иновации – познаването на иновацията е критично за прилагането на правилния подход на управление. Различните видове иновации изискват различни видове организационна среда и различни управленски умения. Всяка една от тях представлява различно предизвикателство за фирмата.

Като обобщение може да се изтъкне фактът, че ако менджмънт на фирмата, която въвежда разрушителни иновации, е проактивен, то е необходимо да се изготви план за действие. В тази стратегия ще трябва да бъдат предвидени и взети навременни мерки, което е най-голямата предизвикателство за успех.

5. Библиография

Electrodeposition of copper on cold rolled copper substrate

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Abstract: The microscopic and macroscopic views of copper electrodeposits obtained on plastically deformed copper substrates of different deformation degrees have been investigated. Experiments have been performed under galvanostatic conditions. There appear, depending upon the degree of reduction realized during substrate rolling, three types of deposit: epitaxial, homogenous and texture. Epitaxial growth is observed on unreformed substrate and on the substrates with lesser deformation degree (up to 60%). With the increase of the substrate reduction degree, heterogeneous type of the deposit appeared and the phenomenon of twinning was stated. On very much deformed substrates, as well as in presence of organic additives, field oriented texture type of the deposit is obtained. On very deformed substrates macroscopic uneven deposits appeared, with the linear structure which follows the direction of substrate rolling. Possible explanations of this phenomenon are given.

KEYWORDS: ELECTROLYSIS, MODELING, DEFORMED COPPER SUBSTRATE, COPPER ELECTRODEPOSITS, DEFORMATION DEGREE, UNDEFORMED AND DEFORMED SUBSTRATE, MICROSTRUCTURE, COLD ROLLING

1. Introduction

The form and structure of metal deposits, which were obtained during electrodeposition, depends, first of all, on overpotential of deposition and desorption of ions and molecules from the solution [1]. According to Fischer [2], there are following types of polycrystalline electrodeposits:

- field oriented isolated crystals type, basis-oriented reproduction type, twinning intermediate type, field oriented texture type, unoriented dispersion type:

This points to a fact that structure of the substrate on which electrodeposition takes place, can also influence the structure of the deposit. In practice, the cases show the tendency that the crystallization in the first layer of metal deposit on electrode of the same metal, takes place in the same way in which crystal surfaces of the substrate are oriented (epitaxial growth). This phenomenon also appears during deposition on the substrates made of other metals if crystal lattice parameters don’t differ more than 15%. With the increase of deposit thickness there happens discontinuance of the epitaxial growth. Twinned crystals, and, in some cases, texture appears. Pangarov [1] explains these phenomena by the introduction of the principle of minimal energy.

Examining layers of electrolytic alloys obtained on single-crystal substrates, Lagiewka [3] identified three zones, in which the crystallites counting upwards from the substrate, take epitaxial, twin and random orientations. He developed X-ray method for direct determination of the ratio of the epitaxial zone in electrolytic Cu-Cd alloys layers. Epitaxial zone thickness increases with the increase of the negative potential. Setty and Wilman [4], as well as Bębczuk de Czuminsky [5, 6] have examined electrodeposition of copper on single-crystal copper substrate under galvanostatic conditions. They have come to a fact that for the stated current density, they get thicker epitaxial layers on the (111) substrates, compared with these on a (110) substrate. The preferred orientation during the thin-film growth appear to be due to low interfacial energies. This has been explained by the influence of the surface density of atoms on those surfaces and the corresponding value of free energy.

Shirokoff and Erb [7] studied the epitaxial silver on silicon single-crystals and concluded that obtained preferred orientations are believed to be due to low interfacial energies. Also, the researches on single crystals [8, 9] have been taken into consideration, as well as the investigation by Maizelis et al. [10].

Cysyewski and Allan [11] have done a considerable review of literature dealing with the examination of epitaxial growth of metals on metal substrates by research using field electron emission microscopy. It is especially striking that many cases of metal/metal epitaxy, the dominant factor determining the epitaxial relationship is the alignment of close—packed atomic rows in low-index crystallographic planes of each metal.

In regard to the fact that energetic condition of metal surface is changed during plastic deformation and that crystal lattice deforms also, there has been put an assignment to discover the

Table 1. Plan of passes with hardness measurements

<table>
<thead>
<tr>
<th>No. passes</th>
<th>b (mm)</th>
<th>h (mm)</th>
<th>h/h%</th>
<th>Hardness (HV)</th>
</tr>
</thead>
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<td>Ø15.8</td>
<td>Ø15.8</td>
<td>0</td>
<td>/</td>
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<tr>
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<td>16.9</td>
<td>11.68</td>
<td>26.7</td>
<td>99.7</td>
</tr>
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<td>2</td>
<td>16.96</td>
<td>9.82</td>
<td>37.85</td>
<td>110</td>
</tr>
<tr>
<td>3</td>
<td>17.15</td>
<td>8.7</td>
<td>44.9</td>
<td>110</td>
</tr>
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<td>4</td>
<td>17.08</td>
<td>8.03</td>
<td>49.2</td>
<td>103</td>
</tr>
<tr>
<td>5</td>
<td>17.3</td>
<td>7.23</td>
<td>54.2</td>
<td>122</td>
</tr>
<tr>
<td>6</td>
<td>17.1</td>
<td>6.5</td>
<td>58.8</td>
<td>123</td>
</tr>
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<td>7</td>
<td>17.46</td>
<td>5.8</td>
<td>63.3</td>
<td>114</td>
</tr>
<tr>
<td>8</td>
<td>17.62</td>
<td>5.03</td>
<td>68.2</td>
<td>115</td>
</tr>
<tr>
<td>9</td>
<td>17.95</td>
<td>4.25</td>
<td>73.1</td>
<td>126</td>
</tr>
<tr>
<td>10</td>
<td>18.3</td>
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<td>82.3</td>
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<td>2.1</td>
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<td>20.5</td>
<td>0.72</td>
<td>95.4</td>
<td>127</td>
</tr>
<tr>
<td>15</td>
<td>21.12</td>
<td>0.33</td>
<td>97.9</td>
<td>126</td>
</tr>
<tr>
<td>16</td>
<td>21.77</td>
<td>0.2</td>
<td>98.7</td>
<td>132</td>
</tr>
</tbody>
</table>

- in the third series of experiments, the substrate was made of parts obtained by cutting a sample wire number 16 (with the
deformation degree being 98.7%). Electrodeposition has been carried out the same like the first series, using the synthetic electrolyte without the addition of the organic compounds, at various current densities.

Before the process of electrodeposition, the samples have been prepared in the following manner:
- on each sample, the constant surface of 2 cm² in the middle part has been defined, so that the influence of the effect of the uneven deformation on the sample width has been reduced, and the remnant has been protected by lacquer resistant to carbon-tetrachloride, diluted nitric acid 1:1 and distilled water,
- just before the experiment, the sample has been washed out by carbon-tetrachloride, diluted nitric acid 1:1 and distilled water,
- anodic polishing of the samples has been done by the 50mA current going on for 10 min,
- after anodic polishing, the electrodes were thoroughly washed out by distilled water and sunk in electrolyte, from which electrodeposition of copper has been done and the voltage has been switched on,
- anode is also made of OFHC copper.

After the completed process of electrolytic deposition, the samples were brought out under the voltage from the electrolyte, they were washed out by the distilled water and alcohol and dried in the air. Then, microscopic examination of the texture and metallographic examination of the deposit structure, were done.

Metallographic examination were done transversally to the direction of rolling. The samples were first dipped into polyacrilate mass and then ground on grinding paper, the fineness of which was 3 to 4/0 and polished by alumina. After polishing the structure was “developed” by ferric-chloride.

3. Experimental results

The first group of experiments has been carried out with the constant current density being 50 A/m². As a substrate for electrodeposition the samples marked as 0, 3, 7, 10 and 16 have been used, to which relative reduction of 0%, 44.9%, 63.3%, 77.85% and 98.7% correspond, respectively. In figures 1 to 5 microstructure of the obtained electrodeposits being magnified 500 times, is shown.

In Figure 1 it is given the microphotography of the substrate made of undeformed wire and grains of the deposit which succeed the substrate growth. The deposit is distinctly massive-grained, so partly it has been separated from the substrate during metallographic preparation. Also on the substrate which had 44.9% deformation degree, massive-grained, clearly defined layer of the deposit has been obtained (Figure 2), which has a distinct epitaxial growth as well as on the undeformed substrate.

The grains of the substrate with the 63.3% deformation degree are elongated (Figure 3). The limits of deposits grains are determined by the elongated grains of the substrate, while the grain growth of the deposit is defined by the direction of the electric field.

In Figure 4 the deformed substrate, ε=77.85%, has very elongated grains and transitive type of deposit. Some substrate grains keep on epitaxial growth, while the growth of other grains is under the influence of the electric field direction. It is here that clear twinning of some crystals appears.

Figure 5 shows microstructure of copper electrodeposit obtained on the sample of wire number 16 with relative reduction of 98.7%. The grains of the substrate are so deformed that can be seen only as fibers. The deposit is clearly defined with periodical exchange of somewhat larger grains and grouped dendrites. The growth is totally defined by the direction of electric field. Macrostructure of this deposit in form of longitudinal rows with fine structure (Fig. 6), clearly marks the direction of sample rolling.

This series of experiments which were carried out by the use of synthetic electrolyte without the addition of the organic additives, has shown that epitaxial growth of electrodeposits is getting weaker with growth of the substrate deformation degree. With the considerable degrees of deformation, conditions are fulfilled for the appearance of crystal twinning, and microstructure is no longer homogenous, but linear with rows which follow the direction of rolling.
On undeformed polycrystalline substrate, its influence on the orientation of the deposit is strongest and disappears last. The factors which can earlier end the substrate influence on the form of the deposit are the existence of more concentrated defects, adsorptions etc. With plastically deformed substrates there appears proportional growth of the number of defects, so that epitaxial growth is observed on the undeformed substrate and on the substrates with lesser deformation degree (up to about 60%) and when the number if defects per surface unit gets to a certain value, transitional (heterogeneous) type of crystal growth appears. On surfaces with the biggest deformation degree the quantity of defects is so big that epitaxial growth is completely omitted. However, macroscopic uneven deposit appears, with the linear structure which follows the direction of substrate rolling. Since it is known that plastic deformation always gets to the formation of relief (traces of gliding both on grain edges and inside the grains themselves), the possible explanation of this phenomenon is that defects (which represent the centers of nucleation) haven’t been arranged evenly on the surface of the substrate, but they have been concentrated alongside certain lines parallel to the deformation direction.

The next possible cause is the fact that surfaces are different at certain grains on the surface of the sample. The grains are very much elongated by the plastic deformation, and the rate of the deposition growth is biggest on surfaces with the greatest Millers index values, so the deposit can look as in Fig. 6.

Also, the interesting phenomenon is the appearance of the twins in the deposits obtained on substrates with bigger relative reduction. The phenomenon of twinning in initial stadiums of electrocrystalization of copper on neutral substrates has been described in detail by Mamontov et al. [15, 16]. Sulphate electrolyte and current densities of 1 to 10 A/m² have been used. The deposit consisted of spheroids while their nucleus becomes first, an then in the next stage of growth the periphery of spheroids appears. The defects which result in twinning, appear together with the becoming of embryo.

The appearance of twins in electrodeposit is shown here, also happens at the very beginning of the process. Twin crystals become narrower with the growth (in the direction of electric field) and they end in the form of pyramids, so that they are present in the part of the deposit which is right next to the substrate, while, first of all, the conditions for total epitaxy must be eliminated. This was also noted in literature which treats electrodeposition on single-crystal substrates.

With spheroids, twins appeared on their periphery also. By this analogy, they could be expected in later layers of electrodeposit over epitaxial layer on less deformed substrates.

II group of experiments

In Figure 7 it is shown the microstructure of electrodeposit obtained on the substrate which had relative reduction of 54.2% by the use of electrolytes which contain the organic additives. This deposit looks typically like all electrodeposits obtained under the same condition on the substrates with relative reduction of 37.85 to 95.4%. Starting from the least deformed substrates already, what dominates is the growth of crystals in the direction of the electric field normally to the basic structure – the deposit shows the characteristic texture, so that the typical example of field-oriented texture type of the deposit was obtained. Macrostructure of the deposit is smooth, which is, also, the result of the presence of gelatin and thyocarbamide in electrolyte. It was observed that the number of crystals are so much more tiny as the degree of substrate deformation is bigger.

III group of experiments

The third group of experiments has been carried out on the substrate which had reduction degree of 98.7%. The same electrolyte has been used as in the first group (so, there were no organic additives). The current density varied from 5 to 25 mA/cm². The experiment with 5 mA/cm² belongs to the first series also, and is shown in Fig. 5. In all experiments of the third series, field oriented texture type of the deposit was obtained. The deposit is uneven. In Fig. 8 microstructure is shown, and in Fig. 8a macrolook of the deposit obtained by the current density of 10 mA/cm². In Figs. 9 and 9a, micro and macrostructure of the deposit obtained by the current density of 15 mA/cm² is shown. The deposit has more tiny, the orientation of the grain growth in the direction of electric field is clearer. Somewhat bigger grains of rectangular form alternate with pillar-like crystals. Macrostructure has two layers visually. The layer next to very deformed substrate is defined longitudinally while that layer extends to the layer of considerably rougher grains in the form of notches, little stars and irregular circles. Deposits are grouped in the form of bands – thicker in the middle of the band than on the edge. Twins appear.
4. Conclusion

During electrodeposition of copper from electrolytes which do not contain neutral organic additives on cold deformed copper substrate there appear, depending upon the degree of reduction realized during substrate rolling, three types of deposit: epitaxial, homogenous and texture.

Epitaxial growth is mostly noticeable on least deformed substrates. With the increase of the substrate reduction degree, there becomes heterogeneous type of the deposit, when it was stated a phenomenon of twining, which become narrower with the growth of the deposit. On very much deformed substrates texture type of the deposit appear.

Macrostructure of the deposit which is obtained on very deformed substrates (ε=98.7%) is considerably linear and follows the direction of substrate rolling.

In the presence of organic additives, fields oriented texture type is obtained and tiny-grain structure of the electrodeposit, not depending on the degree of substrate deformation.

5. Literature

Synthesis and investigation of BiTeSe single crystal doped with As obtained using bridgman method

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Abstract: Researches in this paper included synthesis and characterization of bismuth telluride single crystal doped with arsenic, obtained using Bridgman method. Compounds based on bismuth telluride are very important materials for thermoelectric refrigerators and devices for electricity production. For the monocrystal characterization, SEM - EDS, Hall and Van der Pauw method were used. The results presented in paper show the synthesis of monocrystal ingot, BiTeSe doped with arsenic. An analysis of energy dispersive spectrometry (EDS) was used to determine the chemical composition of the samples studied, as well as checking and confirming the homogeneity of the samples. Measurements of X-ray diffraction (XRD) showed that the resulting crystalline ingot represent a single crystal and confirm the compound of Bi2Te3 type. Mobility, concentration, resistivity/conductivity, of majority of charge bearers and Hall coefficient of single crystal, were determined using a Hall Effect measurement system based on the Van der Pauw method. For the sample of BiTeSe doped with arsenic Hall effect was measured at room temperature with an applied magnetic field strength of 0.37 T at different current intensities. Further characterization of the BiTeSe sample doped with arsenic was not performed, because the expected improvement in the mobility of this sample in comparison with the theoretical value of the n type Bi2Te3 was not obtained.

Keywords: BISMUTH AND TELLURIUM SINGLE CRYSTAL, SEMICONDUCTOR, BRIDGEMANN METHOD, DOPING, SEM - EDS, HALL AND VAN DER PAUW METHOD

1. Introduction

Thermoelectric transport properties of doped Bi2Te3 have been examined for a long time [1 - 7]. Special attention has been paid to increase the thermoelectric figure of merit (ZT) for enabling the widespread use of this method for directly converting heat into electricity [8 - 12]. A parameter that evaluates the quality of thermoelectric materials, thermoelectric figure of merit, Z, is determined by the dimensionless value, ZT, [13 -15] which is defined as:

$$ZT = \frac{S^2 \cdot k \cdot T}{\rho} = \frac{S^2 \cdot T}{k \cdot \rho} - \frac{S^2 \cdot T}{(k_e + k_l) \cdot \rho}$$

where: S - Seebeck coefficient, $\sigma$ - electrical conductivity, k - thermal conductivity, T - absolute temperature, $\rho$ - electrical resistance.

Thermal conductivity has two components: electronic conductivity, $k_e$, and lattice conductivity, $k_l$. The ratio $\frac{S^2 \cdot T}{(k_e + k_l) \cdot \rho}$ is defined as the power factor and determines the electrical properties. Combinations of material properties required for thermoelectric materials to have quality and usable properties are also a challenge for scientists.

2. Experimental

Single crystal ingot of Bi2Te3, doped with arsenic was synthesized using the Bridgman method at the maximum temperature of about 600°C. High purity elements (5 N) were used as the source material. Tellurium (Sigma – Aldrich, 99.999%), bismuth (Sigma – Aldrich, 99.99%), selenium (Alfa Aesar, 99.999%) and arsenic (Koch-Light Laboratories Ltd Colnbrook Bucks England, 99.999%) were taken in a certain proportion. The content of Bi, Te, Se and As in sample was obtained using Energy Dispersive X-ray Spectrometry (EDS) method for the Hall and Van der Pauw measurements. The sample was cut from the ingot in normal to the crystallization direction ($\perp$). In the following, this pattern will be referred to as 5/3 ($\perp$). The same sample was used for the Hall and Van der Pauw measurements.

3. Results and Discussion

The sample tested by the EDS method was cut from the ingot normal to the crystallization direction ($\perp$). In the following, this pattern will be referred to as 5/3 ($\perp$). The same sample was also used for the Hall and Van der Pauw measurements.

![Figure 1. Schematic representation of the location from which the 5/3 ($\perp$) sample was cut from the ingot](image)

Concentrations of elements in studied point are function of the peak areas at EDS diagram (figure 2.). The experimental results of EDS chemical analysis of sample 5/3 ($\perp$) are shown in Table 1. The table shows that Se was not detected.

![Figure 2. EDS picture of sample 5/3 ($\perp$)](image)

| Table 1. Results of EDS analysis of sample 5/3 ($\perp$) |
|-----------------|-----------------|-----------------|
| Element | Measurement values (atomic%) | Average value |
| Bi | 16.39 | 20.06 | 17.82 | 21.46 | 23.06 | 20.02 | 17.45 | 19.465 |
| Tc | 68.74 | 74.71 | 63.78 | 62.36 | 62.94 | 62.59 |
| As | 18.89 | 19.63 | 21.88 | 17.36 | 19.56 | 22.72 |
| Se | None |

Full scale = 20.1 k counts
Count: 11.2275 keV
The samples used for measurements were prepared to be in the form of thin disc (Figure 3.) cut perpendicular to the long axis of a single crystal ingot. All samples were carefully inspected for cavities and scratches and polished if necessary. All measurements were carried out at room temperature (T = 300 K). The source of magnetic field applied perpendicular to the Hall element was a permanent magnet of 0.37 T. Hall effect measurements were done to obtain transport properties.

**Table 3.** from the ingot

<table>
<thead>
<tr>
<th>Current intensity I [mA]</th>
<th>Specific conductivity σ [1/Ωcm]</th>
<th>Specific resistivity ρ [Ωcm]</th>
<th>Bulk carrier concentration n_b [1/cm³]</th>
<th>Sheet carrier concentration n_s [1/cm²]</th>
<th>Mobility μ [cm²/Vs]</th>
<th>Average Hall coefficient R_H [cm²/C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>2.447·10⁹</td>
<td>4.086·10⁴</td>
<td>-3.033·10¹⁸</td>
<td>-4.550·10¹⁹</td>
<td>5.036·10¹⁰</td>
<td>-2.058·10⁷</td>
</tr>
<tr>
<td>0.5</td>
<td>2.900·10⁹</td>
<td>3.448·10⁴</td>
<td>-2.575·10¹⁸</td>
<td>-3.862·10¹⁹</td>
<td>7.030·10¹⁰</td>
<td>-2.424·10⁷</td>
</tr>
<tr>
<td>1</td>
<td>2.881·10⁹</td>
<td>3.471·10⁴</td>
<td>-3.044·10¹⁹</td>
<td>-4.566·10¹⁸</td>
<td>5.908·10¹⁰</td>
<td>-2.051·10⁷</td>
</tr>
<tr>
<td>5</td>
<td>2.914·10⁹</td>
<td>3.432·10⁴</td>
<td>-2.442·10¹⁹</td>
<td>-3.662·10¹⁸</td>
<td>7.450·10¹⁰</td>
<td>-2.557·10⁷</td>
</tr>
</tbody>
</table>

The sample 5/6 (λ) of circular cross-section is 1.55 mm thick.

**Figure 3.** Cross-sectional view of a circular sample 5/3 (λ), cut from the ingot

**Table 2.** The results of the Hall and Van der Pauw method for the sample 5/3 (λ)

**Figure 4.** Schematic representation of the location from which the 5/6 (λ) sample was cut from the ingot

### 4. Conclusion

This paper was the result of testing the properties of an arsenic-doped bismuth telluride semiconductor monocrystalline compound. SEM-EDX, Hall's and Van der Pauw's methods were used for material characterization.

An arsenic-doped bismuth telluride monocrystal was synthesized. The electrical properties of this crystal were measured and the mobility and concentration of the majority charge carriers were observed. On the basis of the Hall coefficient, it was determined that in the monocrystal the majority carriers are electrons. The measured electrons mobility was significantly less than the electron mobility in pure bismuth telluride.

The results of these studies show that the arsenic-doped bismuth and tellurium monocrystal was successfully synthesized by the Bridgman method, and significantly complement existing knowledge of bismuth telluride single crystals.

**Acknowledgement**

Authors wish to thank Professor Academician Pantelija Nikolić on big and selfless efforts and assistance in all stages of investigations. As well, authors wish to thank Stevan Vujatović, a specialized technician, for manufacturing high-quality monocrystalline ingot.

### 5. References


Abstract: Beehive made of ceramic is a relatively novel concept in the feed of the beekeeping industry. One of the reasons behind the idea of changing the classical construction material of the beehives is the relatively better thermal conductivity of the ceramic material in comparison with the wooden. Previous field observations show that in wintertime the temperature in the ceramic beehive is with 1°C to 2°C warmer than the temperature measured in a wooden beehive from the same field. The present study aims to examine the thermographic characteristics of a ceramic beehive and to compare them with the most spread wooden type of hives. For the purpose, it was conducted a thermographic diagnostic of three beehives (two ceramic and one wooden) from the same field. The measurement is conducted with a thermal imaging infrared camera. For the analysis is used a licensed software FLIR Reporter Pro. The results of the comparative analysis show that in terms of balanced thermal distribution and creating a better internal environment, the ceramic beehives outperform the wooden one. What is more, the higher porosity of the ceramic material is proved to be a factor in the provision of a balanced thermal environment for the bee family.

KEYWORDS: CERAMIC BEEHIVE, THERMAL BALANCE, THERMAL DISTRIBUTION, BEEKEEPING

INTRODUCTION

The idea for a beehive made of ceramics starts its development in 2012 with the first theoretical research and expert evaluation. In 2014 the prototypes of the beehive are produced and inhabited. The results from the initial experiments have been published in 2019 [1]. This idea inspired by the ancient ways of beekeeping is reasoned with the comparatively better characteristics of the constructional ceramics over the wood. Until they are well known and already proven in the scientific literature, there are still no publications that examine the real living environment which the ceramic tiles structure creates within the beehive. There are several indicators by which it can be evaluated such as temperature and humidity [2].

GENERAL OVERVIEW OF THE PROBLEM

The temperature within the hive is an extremely important factor for the survival of the bees but also for the quality of the bee products. The researches show that the optimal temperature in the breed is around 35-36°C [3]. Higher temperatures can cause the death of the family. Lower temperatures especially temperatures below 0°C will lead to protective diapause behaviour or will have a lethal effect. The extreme temperatures affect the bee products as well. Overheating causes wax melting and too-quick dehydration of the honey [4] while the low temperatures slow down the dehydration of the nectar which causes problems in the production of the honey. The bees have own regulation mechanisms to maintain the healthy temperature of the hive. Whenever the weather is too hot, they start fanning the hot air out or use evaporative cooling mechanisms. If the temperature gets too low they start generating metabolic heat by contracting their flight muscles [5]. Both these mechanisms consume high energy of the bees and increase their need for food.

The specific physics and mechanical parameters of the ceramic material make it more preferable for construction purposes in comparison with the wood. Such are the better isolation properties; the pore “breathing” structure; the homogeneous clay mix which assures equal physical properties at each part of the tile; and the lower percentage of water absorption. This leads us to the assumption that the ceramic material would be a better option for ensuring a more balanced internal environment of the breed. To test this hypothesis, we have conducted a thermographic diagnosis of both ceramic and wooden beehives and compared the results.

METHODOLOGY

For thermographic diagnosis are presented three different beehives – two ceramic and one wooden. The ceramic breeds are 10-frames Dadant-Blatt type of hives. The four walls of the brood box are four ceramic tiles with a high cavity (>66%) which are connected with construction glue on cement basis with fiber filaments. There are some constructive differences between both ceramic samples and the wooden hive. For the purpose of the present study they are labelled respectively Type 1, 2 and 3:

<table>
<thead>
<tr>
<th>Table 1 Test models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brood box</td>
</tr>
<tr>
<td>Type 1</td>
</tr>
<tr>
<td>Type 2</td>
</tr>
<tr>
<td>Type 3</td>
</tr>
</tbody>
</table>

The measurement is conducted with a thermal imaging infrared camera. For the analysis is used a licensed software FLIR Reporter Pro. The measurement is conducted on November 13, 2019, in Chernoosche Village, Haskovo Municipality. The temperature outside is measured three times with Relative Humidity respectively: t= 9°C, RH= 96%; t=10°C, RH= 95%; t= 11 °C, RH= 94%. The results from the capturing are colour images where the brighter tones stand for higher temperatures. For the purpose of the thermal diagnostics at the second stage of the measurement in each hive has been put a heat source (a bottle of hot water) in order to be observed the heat leakage and the heat distribution on the walls. The last stage of the diagnostics is capturing ceramic and wooden hives which are already inhabited with bees on the beekeeping field. The results obtained for all examined hives are compared.

RESULTS AND DISCUSSION

The beehives were first captured in their normal condition without bees inside.
Ceramic beehives: Type one (left) and Type 2 (right)

Wooden beehive Type 3, Front(left and back)

Table 2 Measured temperature in normal conditions

<table>
<thead>
<tr>
<th></th>
<th>Picture 1 [°C]</th>
<th>Picture 2[°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front (T3)</td>
<td>Back (T3)</td>
</tr>
<tr>
<td>Sp1</td>
<td>12.7 (T2)</td>
<td>14.4</td>
</tr>
<tr>
<td>Sp2</td>
<td>12.0 (T2)</td>
<td>12.0</td>
</tr>
<tr>
<td>Sp3</td>
<td>13.0 (T1)</td>
<td>14.6</td>
</tr>
<tr>
<td>Sp4</td>
<td>12.1 (T1)</td>
<td>12.4</td>
</tr>
<tr>
<td>Sp5</td>
<td>12.3 (T2)</td>
<td>14.7</td>
</tr>
<tr>
<td>Sp6</td>
<td>12.7 (T1)</td>
<td>13.5</td>
</tr>
<tr>
<td>Sp7</td>
<td>12.8 (T2)</td>
<td>14.7</td>
</tr>
</tbody>
</table>

Table 2 Measured temperatures when a heat source is put in the hive

<table>
<thead>
<tr>
<th></th>
<th>Picture 3 [°C]</th>
<th>Picture 4 [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp1</td>
<td>17.3</td>
<td>13.0</td>
</tr>
<tr>
<td>Sp2</td>
<td>15.2</td>
<td>13.9</td>
</tr>
<tr>
<td>Sp3</td>
<td>14.6</td>
<td>14.5</td>
</tr>
<tr>
<td>Sp4</td>
<td>15.9</td>
<td>15.2</td>
</tr>
<tr>
<td>Sp5</td>
<td>16.3</td>
<td>11.9</td>
</tr>
<tr>
<td>Sp6</td>
<td>15.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Sp7</td>
<td>16.6</td>
<td>17.0</td>
</tr>
</tbody>
</table>

What can be observed from pictures 1 and 2 and the table with the measured temperature of the external walls leads us to the conclusion that the temperature of on the surface of the ceramic hive is distributed more balanced. The measured temperature in the different points of each ceramic hive have relatively the same values with a very small deviation. Differences are observed in the measured points where the element is made of wood. The entrance reducer of Type 1 is made of metal and this explains the lower temperature measured there. This information can be used for constructional improvements in the future. What we see in picture 2 is that the heat is not equally distributed in the front Dt(Sp1-Sp2)=2.4°C, Dt2(Sp3-Sp4)=2.2°C, Dt3(Sp5-Sp6)=1.2°C and back. The horizontal planes are heated more than the vertical (the walls) which we can say is due to more accumulated sun heat. The temperature differences could be explained with the wood’s higher moisture absorption which accumulates different heat from the air. The higher measured temperature on the walls of the bee hive can be due to sun exposer at the time the pictures have been taken. Considering the results for the temperature on the plane back of the wooden hive, it is obvious that although in one plane, the temperature in the different points is different which can lead us to the idea that there is moisture in the walls.

At the next stage at each of the beehives was put a heat source with the temperature of 39.9°C. The results after that are presented in Pictures 3 and 4 and Table 3.

Immediately before picture 3 was captured the heat source was moved from Type 1 to Type 2. The heat is moving from the internal walls to the internal cavity of the tiles where it heats the air and from there it moves to the external side of the tile. The heat in the two ceramic hives is distributed relatively balanced. The difference in Sp7 (Picture 3) is due to direct contact of the heat source to the hive’s wall. The only imbalance is observed in the roof area which is made of wood. There is high contrast at Sp 1 (Pic.3) which is due to the exfiltration of hot air through the entrance reducer because it is not well compacted. The thermal decline drops significantly. Considering Picture 4, we see that the heat source leads to an increase in the temperature of those zones of the walls which are dyer. The backside of the wooden hive remains relatively cold (Sp5=11.9°C). At this stage of the analysis, we can conclude that for the ceramic hives in both conditions (with and without a heat source) the heat distributes in even pace to all ceramic parts of the hive. On the other hand, the moisture in the wooden brood prevents this to be observed there. The temperature differences in the different parts of a same wall of the wooden hive make the air move which can cause swirling inside the brood. Such would create a disturbance of the bee family.
The last stage of the diagnostics is the comparison between inhabited ceramic and wooden broods. Both of them are on a beekeeping field under the same atmospheric conditions.

**Table 3: Measured temperatures in inhabited ceramic (left) and wooden (right) hives**

<table>
<thead>
<tr>
<th></th>
<th>Picture 5[°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp1</td>
<td>22.4</td>
</tr>
<tr>
<td>Sp2</td>
<td>14.6</td>
</tr>
<tr>
<td>Sp3</td>
<td>14.9</td>
</tr>
<tr>
<td>Sp4</td>
<td>15.9</td>
</tr>
<tr>
<td>Sp5</td>
<td>15.4</td>
</tr>
<tr>
<td>Sp6</td>
<td>14.7</td>
</tr>
<tr>
<td>Sp7</td>
<td>16.0</td>
</tr>
</tbody>
</table>

The highest measured temperature is at point Sp1 which is due to the presence of bees there which have their own temperature so this point will be neglected during the analysis. The picture is taken at 10:58 when the temperature of the air is 9°C, RH=96%, wind <2m/s. The ground of the field is wet because of rain. Despite the high humidity of the air we can see that the heat distribution on the ceramic walls is relatively balanced. For the wooden hive, we see more clearly a difference in the different points of measurement. This can be explained with the accumulated moisture at some parts of the wooden walls and changes the thermal properties of the material. At the image, we observe that the wooden walls are not tempered evenly and homogeneously which is visible from the high contrast zones. Here should be considered the dynamic nature of the evaluated hives. The captures have been done at a given moment which is part of a continuous movement of energy streams which characterizes the energy exchange and interchange of the brood. In the picture, we see that some parts of the wooden hive, as well as the periphery of both roofs are coloured in contrasting red. We can explain this with the moisture which the wood keeps as the water has higher thermal capacity and stores the accumulated heat for a longer period in comparison with the dry wood. In the conditions of thermal transition when a process of heat exfiltration takes place, it is normal for the wet zones to appear warmer than the dry zones. When the walls are ceramic, the thermal transition waste is lower which decreases the need for the bee family to self-produce an additional quantity of heat.

**CONCLUSION**

The results from the present study show that if the classical wooden walls of the brood structure are changed with ceramic tiles with a high cavity, this would increase the thermal comfort of the bee family because it will ensure a balanced environment in the brood. This statement is derived from the fact that the surface heat of the examined ceramic hives is distributed evenly on each tile. The wood and the ceramics have different porosity and they absorb different quantity moisture from the air. The higher moisture resistance of the ceramic walls improves the living environment and decreases the risks of development of different harmful microorganisms. This may reflect also to the quality of the bee products. At the same time, the unbalanced moisture storage of the wooden walls leads to a change of the thermal coefficient of some zones of the walls. Evidence for this are the contrast zones displayed on image 4. The absorbed water changes the thermal properties of the wood and when in the brood is put a heat source, and a thermal difference between both sides of the wall is created, some zones of it remain colder. When the source is removed and the temperature at both sides of the wooden wall is equalized, we observe that the wet zones become warmer than the dry zones. When it comes to the ceramic hives such events are not observed.

Considering the results of the study we can conclude that for the examined hives, the ceramic ones have better and even heat distribution while the moisture absorption is relatively low. Both factors result in a better living environment for the bees, creating conditions for lower energy waste of the family.

**REFERENCES**

Buckling analysis of columns made of functionally graded materials via Rayleigh-Ritz method

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Abstract: This paper presents the buckling analysis of functionally graded (FG) beams. To solve differential buckling equations of different FG sections the Rayleigh-Ritz method is used. The FG material is supposed to vary continuously over the beam depth according to power law. A set of analytical evaluation is run in order to calculate critical buckling loads in dependents of material power low index. The accuracy of method is confirmed comparing the results with the finite element ones.

Keywords: FUNCTIONALLY GRADED MATERIALS, RAYLEIGH-RITZ METHOD, BUCKLING, CRITICAL LOAD

1. Introduction

This paper presents the flexural in plane buckling analysis of functionally graded (FG) beams using the Reyleig-Ritz method. A development of a new kinds of progressive composites such as functionally graded materials (FGM) in recent years is in a rapid increase. FGMs were first conceptualized at 1980s and after that have been very extensively studied by several researchers. Functionally graded materials are a type of composite materials that have a continuous material property change from one surface to another. Contrary to laminated composites, in such a way, the stress concentration is eliminated. FG material is usually made of a mixture of ceramics and metals. The ceramic can resist high temperature in thermal environments, whereas the metal can decrease the tensile stress occurring on the ceramic surface at the earlier state of cooling [1].

The beam structures are extensively used in engineering practice, both in stand-alone forms or as the stiffeners for plate-like or shell-like structures. Due to their slenderness, such structures are generally very susceptible to buckling.

Critical buckling load can be determinate solving the differential equilibrium equations using the approximate methods, based on the energy principal. The one of such methods is well known Rayleigh-Ritz method. The linearized stability analysis is performed in an eigenvalue manner and it attempts to determine the instability load in a direct manner without calculating the deformations. The lowest eigenvalue is recognized as a critical ones and the corresponding eigenvector corresponded to critical buckling mode. There are so many papers dealing with the buckling or vibration of FG beams, only some of that papers are cited here [2-5].

2. Rayleigh-Ritz method

The Rayleigh-Ritz method is based on existence of a relative minimum of the total potential energy at neutral equilibrium.

\[ \delta \Pi = \delta (U - V) = 0 \]  

(1)

where the \( U \) and \( V \) are potentials of internal and external forces.

For the case of in-plane flexural buckling of axially loaded simply supported beam, (see Fig. 1) the internal potential energy can be expressed as:

\[ U = \frac{1}{2} \int \int E(z)I(z) \left( \frac{d\psi}{dz} \right)^2 dz \]  

(2)

while the potential of external forces can be written as:

\[ V = -F_a w_0 = -F_a \int \frac{d\psi}{dz} \left( \frac{d\psi}{dz} \right)^2 dz \]  

(3)

The total potential is:

\[ \Pi = \frac{1}{2} \int \int E(z)I(z) \left( \frac{d\psi}{dz} \right)^2 - F_a \left( \frac{d\psi}{dz} \right)^2 dz \]  

(4)

According to Rayleigh-Ritz method, the beam deflection can be approximate as:

\[ \psi_i(z) = \sum c_i \cdot \phi_i(z), \quad i = 1, 2, 3, ... \]  

(5)

where the \( \phi_i(z) \) are some known function satisfying the boundary condition while the \( c_i \) are unknown constants that should be determinate from condition defined by in equation 1.

![Fig. 1 Buckling of axially loaded simply supported beam](image)

3. Functionally graded material

Supposing the functionally graded material, (see Fig. 2), the elasticity modulus is varied continuously through the beam height direction according to power-law distribution [6]:

\[ E(y) = (E_{top} - E_{bot}) \cdot V_c + E_{bot} \]  

(6)

where subscripts top and bot indicate the top and bottom surface components, and \( V_c \) represent the volume fraction of the ceramic phase, respectively.

The volume fraction can be calculated according to following formula:

\[ V_c = \left( \frac{1}{2} + \frac{y}{h} \right)^p \]  

(7)
where \( p \) is the power-law index.

\[ \frac{\partial^2 \Pi}{\partial c_j} = c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + \\
- F_x c_j \left( \frac{d \phi_i}{dz} \right)^2 dz - F_y c_j \left( \frac{d \phi_i}{dz} \right)^2 dz - \]

\[ \text{(11a)} \]

\[ \frac{\partial \Pi}{\partial c_j} = c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + \\
+ c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz - F_x c_j \left( \frac{d \phi_i}{dz} \right)^2 dz - \]

\[ \text{(11b)} \]

\[ \frac{\partial \Pi}{\partial c_j} = c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz + \\
+ c_j \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} + c_i \frac{d \phi_i}{dz} \right) dz - F_x c_j \left( \frac{d \phi_i}{dz} \right)^2 dz - \]

\[ \text{(11c)} \]

It can be also written in a matrix form:

\[ \begin{bmatrix} A_1 & A_2 & A_3 \\ A_4 & A_5 & A_3 \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} \]

\[ \text{(12)} \]

The coefficients in equation (12) are prescribed by the following integrals:

\[ A_1 = \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} \right) dz \]

\[ \text{(13a)} \]

\[ A_2 = \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} \right) dz \]

\[ \text{(13b)} \]

\[ A_3 = \int_0^l E(z) I_z \left( \frac{d^2 \phi_i}{dz^2} \right) dz \]

\[ \text{(13c)} \]

\[ A_4 = \int_0^l E(z) I_z \left( \frac{d \phi_i}{dz} \right) dz \]

\[ \text{(13d)} \]

\[ A_5 = \int_0^l E(z) I_z \left( \frac{d \phi_i}{dz} \right) dz \]

\[ \text{(13e)} \]

\[ A_6 = \int_0^l E(z) I_z \left( \frac{d \phi_i}{dz} \right) dz \]

\[ \text{(13f)} \]

\[ B_1 = \int_0^l \left( \frac{d \phi_i}{dz} \right)^2 dz \]

\[ \text{(13g)} \]

\[ B_2 = \int_0^l \left( \frac{d \phi_i}{dz} \right)^2 dz \]

\[ \text{(13h)} \]

\[ B_3 = \int_0^l \left( \frac{d \phi_i}{dz} \right)^2 dz \]

\[ \text{(13i)} \]

\[ B_4 = \int_0^l \left( \frac{d \phi_i}{dz} \right)^2 dz \]

\[ \text{(13j)} \]

\[ B_5 = \int_0^l \left( \frac{d \phi_i}{dz} \right)^2 dz \]

\[ \text{(13k)} \]
Using the five parameter polynomial approximation for deflection, as:

\[ v_1(z) = c_1 \cdot \phi_1(z) + c_2 \cdot \phi_2(z) + c_3 \cdot \phi_3(z) + c_4 \cdot \phi_4(z) + c_5 \cdot \phi_5(z) \]  

(16)

where the approximate functions are:

\[ \phi_1(z) = z^p (l - z); \]
\[ \phi_2(z) = z^p (l - z); \]
\[ \phi_3(z) = z^p (l - z); \]
\[ \phi_4(z) = z^p (l - z); \]
\[ \phi_5(z) = z^p (l - z) \]

(17)

Again, the non-triviality condition should be satisfied in order to form buckling equation:

\[ \frac{\partial \Pi}{\partial \xi_i} = 0; \quad \frac{\partial \Pi}{\partial \xi_2} = 0; \quad \frac{\partial \Pi}{\partial \xi_3} = 0; \quad \frac{\partial \Pi}{\partial \xi_4} = 0; \quad \frac{\partial \Pi}{\partial \xi_5} = 0 \]

(18)

where \( c_1, c_2, c_3, c_4, c_5 \) are unknown constants.

For comparison, critical buckling loads for pure materials evaluated via closed form solution formula \( F_{cr} = \pi^2 EI / l^2 \), well known from the strength of materials gives the solutions for the pure metal \( F_{cr,metal} = 488339.8 \text{ N} \) as well as for the pure ceramics \( F_{cr,ceramic} = 89957.3 \text{ N} \). This value well corresponds to the cases of power-law exponent values \( p = 0 \) and \( p = 1000 \).

**Table 1:** Critical buckling loads versus power-law index for the case of simply supported beam

<table>
<thead>
<tr>
<th>( p )</th>
<th>( F_{cr} \text{ [N]} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>488340</td>
</tr>
<tr>
<td>1</td>
<td>289149</td>
</tr>
<tr>
<td>2</td>
<td>222752</td>
</tr>
<tr>
<td>5</td>
<td>156354</td>
</tr>
<tr>
<td>10</td>
<td>126174</td>
</tr>
<tr>
<td>100</td>
<td>93902</td>
</tr>
<tr>
<td>200</td>
<td>91939</td>
</tr>
<tr>
<td>500</td>
<td>90753</td>
</tr>
<tr>
<td>1000</td>
<td>90355</td>
</tr>
</tbody>
</table>

In the second example, for the same beam geometry and material properties, different boundary conditions are considered. One side of the beam is simply supported while the other side is clamped (see Fig. 4.)

**Fig. 4** Buckling of axially loaded simply supported-clamped beam

In this case the total potential is:

\[ \Pi = \frac{1}{2} \int_L \left[ E(z) I^2 (\frac{d^2 v}{dz^2})^2 - F_{cr} (\frac{dv}{dz})^2 + (Q(l - z))^2 \right] dz \]  

(15)

For results validation purposes, the closed form solution formula \( F_{cr} = \pi^2 EI / l^2 \), well known from the strength of materials gives the solutions for the pure metal \( F_{cr,metal} = 488339.8 \text{ N} \) as well as for the pure ceramics \( F_{cr,ceramic} = 89957.3 \text{ N} \). This value well corresponds to the cases of power-law exponent values \( p = 0 \) and \( p = 1000 \).

**Table 2:** Critical buckling loads versus power-law index for the case of simply supported-clamped beam

<table>
<thead>
<tr>
<th>( p )</th>
<th>( F_{cr} \text{ [N]} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>999031</td>
</tr>
<tr>
<td>1</td>
<td>591531</td>
</tr>
<tr>
<td>2</td>
<td>455698</td>
</tr>
<tr>
<td>5</td>
<td>319865</td>
</tr>
<tr>
<td>10</td>
<td>258122</td>
</tr>
<tr>
<td>100</td>
<td>192101</td>
</tr>
<tr>
<td>200</td>
<td>188086</td>
</tr>
<tr>
<td>500</td>
<td>185658</td>
</tr>
<tr>
<td>1000</td>
<td>184846</td>
</tr>
</tbody>
</table>

**5. Conclusion**

In this research, the analytical model for buckling analysis of functionally graded beams is applied. The model is developed on the basis of Rayleigh-Ritz method. This model is capable of predict accurately the critical buckling loading of axially loaded columns with different types of boundaries. The set of analytical evaluations is run in order to find the spectrum of results for different exponential material distribution. Results are presented with the respect to power law exponent values. The results are validated by comparison to closed form formula results for the cases of pure metal and pure ceramic cases. Very good correlation was observed. The proposed method is found to be appropriate and efficient in analysing buckling problem of functionally graded beams. The same method can also be successfully adapted to beam cross sections structured as sandwich with the pure metal or ceramic skins with the functionally graded core as well as to sandwiches with FG skins and pure metal or pure ceramic core.

**6. Acknowledgement**

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7. References

7. Lanc, D; Turkalj, G; Brnić, J; Thuc P. Vo: Nonlinear buckling behaviours of thinwalled functionally graded open section beams, Composite structures, 152 (2016)
1. Introduction

Fatigue life prediction at different temperatures has a profound significance for rubber parts to ensure their reliability and safety. Several studies can be found on the fatigue life of rubber but there is less research into fatigue life prediction considering temperature changes. The fatigue life decreases when temperature increases. Thus, it is necessary to take into consideration the temperature changes during the fatigue process of rubber parts. In the case of rubber materials, different working temperatures will have different influences on the mechanical properties of rubber parts. Furthermore, another type of temperature changing has a significant role in the fatigue process of rubber. Cyclically loaded rubbers exhibit hysteretic response, showed by a stress difference between loaded and unloaded paths, and generated by the presence of the viscous stress in the rubber medium which deviates from the purely elastic response. In this case the temperature changing derives from the conversion of the dissipated mechanical energy (due to the hysteretic effect) into heat energy. The temperature changing may influence the rubber mechanical response due to its thermo-dependence [1].

2. Methods of fatigue analysis in rubber

Two main approaches can be distinguished for analysing fatigue life in rubber components. These are the crack nucleation approach and crack growth approach. Elevated temperature has a deleterious effect on rubber, both on crack nucleation life, and on fatigue crack growth rate. The first approach considers an already existing crack with initial size and predicts the propagation of the crack until fracture (crack nucleation approach). The second approach focuses on predicting the growth of a particular crack (crack growth approach). The strength and limitations of these approaches are presented. Some information presented in this paper has been summarized previously [4,5,6,7]. Thus, this literature overall updates these above-mentioned reviews.

2.1. Theory of crack nucleation

According to the crack nucleation approach the considered material has an effective life which can be determined by the history of stresses or strains. The fatigue crack nucleation life can be determined by the number of cycles which cause the appearance of cracks with a critical size. The earliest academic study of fatigue was done by Wöhler in the 1860s, which was motivated by the understanding of fracture of railroad axles. An affine approach was applied to rubber in the 1940s [9]. There are two notable fatigue life parameters for predicting the fatigue life of rubber: the maximum principal strain and the strain energy density (SED) [8].

2.1.1. Maximum principal strain

Strain can be determined from displacements, which can be easily measured in rubber. Maximum principal strain is based on Cadwell’s research in the 1940’s on unfilled natural rubber. A good correlation was identified between the maximum principal strain and fatigue life in the case of tensile and shear loading of rubber. According to Cadwell, natural rubber has a superior fatigue endurance compared to synthetic rubber. During constant strain amplitudes the life of natural rubber improves as the minimum strain increases. Furthermore, in the case of rubbers that strain crystallize, increasing the minimum strain of the strain cycle can significantly elongate the fatigue life [10].

2.1.2. Strain energy density

Strain energy density proposes that the energy release rate is proportional to the product of SED and the crack size [7,11]. Several investigations can be found in literature which uses strain energy density as a fatigue life parameter in rubber. According to the Roberts and Benzies’s studies in the case of NR and SBR (styrene butadiene rubber), the equibiaxial tension fatigue life is longer than simple tension fatigue life based on equal strain energy density. When the basis of the comparison is the maximum principal strain the result is the opposite. Roach investigated the cause of this above-mentioned difference and he found that all of the strain energy density is available for flaw growth in the case of simple tension, but only one half of the strain energy density is available in the case of equibiaxial tension.

It is important to note the critical plane approaches. The history of parameters associated with specific material planes are used to predict fatigue life in the case of multiaxial fatigue nucleation life of metals. However, in the case of rubber materials, multiaxial fatigue loading effects are not well understood. Compressive loading quite often occurs in the loading history of rubber parts. This type of loading along one direction is always related with simultaneous shear or tensile loading in other directions. Planes perpendicular to an axis of compression experience closure, planes in other directions experience shear or tension. Cracks will grow and nucleate on these planes.

2.1.3. Cracking energy density

The cracking energy density (CED) is part of the total elastic strain energy density, but concentrates on the energy available to a specific material plane during crack growth. CED is defined as the increase in energy density as the material is subjected to a fatigue load cycle:

\[ dW_c = t \sigma \varepsilon, \quad T = T_c \]

(1)

where \( t = \sigma \varepsilon \) is the traction stress on the plane with normal \( r \), and \( dW_c = d\varepsilon \varepsilon' \) is the change in traction strain on the plane. The energy in this plane is the portion of energy available to be released on a material plane.
To conclude, the classical crack propagation approach assumes a pre-existing crack, which grows until it reaches a failure size. This classical approach is difficult to use for rubbers, as the location of crack initiation could be hard to predict if only the principal strain and strain energy density is known. CED has been shown to be superior to the peak engineering strain as well as the energy density. CED gives superior results when fitting geometries with complex loading histories to a Wöhler curve, however CED is computationally expensive. It means iterating over a finite number of crack orientations in each element of a finite element model. The three fatigue evaluation criteria are compared in Table 1.

<table>
<thead>
<tr>
<th>Strain energy density</th>
<th>Maximum principal strain</th>
<th>Cracking energy density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depend on material</td>
<td>Depend on material and geometry</td>
<td>Less depend on material and geometry</td>
</tr>
<tr>
<td>Worst correlation</td>
<td>In simple load cases</td>
<td>Complex load cases</td>
</tr>
<tr>
<td>Easy computing</td>
<td>Easy computing</td>
<td>High computation times; Implementation must be developed</td>
</tr>
</tbody>
</table>

### Table 1: Comparison of fatigue life prediction parameters

#### 2.2. Theory of crack growth

Several studies had gone into understanding the evolution of fatigue cracks in rubber materials. The crack growth theory considers pre-existing cracks or flaws. According to Griffith’s theory, the fracture criterion based on an energy balance including the mechanical energy of a cracked body and the energy associated with the crack surfaces. This approach was further developed for rubber by Thomas, Lake, Greensmith, Mullins and Rivlin. Thomas extended this approach to analyse the growth of cracks under cyclic loadings in NR [12]. Thomas developed a square-law relationship between peak energy release rate and crack growth rate for unfilled natural rubber.

The cause of the growth of a crack microscopically is the crosslinks between the polymer chains in the rubber structure. These crosslinks are weak bonds and tear apart during subjected to high loads, as presented in Figure 1.

![Crosslinks](image)

**Fig. 1 Crosslinks between the polymer chains when subjected to high loads. Adapted from [13]**

The potential energy in rubber released from surrounding material is spent on reversible and irreversible changes to create new surfaces, according to Griffith’s study. The crack growth is associated with new crack surfaces due to the conversion of a structure’s stored potential energy. The growth of a fatigue crack is measured by the energy release rate, \( T \). It means the measurement of the change in stored mechanical energy \( dU \) per unit change in crack area \( dA \).

\[ T = \frac{dU}{dA} \quad (2) \]

The energy is denoted \( T \), referring to the tearing energy required under static load. The crack growth rate is determined by the maximum energy release rate during pulsating loading [13]. Examples were studied by Greensmith and Lindley in which a single edge cut specimen with a crack of initial size \( a_0 \) subjected to tensile loading. The energy release rate was estimated as a function of the strain energy density, \( W \), crack size \( a \), and coefficient \( k \), which is a function of the principal engineering strain.

\[ T = 2kWa \quad (3) \]

#### 2.2.1. Typical regimes of fatigue crack growth

Lake and Lindley distinguished four regimes of fatigue crack growth behaviour in rubbers as shown in Figure 3, based on the maximum energy release rate per cycle, \( T \), for \( R=0 \) cycles, for unfilled NR and SBR [14].

- **Regime 1**: the crack growth rate \( da/dN \) below \( T_0 \) threshold is independent of the mechanical loading, and crack growth rate is independent of the energy release rate, \( T \). \( T \) is the rate at which energy per square unit is dissipated during fracture of the newly created fracture surface area. It means that rubber has no endurance limit. Furthermore, strain crystallization is a phenomenon that is specific to NR, and it is the primary cause of its unique superior fatigue resistance. Strain crystallization appears during compressive loading, which can have a retarding effect on crack growth rate by crystallization of the crack tip.

![Four regimes of fatigue crack growth and their relation to the energy release rate](image)

**Fig. 2** Four regimes of fatigue crack growth and their relation to the energy release rate. Adapted from [14]

- **Regime 2**: is a transition range of \( T \), between \( T_0 \) and \( T_c \), described by the following relationship, in which \( A \) is a material property.

\[ \frac{da}{dN} = A(T - T_0) + r, \quad T_0 \leq T \leq T_c \]

- **Regime 3**: is a range between \( T_c \) and \( T_e \) over which the relationship between the energy release rate and the fatigue crack growth rate suffice a power-law, where the material properties are \( B \) and \( F \).

\[ \frac{da}{dN} = BT^p, \quad T_c \leq T \leq T_e \]

Regime 4: beyond \( T_e \), unstable crack growth regime follows, where the crack growth rate is infinite.
Several models have been developed to describe the last three regions with one relationship. The Crack-Layer theory for rubber is a single relationship that predicts regimes 2, 3, 4, for loading. This theory was developed by Aglan and Moet and is based on the irreversible thermodynamics of an “active zone” preceding the crack tip [15]. This is the most often used method of estimating life in practical applications, and there can be found many researches on obtaining power laws based of different geometries and load cases. There has not been found any unified method that accounts for the different fatigue effects of rubber. Fatigue correlations always depend on the geometry and composition of the specimen, the temperature, aging, and loading sequence order.

3. Temperature effects on the mechanical and fatigue properties of rubber

Owing to their superior ability to good wear resistance and tear resistance, rubber materials are widely used in the automobile industry. For rubber materials, on the one hand, different working temperatures will have different influences on their mechanical properties. This is the first type of temperature changing. On the other hand, cyclically loaded rubbers exhibit hysteretic response, manifested by a stress between loading and unloading paths, and generated by the presence of the viscous stress in the rubber medium which deviates from the purely elastic response. A significant part of the dissipated mechanical energy due to the hysteretic effect may be converted into heat energy which manifests itself in the form of temperature changing. In the following section, the effect of temperature on the mechanical and fatigue behaviour of rubber will be investigated according to the state of the art.

Table 2: Effect of temperature on the mechanical and fatigue behavior of rubber

<table>
<thead>
<tr>
<th>Framework</th>
<th>Investigated property</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars and Fatemi</td>
<td>Elastic response of rubber</td>
<td>depends on temperature.</td>
</tr>
<tr>
<td>Treloar</td>
<td>Crystallinity</td>
<td>is limited by temperature.</td>
</tr>
<tr>
<td>Lu et al, Lake and Lindley</td>
<td>Fatigue resistance</td>
<td>decreases when temperature increases.</td>
</tr>
<tr>
<td>Zhang et al.</td>
<td>Thermal-oxidative ageing (sulfur bond failure and recombination)</td>
<td>accelerates when temperature increases and it leads to decay its antifatigue property.</td>
</tr>
<tr>
<td>Rueellan et al.</td>
<td>Fatigue life reinforcement due to SIC</td>
<td>is affected by temperature.</td>
</tr>
<tr>
<td>Zhang et al.</td>
<td>Elastic response of rubber</td>
<td>decreases SIC (strain induced crystallization)</td>
</tr>
<tr>
<td>Mars and Fatemi</td>
<td>Rate-independent hysteresis</td>
<td>depends on temperature.</td>
</tr>
</tbody>
</table>

When the working temperature increases, the thermal-oxidative aging reaction of rubber materials will accelerate. Zhang et al. carried out fatigue tests at elevated temperature which generated thermal and thermo-oxidative aging [12].

To conclude there are some areas in which future progress can be made, i.e.: in the area of SIC there are two unanswered questions: which are the conditions of fatigue-induced SIC and what is the minimum crystallinity level required to ensure reinforcement?

4. Prediction methods of fatigue life

Fatigue life prediction due to temperature changes has a substantial significance for rubber components to ensure their reliability and safety. There are several studies on the fatigue life of rubber materials, but there is less research into fatigue life prediction considering temperature factors. Several scholars have performed their research on the prediction of rubber fatigue life.

- Zhang et al. established a fatigue life prediction model with strain energy as damage parameter and the fatigue characteristics under different temperatures are predicted by the relationship between their model parameters and temperature [12].

- Fatemi and co-workers determined a prediction method for rubber components in which the maximum principal strain was used as a damage criterion, and Miner’s linear cumulative damage rule was applied based on the crack initiation life and fatigue crack growth [18].

- Woo et al. applied finite element analysis and life prediction of the rubber composites by using Green-Lagrange strain as fatigue damage parameter [13].

To conclude: the fatigue life forecast by the prediction models was compared with the experimental life, that showed that the prediction model which used the effective stress as damage parameter had the best accuracy [14].

At present, the prediction of rubber fatigue life under the influence of temperature is faced with two major difficulties. First of all, it is necessary to execute the suitable fatigue test and establish a model to analyse the fatigue characteristics of such parts because of the large variation of working temperature and complex loading conditions. Secondly, it is difficult to create the relationship between temperature and fatigue life model to predict the rubber fatigue life at different temperatures.

4.1. Prediction methods of fatigue life under the influence of temperature

Mars and Fatemi presented that the fatigue life of rubber material changes with temperature. Neuhaus et al. carried out fatigue tests to study the influence of chemical and thermal aging. Shangguan et al. established three kinds of fatigue life prediction models at different temperatures using the engineering strain as damage parameter [8].

These studies investigate the fatigue characteristics under the influence of temperature, but no model was established to demonstrate the relationship between temperature and fatigue life prediction.

Table 3 contains and summarizes the fatigue life prediction methods for rubber materials and fatigue life prediction methods in consideration of the effects of temperature [9].

Table 3: Fatigue life prediction methods of rubber

<table>
<thead>
<tr>
<th>Framework</th>
<th>Prediction method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars and Fatemi</td>
<td>Investigated that the fatigue life of rubber material changes with temperature.</td>
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<tr>
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<td>Established three kinds of fatigue life prediction models</td>
</tr>
</tbody>
</table>
at different temperatures using the engineering strain as damage parameter.

Fatemi et al. Applying damage criterion: maximum principal strain and Miner’s linear cumulative damage rule and using FEA.

Woo et al. FEA and life prediction of rubber composites by using Green-Lagrange strain as fatigue damage parameter.

Suryatal et al. Predicted the fatigue life of a railway elastomeric pad by combining the experiment of material properties and using the Mooney-Rivlin model for FEA. Maximum first principal elastic strain was selected as fatigue damage parameter.

Seichter et al. Summarized the advantages of fatigue crack growth theory.

Wang et al. Computed three fatigue damage parameters by finite element method, namely: logarithmic principal strain, Cauchy principal stress and strain energy density for fatigue life. Their prediction model is based on the least-square method.

Shangguan et al. Predicted the fatigue life of rubber isolator by choosing and analysing different fatigue damage parameters.

Zhang et al. Proposed a prediction model with temperature as the dependent variable and predicted the fatigue life of rubber materials at different temperatures.

Very few contributions dealing with the thermomechanical constitutive modelling of polymers. Most of these papers do not investigate the temperature changing due to dissipative heating. Guo et al. defined network thermal kinetics and network damage kinetics and used to alter the relaxed network during fatigue loading process. In order to take into consideration the rubber network properties, the relaxed free energy function is defined by Arruda and Boyce in this model. The average chain length and the average chain density are taken as functions of the temperature and fatigue level required to ensure damage [25, 26].

5. Concluding remarks

This paper summarized the influence of temperature and temperature changes on the fatigue behavior of rubber and provided an overview of the state of the art on the fatigue life prediction of rubber with primary focus on the different methods available for prediction of fatigue life under the influence of temperature and temperature changes. To conclude there are some areas in which future progress can be made, i.e.: in the area of SIC there are two unanswered questions: which are the conditions of fatigue-induced SIC and what is the minimum crystallinity level required to ensure reinforcement? Furthermore, the prediction of fatigue behavior under complex mechanical loading histories has not been cleared, because multiaxial effects on crack nucleation life are not investigated. It is necessary to integrate environmental factors into fatigue life predictions. Models for the effects of temperature must be integrated with predictions on mechanical load history. Guo et al. developed a new approach which is able to predict the fatigue thermomechanical response in rubbers, and in which the authors used the Arruda-Boyce model to determine free energy functions. The question is raised what are the results of this approach using other models to predict the fatigue thermomechanical response [9].

This study is the basis of the following research which will include the modelling of the temperature-changing induced fatigue behaviour and fatigue life prediction of rubberlike materials by using self-developed finite element code.

Acknowledgement

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References


Alkali and acid activated geopolymers based on iron-silicate fines - by-product from copper industry

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Abstract: Geopolymer based on iron-silicate fines (fayalite slag) were synthesized in alkaline and acidic media using activation solution comprised of respectively alkali silicate and phosphoric acid solutions. The raw material consists of fayalite, magnetite and pyroxene which could be a conglomerate in some particles. The alkali activation occurs very slow at room temperature, while acid activation take place very rapid. The acid activated geopolymer binder phase include cracks probably formed by thermal gradient because of the rapid exothermal reaction. The morphology of the alkali activated geopolymers were presented by porous structure.

Keywords: GEOPOLYMER, IRON-SILICATE FINES, FAIALITE, IRON-RICH SLAG, ALKALI, ACID, COPPER

1. Introduction

The total copper content of world mine production was 22.046 thousands of short tons copper for 2017 [1]. The slag from the flash furnace and the converters contains residual copper which is extracted through grinding and flotation. Two products are produced at the flotation plant: flotation copper concentrate and flotation product called iron-silicate fines. The flotation product is deposit into flotation pond or been processed as pressing to decrease water content to about 10-12% humidity prior to landfill deposition or utilization. The main mineral phase of the iron-silicate fine material is fayalite, hence the material is commonly named fayalite slag. The fayalite slag is powder material with high content of iron in the form of minerals fayalite, magnetite. There is no economic reason to extract the iron from the slag at this level of technology advance. The slag is barely usable, because of its specific fineness, high weight, contamination of heavy metals, etc. However, fayalite slag is marketable as a road surface, Portland cement production and concrete additive. Still huge amount of the produced iron-silicate fines remains unutilized deposited in landfills. With this in mind, geopolymer technology is potential solution to this rising problem.

Geopolymers are a class of inorganic polymer materials with amorphous or semi-crystalline three-dimensional structure [2]. The geopolymer materials possess high compressive strength, chemical resistance, thermal and fire stability [3], low CO₂ footprint, possibility of utilizing industrial waste materials, etc [4]. There are other names describing the same or similar materials, including the terms: “alkali-activate material”, “alkali-bounded-ceramics”, “hydroceramics”, “inorganic polymer concrete”, “alumino-silicate inorganic polymer”, etc [5]. However, these materials seem promising and they are potential alternative of conventional Portland cement and ceramics.

The term ‘geopolymer’ was coined by Joseph Davidovits. There are two routes of geopolymer synthesis: in alkaline medium using alkali hydroxides and silicates; and acidic medium with phosphoric acid [2]. Depends on the precursors and synthesis route following terminology was adopted to describe geopolymers comprised by following molecular units (or chemical groups):

- Si-O-Si-O-siloxo, poly(siloxo)
- Si-O-Al-O-sialate, poly(sialate)
- Si-O-Al-O-Si-O-sialate-siloxo, poly(sialate-siloxo)
- Si-O-Al-O-Si-O-Si-O-sialate-disiloxo, poly(sialate-disiloxo)
- P-O-P-O-phosphate, poly(phosphate)
- P-O-Si-O-P-O-phospho-sialate, poly(phospho-sialate)
- P-O-Si-O-Al-O-P-O-phospho-sialate, poly(phospho-sialate)
- (R)-Si-O-Si-O-(R) organo-siloxo, poly-siloxone
- Al-O-P-O-alumino-phospho, poly(alumino-phospho)
- Fe-O-Si-O-Al-O-Si-O-ferro-sialate, poly(ferro-sialate) [6].

The geopolymers are two component binder: main powder material and activator solution. The most common activation solution is mixture of sodium silicate and potassium/sodium hydroxide [4], [7]. Recent studies of Nikolov showed suitable activator concentration to prepare alkali-activated geopolymers based iron-silicate fines [8]. The material hardens slowly at normal temperature. Additional, alkali activation of similar slags were also studies by: Komnitsas et. al [9]-[11]; Maragkos et. al using Greek ferronickel slag [12]; and the research team of the University of Leuven using Belgium fayalite slag [13], [14].

So far limited studies were found on acid activation fayalite or similar slag. Nikolov et. al used same Aurubis fayalite slag [15] to synthesis geopolymers and Katsiki et. al used Belgium fayalite slag [16] to prepare geopolymer (inorganic polymer), both with up to 19 MPa compressive strength. The phosphate activation acts very rapid with setting time within a minute.

In the present study geopolymers based on fayalite slag (iron-silicate fines) were synthesized by two routes: in acid media with phosphoric acid solution and in alkaline media – using sodiumsilicate and potassium hydroxide solution. The purpose of the study is to compare the differences of using acid or alkaline activator solution.

2. Experimental

3.1. Method of analysis

The chemical composition of the iron-silicate fines (fayalite slag) was determined by XRF using Panalytical Axios Max WD. Powder X-Ray diffractograms (XRD) were produced with a Bruker D-8 Advance instrument with Bragg-Brentano geometry, using a CoKα source. The optical properties of the raw fayalite was studied in polished specimen using light polarized microscope Leitz Orthoplan. SEM images were obtained with different magnification by using electron microscope JEOL 6390, INCA Oxford analyzation and energy disruptive spectroscope (EDS).

2.2. Materials

The geopolymer precursor was iron-silicate fines from local copper plant – Aurubis, Bulgaria. The iron-rich fayalite precursor was dried to constant mass in oven at 105 °C. The chemical and mineral composition are presented below.

The activator solutions were prepared by using solid KOH pellets, sodium silicate (SiO₂/Na₂O=3), orthophosphoric acid (H₃PO₄) and tap water. The ingredients were mixed by magnetic stirrer and tempered prior usage as activator.

2.3. Geopolymer synthesis

The geopolymers in the presented study were prepared based on previous works [8], [15]. The composition of the prepared geopolymer pastes is presented by molar ratios as follows: alkali activated (series 15F3) H₂O/M₂O=11.40, Fe₂O₃/M₂O=4.00, Al₂O₃/M₆O=0.50; acid-activated FeO/P₂O₅=3.76; H₂O/P₂O₅=1.71, (where M is K + Na). The water to solid ratio of the mixtures were respectively 0.15 and 0.196 in order to obtain workable mixtures. The alkali-activated homogenized mixture was...
poured in metal cubic moulds (3.17 mm) and was placed in plastic bags in laboratory conditions (23 °C, w=65%). On 28th day was demoulded because of the slow strength gain. Other hand, acid-activated geopolymers showed rapid setting. The mixtures were homogenized for 30 s and placed in cylindrical plastic container (50x30mm). In 1-2 minute the mixture was hard enough to demould. Still it was demoulded after 1 hour tempering because of high exothermicity of the reaction and possibility of detrimental temperature gradient during cooling.

3. Results and Discussion

3.1. Characterization of the raw material

The chemical composition of the geopolymer precursor was determined by XRF and the results are presented in Table 1. The results from powder XRD examination showed that the geopolymer precursor consists of fayalite, magnetite and small amount of pyroxene (Figure 1). The main phase fayalite is end member of the olivine group. The Fe and Mg can substitute freely for one another in the mineral’s atomic structure. In detailed observation with optical microscope of polished specimens made of powder in epoxy resin, it was visible that some particles were conglomerate of magnetite, fayalite and pyroxene (Figure 2). This phenomena makes the magnetic separation of the different mineral phases inconvenient. The chemical point analysis in SEM-EDS showed the difference in chemical composition of a particle (Figure 3).

<table>
<thead>
<tr>
<th>Fe2O3</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>CaO</th>
<th>ZnO</th>
<th>MgO</th>
<th>K2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>58.42</td>
<td>29.34</td>
<td>4.40</td>
<td>2.66</td>
<td>1.32</td>
<td>0.89</td>
<td>0.71</td>
</tr>
<tr>
<td>Na2O</td>
<td>CuO</td>
<td>PbO</td>
<td>TiO2</td>
<td>MoO3</td>
<td>SO3</td>
<td></td>
</tr>
<tr>
<td>0.58</td>
<td>0.49</td>
<td>0.37</td>
<td>0.30</td>
<td>0.27</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Powder XRD curve of the geopolymer precursor - iron-silicate fines (fayalite) from Aurubis, Bulgaria. F - fayalite, M – magnetite, P – pyroxene.

Figure 2. Optical microscope image of the raw material - iron-silicate fines (fayalite) from Aurubis, Bulgaria

3.2. Alkali and acid activated geopolymers

The XRD results did not show any significant differences between raw material and hardened geopolymer, so they are not presented. The main phases stayed mostly inert, for little exception of fayalite, which probably was partly dissolved based on small decrease of it intensities compared to magnetite.

On Figure 4 are presented SEM-EDS images of hardened acid (a,b) and alkali (c,d) activated geopolymers. In both geopolymers it was observed that particles of magnetite and fayalite act as inert filler. In acid activated geopolymers there was more visible geopolymer binder phase between filler particles characterized by 7-11% phosphorous content (point 1 and 2, Figure 4 – a). The newly formed geopolymer gel was homogenous with difference in elemental composition which is visible by brighter spots on backscattered scanning electron image (Figure 4 – b). However, the binder phase include many cracks probably formed by thermal gradient because of the rapid exothermal reaction.

The morphology of the alkali activated geopolymers differentiate significantly from the acid activated. The structure was very porous. The alkali-activation geopolymers represent a heterogeneous material composed of geopolymer gel matrix and partially reacted or unreacted particles. The high alkalinity and long hardening process lead to partly dissolution of the precursor particles. Bigger particle reacted only on surface. On Figure 4 – d, Point 3 was probably geopolymer gel which was characterized by higher K and Na content and homogenous texture.

4. Conclusion

The presented studies showed that iron-silicate fines form local copper industry could be successfully used as geopolymer precursor synthesized in both acidic or alkaline media. The raw material consists of fayalite, magnetite and pyroxene which could be a conglomerate in some particles, which makes the magnetic separation of the different mineral phases inconvenient. Further more detailed studies are needed to develop materials with practical application.
5. Acknowledgement

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6. References

Synthesis and application of new nanostructured materials for the degradation of organic pollutants from municipal landfill leachate

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Abstract: The photocatalytic degradation of pharmaceutically active compounds, persistent contaminants in aquatic media, based on advanced oxidation processes was the subject of investigation. The study evaluates application of three different nanopowder mixtures (ZnO/SnO2, ZnO/TiO2 and ZnO/In2O3) for decomposition of diclofenac, naproxen, ibuprofen and ketoprofen, some of frequently detected pharmaceuticals in wastewaters and landfill leachates. The phase morphology, composition, specific surface area, crystalline structure and optical properties of the newly synthesized nanopowders, prepared by three step mechanochemical solid-state treatment, were characterized in detail. Effects of optimization parameters on degradation rate were examined and a set of experiments were performed in order to investigate influence of catalyst concentration (0.10–0.60 mg mL-1), pH values of ambience (5-9) and initial concentration of pharmaceuticals (0.002–0.010 mg mL-1) for this purpose.

Keywords: PHOTOCATALYSIS, NANOPOWDERS, ZnO, PHARMACEUTICALS

1. Introduction

Removal of pharmaceutically active compounds is of a great importance considering that pharmaceutical pollutants are persistent contaminants in aquatic media and that conventional treatment plants are inefficient for their removal [1-3]. Advanced oxidation processes (AOPs) represents an efficient method for treating a wide range of emerging pollutants in municipal effluents and landfill leachates [4 - 9].

Diclofenac, naproxen, ibuprofen and ketoprofen are some of the commonly used NSAIDs (non-steroidal anti-inflammatory drugs) and some of the most frequently detected emerging pollutants (EP) in water matrix. Unlike the vast majority of water pollutants (phenols, phthalates, PCBs etc.) pharmaceutical molecules bear certain differences in their molecular structure which render them less amenable to photodegradation. To alleviate this problem, presented project has been conducted in order to investigate the possibility of application of modified mixed oxides for better photocatalytic activity. Moreover, investigation has aimed to optimize to photodegradation conditions and degradation of mixtures of pharmaceutical.

Fig. 1 Synthesis procedure for mixed nano-powders

2. Materials and Methods

Mixed nanopowder photocatalysts were prepared using a simple, low-cost, and three-step mechanochemical solid-state method. Starting precursors (Sigma Aldrich, purity 99.9%) were grounded in an agate mortar, annealed at 700°C in air for two hours and grounded again for 10 min (Figure 1). ZnO/SnO2, ZnO/TiO2 and ZnO/In2O3 nanopowders are prepared bearing in mind that previous investigations have pointed put to ZnO’s superior photocatalytic properties and enhanced solubility even at slightly acidic pH solutions, being therefore not the best choice for real life PC applications [8]. In this sense, the ZnO based mixtures emerge as good candidates in the search for alternative materials that compromise the above properties, i.e. PC activity and chemical stability.

The phase morphology, composition, specific surface area, crystalline structure and optical properties of the newly synthesized nanopowders, prepared by three step mechanochemical solid-state treatment, were characterized in detail. The morphology of the powders was characterized by field-emission scanning electron microscopy (Figure 2). X-ray diffraction (XRD) was carried out using Rigaku Miniflex 600 instrument, with CuKα radiation, and a step scan mode with 0.02° step and a dwell time of 2 s in the angular range 20–100°. The 441.6 nm laser line emerging from a He-Cd laser was used to excite Raman spectra. Light was focused by an objective (50×) while the same objective was used to collect the backscattered light which was analyzed by a single monochromator (Labram HR800, Jobin-Yvon) and detected by a liquid-nitrogen cooled CCD detector. Diffuse reflectance spectra of obtained samples were recorded by a double-beam UV/VIS/NIR Perkin-Elmer spectrophotometer (model Lambda-950) in the spectral region from 300 nm to 1500 nm using an integrating

Fig. 2 SEM image of a) ZnO/In2O3 b) ZnO/SnO2
sphere. Spectral parameters were used for estimating the optical bandgap of the materials. The specific surface area of the samples was measured with a N2 adsorption analyzer (Micromeritics Gemini) by using the Brunauer-Emmett-Teller (BET) method. Detailed results of previously described investigations are published in References [5,6]. The photocatalytic decompositions of chosen pharmaceuticals were carried out at ambient temperature in aqueous solution in batch mode. The stock solution of the analyzed pharmaceutical was prepared by dissolving 5 mg of standard in 25 ml of acetonitrile (200 mgL-1). Distilled water was used as the aqueous model. The aqueous solution was stirred for 1 h in the dark to establish adsorption-desorption equilibrium between the pharmaceutical and photocatalyst before being irradiated. The aqueous solutions were exposed under continuous UV irradiation. The source of the UV light was high-pressure mercury lamp (Philips, HPL-N, emission bands in the UV region at 304, 314, 335, and 366 nm, with maximum emission at 366 nm). UV source flux was measured by Lutron YK-35UV UV meter (Figure 3).

![Fig. 3 Lutron YK-35UV UV meter](image)

The solutions were stirred with the aid of a magnetic agitator at 130 rpm. In order to investigate the change in composition of the investigated pollutants, aliquots were collected at certain time intervals (5, 10, 20, 30, 40, 50, 60 and 90 minutes). Each sample was filtered through filter in order to separate the nanoparticles from the solution. After the filtration step, 1 ml of sample was transferred into 2 ml vials.

![Fig. 4 HPLC Agilent 1260](image)

A HPLC (high performance liquid chromatography) with diode array detector (Agilent 1260 series) was used for the measurement of diclofenac, ibuprofen, naproxene and ketoprofen concentrations after photocatalytic degradation. Chromatography separation was performed at reverse, stationary phase Eclipse XDB-C18 (150 x 4.6, particle size 5µm) at flow rate of 0.8 mL min⁻¹ and injection volume of 10 µL at room temperature. Mobile phases consisted of: A (50%) – 0.1 formic acid and B – acetonitrile in 7 minute initial conditions. The stationary phase temperature is 25 °C. Effects of optimization parameters on degradation rate were examined and a set of experiments were performed in order to investigate influence of catalyst concentration (0.10–0.60 mg mL⁻¹), pH values of ambience (5-9) and initial concentration of pharmacies (0.002–0.010 mg mL⁻¹) for this purpose.

3. Results and Discussion

The degradation kinetics of investigated pollutants was quantified by fitting the experimental data with the Langmuir-Hinshelwood (LH) model [10, 11] where the concentration change depends logarithmically on time:

\[ \ln\left(\frac{c_0}{c}\right) = kt \]

where \( k \) is the rate constant and \( c, c_0 \) are the analyte concentrations before and after UV irradiation, respectively. Figure 5. shows, as an example, degradation rate of NPX dependence on time. The experiment was performed in mixture of all investigated pharmaceuticals and the used nano-powder was The line is a linear fit, according to LH model.

![Fig. 5 NPX degradation rate dependence on time in mixture of pharmaceuticals. Linear fit is according to the Langmuir-Hinshelwood (LH) model. (nanostructured photocatalysts ZnO/TiO₂)](image)

It is important to emphasize here that presence of other pharmaceutical significantly influences degradation rate and that degradation rate varies greatly for different organic pollutant (Figure 6). E.g. in upper case of NPX, if NPX was a sole pollutant in matrix, under the same conditions, degradation rate was significantly higher, namely, 0.076 s⁻¹ [6].

![Fig. 6 Comparison of degradation rates of investigated pollutants (LH model.; nanostructured photocatalysts ZnO/TiO₂)](image)
Overall, comparing the performance of all three nanostructured photocatalysts ZnO/TiO$_2$ is by far the best choice for the photodegradation. This mixed nano-powder combines the efficiency of ZnO and chemical stability to in the acidic environment, which is usual in environmental aquatic matrix. Moreover, investigation of influence of pH has shown that in case of ZnO/TiO$_2$ the highest degradation is achieved at non modified aquatic medium. Under acidic and alkaline conditions, as well as in values of the initial concentrations of pharmaceuticals outside the interval of 4-5 mg L$^{-1}$, ZnO/SnO$_2$ is a better choice [5, 6].

3. Future perspectives

As it has been previously reported in [12], investigations conducted within the acknowledged project showed that most frequently detected substance in landfill leachate in Subotica, Zrenjanin, Sombor, Sremska Mitrovica and Novi Sad, Autonomous Province of Vojvodina, Republic of Serbia, which is present on NORMAN list of Emerging substances is bisphenol A. In addition, bisphenol A has a huge potential for contamination and threatening groundwater due to its physico-chemical characteristics, especially persistency. Leachate analysis of five landfills showed a presence of different organic and inorganic constituents such as phthalates, benzothiazole and benzene-sulfonamide. Figure 7 shows example chromatograph of landfill leachate in Zrenjanin.

![Example chromatograph of landfill leachate in Zrenjanin](image)

Fig. 7. Example chromatograph of landfill leachate in Zrenjanin [13].

For efficient removal of these types of emerging compounds and organic pollution, it is necessary to apply other treatment processes such as photocatalytic degradation process, whose application has showed high efficiency in case of selected pharmaceuticals.

4. Conclusions

Due to the existing data on presence of pharmaceuticals and other persistent and pseudo-persistent organic compounds in the landfill leachate, more effective treatment technologies are needed to be developed than those currently in use in wastewater treatment plants. Mixed, tailor-made nanopowders have shown high efficiency in photodegradation of selected pharmaceuticals: ibuprofen, diclofenac, naproxene and ketoprofen. Project results imply further investigation of synthesis and application of novel nanopowders for photocatalytic degradation, with the aim of preparing photocatalysts that are simultaneously efficient for the degradation of more than one category of pollutants since diverse contaminants may be found in the aquatic environment. Bearing in mind the efficiency, chemical stability and commercial reasons (this must be taken into consideration), ZnO/TiO$_2$ emerges as nanopowder that should be in the scope of further investigation.

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5. References


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5. References

Peculiarities of the technological process in the preparation of metal powders

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Abstract: This publication traces the peculiarities of metal powder production for powder metallurgy. Of the variety of methods, particular attention is paid to those that are most widely used in practice - reduction and powdering methods. Metallurgical photo of iron powders obtained by different technological processes are presented, as well as tables with the basic technological properties of iron powders obtained by reduction and powdering.

Keywords: POWDER MATERIALS, IRON POWDERS, POWDERING, REDUCTION, TECHNOLOGICAL PROPERTIES

1. Introduction

Since the beginning of the industrial application of metal powders in powder metallurgy, that is, since about 1930, a number of methods for their production have emerged. For various technical or economic reasons, some of these methods have not been industrialized at all and others have been used for a short time. Among the relatively short-lived methods used, however, which are an important step in the development of these processes, the Hametag method and the electrolysis method should be mentioned. The Hametag process is the grinding of soft metal wire to powder. It was used during the Second World War in Germany. The metal powder electrolysis process was developed in the mid-1940s in Sweden and England and has been applied for about 20 years. The iron powder obtained is characterized by high purity and very good compressibility.[3,5]

In this study, we traced the peculiarities of the technological processes for the production of iron powders by powdering and reduction, and also identified the main technological characteristics of the most common brands of powders.

2. Exposition

Of the many iron powder production methods, only two have lasted their technical and economic benefits: [3]

- the method of reduction;
- the powdering method.

The two methods have different modifications. In the reduction method, the modifications relate to the raw material used and to the completion of the reduction process. The raw material used is iron ore or slag, and the reduction process is carried out in one or two steps.

In a one-step process, the iron oxide is usually reduced with hydrogen in a blast furnace.

In the two-step process, also known as the Hoganes method, the iron ore (or slag) is first reduced by hard carbon in the blast furnace to molten cast iron - C> 4%, followed by thermal treatment to decarbonise the material and reduce oxygen to the surface of the particles - the process is known as the RZ process;

- Granulation or powdering of high-purity cast iron melt to relatively coarse particles which, after milling in ball mills, are subjected to reduction-heat treatment to remove carbon and oxygen;
- Direct water spray melt of steel to powder with desired particle size, subjected to temperature treatment in furnaces with reducing medium. The production of iron and steel powders by this state-of-the-art method began in 1965 year in USA. Shortly thereafter, the same method began to be used at Hoganes (Sweden), Manesman-Pulvermetal (FRG) and Kobe Style (Japan). A variant of this method is the process developed by Sumitomo (Japan) to powdering with oil melt.

Of the elements of the first group, carbon is of greatest importance. High quality iron powders typically contain less than 0.02% carbon. The content of the other elements is also very low and depends on the type and quality of the starting materials used in the production of the iron powder. All iron powders contain certain non-metallic inclusions, but their amount is significantly lower in the powders obtained by powdering.

Table 1 shows the experimental results of the study of impurities in two of the most characteristic iron powders obtained by reduction and powdering.

<table>
<thead>
<tr>
<th>Compounds, %</th>
<th>Iron powder type</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS100.24</td>
<td>NC100.24</td>
</tr>
<tr>
<td>C</td>
<td>0.008</td>
</tr>
<tr>
<td>Mn</td>
<td>0.030</td>
</tr>
<tr>
<td>Si</td>
<td>-</td>
</tr>
<tr>
<td>Cr</td>
<td>0.002</td>
</tr>
<tr>
<td>Ni</td>
<td>0.020</td>
</tr>
<tr>
<td>Mo</td>
<td>0.0001</td>
</tr>
<tr>
<td>Cu</td>
<td>0.003</td>
</tr>
<tr>
<td>Sn</td>
<td>0.0003</td>
</tr>
<tr>
<td>SiO₂</td>
<td>0.140</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.190</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.140</td>
</tr>
<tr>
<td>MgO</td>
<td>0.240</td>
</tr>
<tr>
<td>CaO</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Several decades ago, there were only a few brands of iron powder for use in powder metallurgy. Today, more than 50 special types are available. This requires that the properties of the powders are very well known in order to select the most appropriate type for each case.

Pressability is undoubtedly one of the most important properties to consider when selecting the type of iron powder, as it determines the density that can be obtained when pressed, and hence the physical and mechanical properties of the product.[4] When we talk about pressability, we have in mind both sides - compactability and moldability. Tables 2 show the experimental results for the moldability of iron powders by pulverizing and reducing.
It is determined by the crude strength of specimens with a density of $6.5 \times 10^3 \, \text{kg/m}^3$.

**Table 3**: Experimental results for the moldability of iron powders with a density of $6.5 \times 10^3 \, \text{kg/m}^3$

<table>
<thead>
<tr>
<th>№</th>
<th>Brand of powder</th>
<th>Method of preparation</th>
<th>Rm, MN/m$^2$</th>
<th>Max. compaction at 420MPa, $10^3 , \text{kg/m}^3$</th>
<th>Max. $O_2$, %</th>
<th>Max. C, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MH 65.17</td>
<td>reduction</td>
<td>36</td>
<td>6.20</td>
<td>0.45</td>
<td>0.04</td>
</tr>
<tr>
<td>2.</td>
<td>MH 80.23</td>
<td>reduction</td>
<td>20</td>
<td>6.35</td>
<td>0.35</td>
<td>0.04</td>
</tr>
<tr>
<td>3.</td>
<td>NC 100.24</td>
<td>reduction</td>
<td>12</td>
<td>6.19</td>
<td>0.55</td>
<td>0.10</td>
</tr>
<tr>
<td>4.</td>
<td>EC 100.24</td>
<td>reduction</td>
<td>10</td>
<td>6.40</td>
<td>0.30</td>
<td>0.02</td>
</tr>
<tr>
<td>5.</td>
<td>SC 100.26</td>
<td>reduction</td>
<td>8</td>
<td>6.63</td>
<td>0.15</td>
<td>0.01</td>
</tr>
<tr>
<td>6.</td>
<td>AHC 100.29</td>
<td>powdering</td>
<td>6</td>
<td>6.45</td>
<td>0.30</td>
<td>0.02</td>
</tr>
<tr>
<td>7.</td>
<td>ASC 100.29</td>
<td>powdering</td>
<td>5</td>
<td>-</td>
<td>0.35</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The crude strength depends on the particle structure and the compression pressure. This is primarily a technological feature related to the pressing operation. Pressed articles must be able to withstand the forces that they exert upon release from the pressing tools and must not be dipped when transported to the kiln. For all powders intended for the manufacture of low density products, the crude strength is a basic characteristic. Therefore, the ratio between the crude density (the formability of the powder) and the compactness must be selected on a case-by-case basis. It is known that the physic-mechanical properties of powder metallurgical products depend to a great extent on the quality of the starting material. Reducing powders produced in the USA and Canada are also based on Swedish ore.

In tables 3 and 4 we have defined the main technological properties of the most used brands of iron powders.

Powder brands offered by different companies are in many cases comparable in their qualities, but very rarely could be completely replaced. This applies in particular to powders obtained by the melt powdering method. The production of quality powders by the reduction method is the exclusive monopoly of the Swedish company Hoganes, which uses high quality ore from a large field in northern Sweden as raw material. Reducing powders produced in the USA and Canada are also based on Swedish ore.

There is no generally accepted classification of iron powder brands. Each company uses its own designations. The letters of the Hoganes company indicate the method of manufacture (M, N and S - reduction, A - powdering).

**Table 4**: Experimental results for technological properties of powdering iron powders

<table>
<thead>
<tr>
<th>Powder mark</th>
<th>Max. particle size, µm</th>
<th>Bulk density, $10^3 , \text{kg/m}^3$</th>
<th>Max. flowability, s</th>
<th>Max. compaction at 420MPa, $10^3 , \text{kg/m}^3$</th>
<th>Max. $O_2$, %</th>
<th>Max. C, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHC100.29</td>
<td>169</td>
<td>2.95</td>
<td>25</td>
<td>6.69</td>
<td>0.10–0.20</td>
<td>0.01–0.02</td>
</tr>
<tr>
<td>ASC100.29</td>
<td>170</td>
<td>2.95</td>
<td>25</td>
<td>6.82</td>
<td>0.10–0.15</td>
<td>0.01–0.02</td>
</tr>
<tr>
<td>WP150</td>
<td>200</td>
<td>2.80–3.10</td>
<td>26</td>
<td>6.65</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>WP150HD</td>
<td>210</td>
<td>2.90–3.20</td>
<td>30</td>
<td>6.81</td>
<td>0.15</td>
<td>0.01</td>
</tr>
<tr>
<td>WP400</td>
<td>400</td>
<td>3.00–3.30</td>
<td>30</td>
<td>6.65</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>WPL200</td>
<td>200</td>
<td>2.50–2.70</td>
<td>33</td>
<td>6.61</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>KIP260A</td>
<td>250</td>
<td>2.55–2.75</td>
<td>35</td>
<td>6.60</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>KIP280A</td>
<td>200</td>
<td>2.70–2.90</td>
<td>30</td>
<td>6.62</td>
<td>0.19</td>
<td>0.02</td>
</tr>
<tr>
<td>KIP300A</td>
<td>200</td>
<td>2.80–3.10</td>
<td>30</td>
<td>6.70</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>KIP300AS</td>
<td>200</td>
<td>2.80–3.10</td>
<td>30</td>
<td>6.78</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>300M</td>
<td>220</td>
<td>2.85–3.10</td>
<td>30</td>
<td>6.64</td>
<td>0.25</td>
<td>0.02</td>
</tr>
<tr>
<td>500M</td>
<td>250</td>
<td>2.85–3.10</td>
<td>30</td>
<td>6.65</td>
<td>0.25</td>
<td>0.02</td>
</tr>
</tbody>
</table>
The first group of digits is the particle size of the dust particles and the second group of digits is the bulk density. The letters of the company Manesman (Germany) also give information about the method of producing the powder (WP - water powdering), and the figures determine only the largest particle size in μm.

Of the reducing sponge iron powders manufactured by Hoganes (Sweden), the most widely used powder brand is NC 100.24. The powder compaction is very good. Due to its spongy structure, its formability is particularly high. Iron powder SC 100.26 has a very high density after single pressing and sintering. It is recommended to produce parts that will undergo chemical-thermal treatment. Unlike NC 100.24, the iron powder MH 100.28 has a high density. Thanks to it - 2,8·10³ kg/m³, it is preferable for the production of long and thin details in order to obtain a smaller bulk height. To adjust the bulk density of mixtures, MH 100.28 is often added to other grades of iron powder. At equal pressure, MH 100.28 gives a slightly higher product density than NC100.24. MH 80.23 is a specially created brand for the production of self-lubricating bearings. It has excellent formability. The crude strength of the pressed powder is 50% better than that of NC100.24. MH40.24 and MH40.28 are more coarse-grained than NC 100.24 and MH 100.28 and can be used when high requirements for the smoothness of the surfaces of the pressed products are not met. However, their crude strength is not as high as that of NC100.24. MH300.25 iron powder is often used as an additive to NC100.24 in the manufacture of structural parts when particularly demanding surface smoothness requirements are imposed. Such an additive is also useful when dust specimens are required. MH65.17 has very high formability - the crude strength of the pressed specimens is almost twice that of NC 100.24. It is mainly used in the production of friction materials.

The most common brand of iron powder obtained by the spray method is ASC 100.29. It is the highest quality iron powder brand. With its very high purity, it has excellent compaction, which allows a density of 7,2 ÷ 7,3·10³ kg/m³ to be reached with a single pressing. It is especially suitable for the manufacture of high-density structural products, as well as for products with certain magnetic characteristics. Its use has a beneficial effect on the durability of the press tools. The AHS 100.29 iron powder has a very good seal. Its use is similar to SC100.26. WPL 200 is a high quality iron powder. It is characterized by high purity, very good sealability (at a pressure of 600 MPa a density of 7,0·10³ kg/m³ is reached) and formability. WP150 and WP150HD are powders with very good sealability and purity. In terms of these characteristics, they are similar to the AHC100.29 and ASC 100.29 respectively. Their formability is worse than the WPL 200. The WP 400 iron powder has a larger particle size and is suitable for large parts. The KIP 260A iron powder has good formability and sealability. Its properties are similar to those of the WPL 200. The KIP 280A and KIP 300A powders are highly compacted. They are comparable to the WP150 brand. The KIP 300AS iron powder has high compaction and purity. It is particularly suitable for magnetic materials, is comparable to the WP 150HD and is close to the ASC100.29.

3. Conclusions

From the researches made about the dependence of the technological properties of iron powders on the way of their production, the following generalizations can be made for the choice of the type of iron powder in the manufacture of structural parts:

- Reducing spongy and iron powders are particularly applicable where particularly high density (eg anti-friction products) is required. Their use is obligatory when the product has to have high raw strength, as with some friction materials, with long and thin details, etc.;
- Medium-density products can be made with either sponge or powder. The choice for each case is made by technical and economic considerations;
- In the manufacture of high density articles, powdered iron powder with high compaction and purity is used. Powdered iron powder is also used in the manufacture of magneto-mechanical and hot-rolled products, since it contains less impurities.

4. References

Current trends in the development of high dielectric permittivity ceramics

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Abstract: The proposed review looks at some aspects concerning ferroelectrics that are characterized by high dielectric constant at/ or near Curie temperature. Particular attention has been paid to the doping of BaTiO₃ with rare earth elements because they prove to be very promising for the production of supercapacitors. It is pointed out that the preparation of ceramic materials with high dielectric permittivity by sol-gel method is of huge interest due to the numerous advantages inherited to this technology.

Keywords: BaTiO₃, CERAMIC MATERIALS, HIGH PERMITTIVITY, RARE EARTH ELEMENTS

1. Introduction

In recent years, interest in the development of new ceramic materials has increased significantly. A directive from the European Union has been introduced to restrict the import and production of lead-containing materials. [1] According to the norms presented, lead should not be contained in dielectric materials that are part of integrated circuits or discrete semiconductor devices. This is how ideas for the creation of high quality lead-free ceramic materials are born. [2]

For a number of simple electronic applications such as ceramic multilayer capacitors (MLCC), they have quite low thermal stability. The dielectric permittivity characteristics of these MLCCs generally meet the temperature specification "YSV" of the "Electrical Industry Association" (EIA). The 'YSV' specification for condenser materials operates in the temperature range from -30°C to +85°C. Capacity will not increase above 22% and will not decrease below 82% of its nominal value. In the field of electronic components, there is a continuing trend of miniaturization, involving multi-layer capacitors of chips. Therefore, the rapidly expanding market for surface mounted technology chips requires higher and higher compact MLCCs, i.e. greater volume capacity. The required increase in specific capacity is realized in two ways:

- Increasing the relative dielectric permittivity.
- Reducing the thickness of the dielectric layer. [3]

YSV" dielectric materials typically use the maximum transmittance arising at the Curie point (Tc). The temperature characteristics of "YSV" materials generally correspond to a simple, wide dielectric close to room temperature. The most commonly used base material for MLCCs is BaTiO₃, showing a Tc of 130°C and a relative dielectric permittivity £r = 2000. The maximum dielectric constant is shifted to room temperature by chemical modification of the ceramic material.[4]

BaTiO₃ is a well-known ecological material, one of the lead-free materials with a perovskite structure that is widely used in the electronics industry. [5,6] BaTiO₃ pertains to compounds with the general formula ABO₃, where B ions take the place of A and Ti occupy the B places [5,6]. The doping of such ABO₃ ceramics has been studied for many years in order to improve its electrical and dielectric properties.

2. Influence of modifiers

In recent years, particular attention has been paid to the production of high dielectric permittivity (£r) ceramic materials (ferroelectrics) by doping of BaTiO₃ with ions of various metals in order to apply them as supercapacitors. A significant feature of high dielectric permittivity is also the Curie temperature (Tc) which pertains to the phase transition from ferroelectric to paraelectric state. The combination of high dielectric permittivity with the appropriate Curie temperature (close to room temperature if possible) is crucial for the application of ferroelectric materials to various technological applications (including as supercapacitors). Therefore, this review pays particular attention to the two mentioned characteristics.

Very high dielectric permittivity is registered for BaTiO₃ doped with trivalent ions of rare earth elements, which induces a significantly increase in the dielectric permittivity [7,8], thus improving the performance of relevant energy storage devices. It has been found that the permittivity depends very strongly on the crystallites sizes and with size decreasing it initially enhances but then diminishes, i.e. a maximum is observed [9]. The permittivity of the rare earth element (RE) doped BaTiO₃ is also determined by the crystal lattice distortion and the presence of point defects in the newly formed perovskite structure. If the radius of the (RE) doping ion is smaller than that of Ba²⁺ and of Ti⁴⁺ the substitution is realized in A sites. This is observed at Nd³⁺, La³⁺, Sm³⁺ and the doping ions improve the dielectric properties of the ferroelectrics. At a larger (RE) radius than Ba²⁺ and Ti⁴⁺ the doping ions substitute in B sites. In the intermediate case, as in Y³⁺ and Er⁵⁺, both A and B are replaced at the same time. [10] In general, both the Ba and the oxygen-compensating vacancies are formed. [10] Characteristic of all ferroelectrics obtained by doting BaTiO₃ with rare earth elements (except Er) is that the temperature of the ferroelectric - paraelectric phase transition can be lowered to room temperature. [11]

Using the doping of BaTiO₃ with rare earth elements, a number of authors have prepared ferroelectrics with high £r values. The dielectric permittivity of ferroelectrics obtained by the addition of neodymium to barium titanate has been found to depend very strongly on the size of the crystallites, passing through the maximum. At room temperature (Tc) it reaches a surprisingly high value of £r = 5500000 [10]. The Sm doped BaTiO₃ exhibits dielectric permittivity 6400 at Tc 50°C [9]. A very high Er = 10130 was registered at Tc equal to 22°C for Ce doped barium titanate. [12] Ferroelectric Ba₀.95La₀.05TiO₃-x with surprisingly high permittivity 8000000 room (Tc) has been synthesized by adding La to BaTiO₃ [13] There is evidence in the literature for the preparation of Gd substituted BaTiO₃ by the hydrothermal method and subsequent heating in a nitrogen atmosphere. [14] The material exhibited a high relative dielectric constant of 20000 at room Tc.

High dielectric permittivity ceramic materials have been prepared by doping of BariO₃ with elements that do not belong to the rare earths. Thus a ferroelectric with £r, 2500 at room Tc is synthesized by doping of barium titanate with Sr. [15] When Zr is added to BaTiO₃, the resulting Baₓ(Zr₁₋ₓ)Ti₃O₁₂ ferroelectric exhibit a dielectric permittivity of 10586 at room Curie temperature [16] Another Zr substituted barium titanate with a formula Ba(Ti₀.₉₂Zr₀.₀₈)O₃ has a dielectric permittivity of 5000 at room Tc [17]

The direct metal substitution in BaTiO₃ has been also applied in order to prepare ceramics with high dielectric permittivity. As a rule the synthesis proceeds in a reducing medium. Thus Fe-doped BaTiO₃ ferroelectric with a surprisingly high £r 66500 at room Tc was synthesized.[18] The codoping of BaTiO₃
3. Preparation

A very effective approach for the synthesis of high dielectric permittivity is sol-gel technology. This method belongs to the methods of "soft" chemistry, i.e., the preparation of the materials is carried out at relatively low temperatures and atmospheric pressure, without the need for expensive apparatus (peculiar to the physical methods). Other positive features of this technology are (i) possibility for the production of a very large number of materials and compounds and with complex structure and phase composition (including hybrids, composites); (ii) effective stoichiometry control of the of the materials obtained, as well as the use of both inorganic and organic precursors [11]. The synthesized samples are distinguished by their homogeneity. The use of sol-gel technology allows the synthesis of high $\varepsilon_r$ ferroelectrics at significantly lower temperatures than the most commonly used solid phase synthesis. This results in materials with much smaller grain sizes, high homogeneity, and to preparation of high relative dielectric permittivity ceramics at low Curie temperatures and proves to be very effective for the preparation of various ferroelectric materials suitable for high-capacity devices. The sol gel technology was successfully applied to obtain Ce doped BaTiO$_3$ [12], Sr doped BaTiO$_3$.[15]

Suitable for the synthesis of ferroelectrics, with surprisingly impressive dielectric permeability is the sol-gel hydrothermal method applied by Sun et all [13]. It can be considered as a variant of sol-gel technology. The method allows the synthesis of a pure phase composed of nanoparticles with a narrow size distribution, which proves to be extremely favorable for the production of ceramic materials with high dielectric permittivity.

The most commonly applied method for preparation of ferroelectrics with high dielectric permittivity is conventional solid-phase synthesis. Thus, BaTiO$_3$ is doped with Zr,[16,17] Gd, Y, Yb,[14] Nd,[20,21] Sm and Mn [18] etc. The preparation by solid state reactions requires as a rule higher temperatures in order to obtain doped BaTiO$_3$ than sol-gel technology.

Recently, the production of dielectric ceramics with high $\varepsilon_r$ by direct doting of BaTiO$_3$ with metal has also aroused interest. Fe-doped barium titanate was thus synthesized [19]. The drawback of the method is the compulsory use of a reducing atmosphere.

The synthesis of high dielectric permittivity such as La doped BaTiO$_3$ [13] has also been accomplished through some physical methods such as spark plasma. Physical methods, however, require expensive and complex apparatus as opposed to the sol-gel method.

4. Conclusions

The dielectric ceramics prepared by rare-earth element(s) doped BaTiO$_3$ (RE: BaTiO$_3$) has been considered as one of the most suitable materials for ferroelectric capacitors, because of its high $\varepsilon_r$. This high dielectric permittivity of RE: BaTiO$_3$ is intimately related to the structural distortion and chemical defects surrounding the dopants. The sol-gel method is considered to be very suitable for preparation of high permittivity ferroelectrics due to its advantages: (i) to obtain homogeneous ceramic materials, (ii) the low temperature of synthesis and sintering, (iii) to synthesize materials and compounds with complex structure and phase composition and small grain sizes.

Acknowledgements

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Conditions for obtaining and characteristics of lead-free passive elements for high energy impact

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Abstracts: Compression was carried out of modified copper powder workpieces at a pre-determined value of the pressure. High temperature sintering of the workpieces in a neutral medium at a temperature of 1,000°C was performed. A high density metal-ceramic composite material was obtained. Its structure and physico-chemical parameters were determined. Lead-free prototypes were created, corresponding to the weight and dimensions of the reference standard lead passive elements for high energy impact.

KEYWORDS: PRESSING, HIGH TEMPERATURE SINTERING, HIGH ENERGY IMPACT

1. INTRODUCTION

The use of lead in many products and devices such as piezoelectric elements, passive high energy impact elements and others poses certain risks to the human health and the environment. This calls for seeking alternatives and creating lead-free prototypes that perform the same functions. As of 1 June 2006, restrictions on the production and import of electronic components and other articles containing lead, as well as of equipment containing lead, have been introduced in the European Union. The requirements are set out in a series of EU documents (RoHS directives). In 2013, the Council of Ministers of the Republic of Bulgaria adopted a Decree on the conditions and procedure for equipment marketing in line with the restrictions on the use of certain hazardous substances (Decree of the Council of Ministers No 55/06.03.2013, published in the State Gazette No 24 of 12.03.2013).

According to the norms stated, as of 21.07.2016, no lead should be contained in ceramic, dielectric, metal-ceramic and composite materials which are part of integrated circuits, discrete semiconductors or high energy impact elements [1].


Lead is prohibited in water pipes and as an additive in motor fuels and paints. It is also prohibited for use in hunting ammunition and as fishing tackle in most of Europe. The European Union with its Directive 2012/65/EU has also banned its use in balancing tires, as well as in electrical and electronic equipment.

Increasingly, regulatory burdens, processing costs and the costs of atmospheric discharges are also affecting the use of lead, including in the automotive, aerospace and nuclear energy industries and in consumer and sports goods, for medical purposes and more. [2, 3, 4, 5]

In the present study, experiments and studies have been carried out and a metal-ceramic composite has been created based on a modified copper powder, with a sediment composition of less than 100 microns, which complies with EC No 231-159-6. The chemical composition of the powder comprises the following chemical elements in weight %: Cu 99.5%; Ag 0.005%; Ag 0.005%; As 0.0002%; Fe 0.005%; Mn 0.002%; Pb 0.05%; Sb 0.005%; Sn 0.005%.

Workpieces were obtained whose density, hardness, microhardness, compressive strength and structure are equivalent to those of a standard lead sample. The new material from which the samples are made does not pose a toxic or environmental threat and can be successfully recycled after first use or at the end of the useful life of the product.

2. EXPERIMENTS

From the modified copper powder and using the powder metallurgy method, 10 pieces of sample bodies were compressed by bilateral pressing in a small matrix - Figure 1, [6].

The measured density $\rho$ of 6 sample bodies is shown in Table 1, and a plot of the change in their density as a function of the applied force $P$ is shown in Figure 2. Using the $P - \rho$ curve of Figure 2, the optimal force $P = 8,000$ kg is determined, for which the density $\rho$ corresponds to that of the reference lead samples.

The experimental research results were preliminary, as changes in the samples were expected to occur at their high temperature sintering at 1,000°C, with a retention time of $t = 60$ min. Indeed, the curve showing the dependence of the density after sintering $\rho$ on the force $P$ undergoes modification, as shown in Table 2 and Figure 3, and the compression pressure required for the final useful and correct density changes.

![Figure 1. Photo of the matrix for molding workpieces of passive elements](image1)

![Figure 2. Dependence of the density $\rho$ [g/cm$^3$] of copper based sample bodies on the applied force $P$ [ton]](image2)

<table>
<thead>
<tr>
<th>No</th>
<th>$P$ [ton]</th>
<th>$d$ [mm]</th>
<th>$H$ [mm]</th>
<th>$V$ [cm$^3$]</th>
<th>$G$ [g]</th>
<th>$\rho$ [g/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>10</td>
<td>14.40</td>
<td>1.13</td>
<td>6.88</td>
<td>6.08</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>10</td>
<td>11.30</td>
<td>0.89</td>
<td>6.30</td>
<td>7.10</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>10</td>
<td>10.50</td>
<td>0.82</td>
<td>6.40</td>
<td>7.77</td>
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<tr>
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<td>8</td>
<td>10</td>
<td>11.00</td>
<td>0.86</td>
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<tr>
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<td>11</td>
<td>10</td>
<td>9.80</td>
<td>0.77</td>
<td>6.50</td>
<td>8.15</td>
</tr>
</tbody>
</table>
Figure 3 shows that a force of 5.5 tons must be applied to achieve a value of the density $\rho \approx 8$ g/cm$^3$ after sintering.

Table 2. Density of copper based samples after heat treatment

<table>
<thead>
<tr>
<th>No</th>
<th>$P$ [ton]</th>
<th>$d$ [mm]</th>
<th>$H$ [mm]</th>
<th>$V$ [cm$^3$]</th>
<th>$G$ [g]</th>
<th>$\rho$ [g/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>14.78</td>
<td>29.60</td>
<td>5.90</td>
<td>31.00</td>
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<td>2</td>
<td>5.5</td>
<td>14.73</td>
<td>31.11</td>
<td>5.31</td>
<td>34.58</td>
<td>6.52</td>
</tr>
<tr>
<td>3</td>
<td>5.5</td>
<td>14.80</td>
<td>27.90</td>
<td>4.80</td>
<td>31.13</td>
<td>6.48</td>
</tr>
<tr>
<td>4</td>
<td>5.5</td>
<td>14.80</td>
<td>25.00</td>
<td>4.30</td>
<td>27.90</td>
<td>6.49</td>
</tr>
<tr>
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<td>5.5</td>
<td>14.80</td>
<td>25.35</td>
<td>4.36</td>
<td>28.47</td>
<td>6.54</td>
</tr>
<tr>
<td>6</td>
<td>5.5</td>
<td>14.80</td>
<td>27.80</td>
<td>4.78</td>
<td>30.92</td>
<td>6.40</td>
</tr>
<tr>
<td>7</td>
<td>5.5</td>
<td>14.80</td>
<td>27.20</td>
<td>4.67</td>
<td>30.46</td>
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<td>14.80</td>
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<td>4.73</td>
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<td>4.76</td>
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<td>6.57</td>
</tr>
<tr>
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<td>5.5</td>
<td>14.80</td>
<td>29.90</td>
<td>5.14</td>
<td>32.12</td>
<td>6.25</td>
</tr>
</tbody>
</table>

The prototypes were made using a cutting machine, a conventional lathe, a semi-automatic lathe CNC 500SAN-Lynx/220 LM, and a programmable automatic 5-axis CNC machining center Hurco VMX - 30U for the milling.

10 workpieces were molded in working matrices with diameters roughly between 14.73 mm and 14.80 mm under the above mentioned conditions: force of 5.5 ton, sintering temperature of 1,000°C and isothermal retention time of 60 min. The parameters of the workpieces after pressing are shown in Table 3, and the parameters after high-temperature sintering are shown in Table 4.

Table 3. Density of copper specimens pressed with force $P = 5.5$ ton

<table>
<thead>
<tr>
<th>No</th>
<th>$P$ [ton]</th>
<th>$d$ [mm]</th>
<th>$H$ [mm]</th>
<th>$V$ [cm$^3$]</th>
<th>$G$ [g]</th>
<th>$\rho$ [g/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.5</td>
<td>14.78</td>
<td>29.60</td>
<td>5.90</td>
<td>31.00</td>
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<td>27.90</td>
<td>4.80</td>
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<td>6.48</td>
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<tr>
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<td>5.5</td>
<td>14.80</td>
<td>25.00</td>
<td>4.30</td>
<td>27.90</td>
<td>6.49</td>
</tr>
<tr>
<td>5</td>
<td>5.5</td>
<td>14.80</td>
<td>25.35</td>
<td>4.36</td>
<td>28.47</td>
<td>6.54</td>
</tr>
<tr>
<td>6</td>
<td>5.5</td>
<td>14.80</td>
<td>27.80</td>
<td>4.78</td>
<td>30.92</td>
<td>6.40</td>
</tr>
<tr>
<td>7</td>
<td>5.5</td>
<td>14.80</td>
<td>27.20</td>
<td>4.67</td>
<td>30.46</td>
<td>6.53</td>
</tr>
<tr>
<td>8</td>
<td>5.5</td>
<td>14.80</td>
<td>27.50</td>
<td>4.73</td>
<td>29.67</td>
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<tr>
<td>9</td>
<td>5.5</td>
<td>14.80</td>
<td>27.70</td>
<td>4.76</td>
<td>31.30</td>
<td>6.57</td>
</tr>
<tr>
<td>10</td>
<td>5.5</td>
<td>14.80</td>
<td>29.90</td>
<td>5.14</td>
<td>32.12</td>
<td>6.25</td>
</tr>
</tbody>
</table>

From the workpieces were produced 10 prototype samples of passive elements for high energy impact, equivalent not only in structure and physico-chemical properties, but also in size to the standard lead samples, as shown in Figure 4.

Table 4. Density of copper based specimens pressed with force $P = 5.5$ ton, temperature $T = 1,000°C$ and retention time $\tau = 60$ min

<table>
<thead>
<tr>
<th>No</th>
<th>$P$ [ton]</th>
<th>$d$ [mm]</th>
<th>$H$ [mm]</th>
<th>$V$ [cm$^3$]</th>
<th>$G$ [g]</th>
<th>$\rho$ [g/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.5</td>
<td>13.50</td>
<td>27.55</td>
<td>3.82</td>
<td>30.40</td>
<td>7.96</td>
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<td>2</td>
<td>5.5</td>
<td>13.50</td>
<td>29.77</td>
<td>4.26</td>
<td>33.99</td>
<td>7.98</td>
</tr>
<tr>
<td>3</td>
<td>5.5</td>
<td>13.50</td>
<td>26.42</td>
<td>3.78</td>
<td>30.16</td>
<td>7.98</td>
</tr>
<tr>
<td>4</td>
<td>5.5</td>
<td>13.90</td>
<td>25.23</td>
<td>3.58</td>
<td>28.53</td>
<td>7.97</td>
</tr>
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<td>5.5</td>
<td>14.00</td>
<td>23.92</td>
<td>3.68</td>
<td>29.26</td>
<td>7.95</td>
</tr>
<tr>
<td>6</td>
<td>5.5</td>
<td>13.80</td>
<td>26.02</td>
<td>3.89</td>
<td>31.08</td>
<td>7.99</td>
</tr>
</tbody>
</table>

In Table 5 are shown the physico-mechanical parameters of the composite material from which the prototypes were made.

Table 5. Production parameters and physico-mechanical characteristics of a passive element for high energy impact

<table>
<thead>
<tr>
<th>No</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Force $P$, [kg]</td>
<td>5.500</td>
</tr>
<tr>
<td>2</td>
<td>Average density after pressing $\rho$, [g/cm$^3$]</td>
<td>5.25 – 6.57</td>
</tr>
<tr>
<td>3</td>
<td>Density after high temperature sintering $\rho$, [g/cm$^3$]</td>
<td>7.44 – 7.95</td>
</tr>
<tr>
<td>4</td>
<td>Compressive strength, [kg/cm$^3$]</td>
<td>4,800 – 5,480</td>
</tr>
<tr>
<td>5</td>
<td>Microhardness, [MPa]</td>
<td>925 - 517</td>
</tr>
</tbody>
</table>

It should be noted that the table shows the average microhardness obtained at five points for each sample.

3. ANALYSIS OF THE MICROSTRUCTURE OF A SAMPLE OF SINTERED COPPER POWDER

Of interest is the structure of the obtained metal-ceramic composite material – see Figures 5 - 8.

Subjected to metallographic analysis was a sample of sintered Cu powder with the following composition: Cu 99.5%; Ag 0.005%; As 0.0002%; Fe 0.005%; Mn 0.002%; Pb 0.05%; Sn 0.005%. To prepare it for analysis of the microstructure, the specimen underwent the standard procedure - embedding in acrylic resin, grinding using glass-paper of grade up to 2,400, mechanical polishing with diamond paste and etching with a solution of 5 ml FeCl$_3$, 30 ml HCl and 100 ml H$_2$O.

The metallographic analysis was performed using a Reichert-Jung Polyvar Met optical microscope coupled to a ProgRes CT3 digital camera using ProgRes CapturePro image processing software.
The microhardness was measured using a MicroDuromat 4000 microhardness meter with a load of 20 gf, a loading time of 10 s and a retention time of 10 s.

Figure 5 shows the microstructure of a polished metallographic specimen. Imperfections in the microstructure are observed in the form of small air cell segments, most of which are located at the periphery of the specimen.

The measured microhardness HV0.02/10/10 of the sample varies from 94.3 kgf/mm$^2$ (925 MPa) at the periphery of the sample to 52.7 kgf/mm$^2$ (517 MPa) in its central part. Figure 6 shows the imprints from the measurement of the microhardness at the periphery (Figure 6a) and in the central part (Figure 6b) of the sample.

In a part along the periphery of the specimen (less than ¼ of its circumference), a dark coating layer is observed (Figure 7), with a maximum measured coating thickness of about 93 µm.

The measured microhardness of the coating (layer) is 199.5 kgf/mm$^2$ (1956 MPa). In machining, this coating layer is removed and the real prototype is obtained only from the inner layer.

Figure 8 shows the microstructure of the sample after etching. A correlation was observed between the measured microhardness in the individual zones and the microstructure. It was observed that it is more pronounced along the periphery (Figure 8b) than in the central part (Figure 8a). Dark areas are observed, which are gray and more densely located along the periphery (Figure 8b) and black in the central part (Figure 8a), where Cu grains with twins can be noticed below the latter.
4. CONCLUSIONS

1. The ability to control the density of the obtained non-toxic composite metal ceramics in order to meet the customer’s needs, thereby replacing the metal material – in this case toxic lead – is the most important attribute of the obtained material.

2. The ability to formulate and produce this composite material with acceptable physical properties at a sufficiently high relative weight is a challenge that has been overcome.

3. The high density 8 g/cm\(^3\) ±1% composite metal-ceramic material is capable of providing optimum sample weight 4. The new non-toxic, high density composite material is available to engineers and designers for use in applications requiring weight adjustment, balancing, damping, crushing or breaking in sport shooting.

5. The non-toxic material can replace lead and other traditional metallic materials in a more cost-effective way by offering improved physical properties and workability with conventional equipment.

5. REFERENCES

1. The manufacture and sale of Ecomass Compounds are licensed by Ecomass Technologies (Austin Texas) to Technical Polimers LLC (Buford, Georgia) and protected by U.S. and international patents. Additional information available at [www.ecomass.com](http://www.ecomass.com)


3. X-ray Manufacturer Gets the Lead Out, a case study at [www.ecomass.com](http://www.ecomass.com)

4. Tungsten has the highest melting point of all elements except carbon at 3,400\(^\circ\) C with good high-temperature mechanical properties and the lowest expansion coefficient among all metals, with a density of 19.25 g/cc. It is among the heaviest metals. The name itself is of Swedish origin: tung (heavy) and sten (stone), in deference to the Swedish chemist/mineralogist who first discovered and described the ore. It is also known as wolfram, which gives tungsten its chemical symbol, W. (Source: Tungsten Industries Association [London].)

5. Report dated August 13,1498 of tests performed at The Nuclear Science Center, Texas A & M University, College Station, Texas. Complete at [www.ecomass.com](http://www.ecomass.com)

First order phase transition in 3D printer – numerical experiments

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Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre „Acad. Angel Balevski“ Sofia, Bulgaria

Abstract: A methodology for analyzing and evaluating macroscopic level of first-order phase transition in 3D printer technology is proposed. A classic Stefan-Schwarz task was used. A 3D mathematical model of the Stefan-Schwarz problem is made. The finite element method for numerical solution is applied.

A numerical experiment was evaluated. A geometric drop (flow) model in 3D printer technology is proposed. The idea of filling a “flow” drop by smaller droplets than a “flow” has been investigated numerically. The temperature field at filling in the flow as hereditary was investigated.

Keywords: PHASE TRANSITION OF FIRST ORDER, 3D PRINTER, STEFAN-SCHWARZ TASK, NUMERICAL EXPERIMENTS.

1. Introduction – macroscopic description of first order phase transition in 3D printer

First order phase transition we describe only of macro-level in the frame of mathematical heat conductivity theory by Stefan-Schwartz task [4, 5] in Foundry is:

\[ V_{YS} = (V_C \cup S_{Font} \cup V_S) \cup B_{WS} \cup (V_M \cup B_M), \text{ (OTSF)} \]

- Equation of the heat conductivity:
\[ (c + S_T Q_m) \frac{\partial T}{\partial t} = \lambda (\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}) \text{ in } V_{YS}. \]

- Stefan’s boundary condition (S):
\[ -\lambda_L V_T L_{YS} = \rho_S Q_m - \lambda_S V_T S_{SF}. \]

or
\[ R = \left[ \lambda_L V_T L_{YS} - \lambda_S V_T S_{SF} \right] / \rho_S Q_m \]

- Boundary condition at the mold’s work surface (B_{WS}):
\[ -\lambda_C V_T C_{WS} + \alpha_{B_{WS}} (T_C_{B_{WS}} - T_{M_{B_{WS}}} ) = -\lambda_H V_T M_{B_{WS}}. \]

- Boundary condition mold-environment (B_M):
\[ -\lambda_H V_T M_{B_M} = \alpha_B (T_{M_{B_M}} - T_{En}). \]

- Initial conditions at t = 0:
\[ T_I(x, y, z, t) = const. \]

where \( T \) is the temperature with indexes for the cast (C) liquid (L) and solid (S) phases and mold (M); the thermophysical coefficients of the (OTSF) are: thermal conductivity (\( \lambda \)), thermal capacity (c), density (\( \rho \)), \( S_T \) is function of the heat source, \( Q_m \) is latent heat of the melting at the melting temperature \( T_m \).

Methodology of the first order phase transition (see Fig.1): 1. Finite Elements Method (FEM); 2. Min volume: \( 1 \mu m^3 \) or min Sum of \( 8 \mu m^3 \) of (FE); 2.2 Max volumes: of the Cast is \( 64 \mu m^3 \) and the Substrate (Mold) is \( 24 \mu m^3 \). The first order phase transition is cold crystallization (or solidification) [1-3, 7 and 8] on the base of the velocity of moving and the geometry of the isothermal surface in the Stefan’s boundary eq.(1, 2) or eq.(1, 2, 1). On the Fig. 1 we introduce geometry of (OTSF) for numerical investigation of the first order phase transition in the droplet of the 3D printer.
The calculation data for the Stefan-Schwartz task (1) are: $T_L = \text{const} = 690.5^\circ C$; $T_M = \text{const} = 50^\circ C$; temperature of melting $T_m = 660.1^\circ C$ with interval of transition $\pm 3.5^\circ C$; $Q_m = 401819 \text{ J/kg}$; $\alpha WS = 56000 \text{ w/m}^2\text{Ks}$, $\alpha WM = 56000 \text{ w/m}^2\text{Ks}$; cast: $\lambda_L = 104.675 \text{ w/mKs}$, $c_L = 1088.23 \text{ J/kgK}$, $\rho_L = 2380 \text{ kg/m}^3$, $\lambda_S = 209.275 \text{ w/mKs}$, $c_S = 1130.085 \text{ J/kgK}$, $\rho_S = 2540 \text{ kg/m}^3$; $\lambda_M = 385 \text{ w/mKs}$, $c_M = 1090 \text{ J/kgK}$, $\rho_M = 8930 \text{ kg/m}^3$. The aim of this work is to estimate the non-stationary temperature field of 1-st order phase transition upon filling by adding a 4 $\mu$m droplet.

2. Numerical Experiments

We assume that the continuously added material flowing from the 3D printer has some flow, which for us is already physically a droplet (Fig. 1 and Fig. 2). It is apparent from Figure 2 that the possibility of evaluating the thickness (volume) flow rate of the printer is considered one of the basics. It follows: what is the temperature of the "old" drop and the effect of the "fresh" drop, which creates the flow called by us the "big drop 64 $\mu$m" i.e. a major question about the "inherited temperature field" in the 3D printer and substrate flow rate.

The residence time of the 8 $\mu$m droplet of Fig. 1 is up to $\sim 3 \times 10^4$ $\mu$s and the thermodynamic state of the former is determined!

The methodology and its geometric appearance is shown in FIG. 1: 1. The first row of drops that are in contact with the substrate (shape) is filled and the first row consists of drop 1 to drop 4; 2. The second row is filled from drop 5 to drop 8 and lies on the first row; 3. The third row is filled with drops from 9 to 12; 4. The fourth line consists of drops from 13 to the last 16 drops.

The state of the system changes with each fresh drop: The beginning of the process is the first drop with its initial temperature and substrate with its initial temperature. The system is cooled down to the next drop, etc. The temperature field of the system immediately before each drop is called a "hereditary temperature field".

Initial state of the system: the droplet temperature is 690 $^\circ C$ and the substrate is 50 $^\circ C$. In Fig. 3 shows the hereditary temperature field as follows: The hereditary temperature field is represented by two scales, one for the cast, marked "C", the other for the substrate and marked "M".

1-st "hereditary temperature field"

2-nd "hereditary temperature field"

3-rd reduction of the melt temperature
The introduction of fresh drops in the adopted methodology indicates that the storage of the liquid phase state is ahead of the starting point for phase conversion.
The phase transition temperature range is \((T_m + 3.5, T_m - 3.5)\) = \((660.1 + 3.5, 660.1 - 3.5)\). It has been learned from previous experiments that even with this maximum heat exchange, curing conditions can be found that relate to future potentialities. The next last numerical experiment is to represent the process of solidifying a large drop equivalent to a flow rate. In FIG. 4 presents the process for solidifying the large drop (flow):

Fig. 4 Work principle of 3D printer: nonstationary temperature field at first order phase transition in the large droplet.

This experiment presents a very good opportunity to describe the temperature field of a phase transition with a very large number of temperature curves in small temperature intervals from 1.09 to 2.5°C.
3. Analysis

The works of J. Stefan [4] and C. Schwarz [5] are the mathematical foundation of the theory of casting. These tasks [4 and 5] are an important section in the mathematical theory of thermal conductivity. Along with classical crystallization theory, theoretical and applied thermodynamics are at the heart of theoretical material science.

Phase transitions of the first and second order are fundamental processes of material science because they are in the nature of the formation of structures of pure metals, alloys and composite materials [1, 2, and 3]. It is known that in the foundry, in addition to crystallization, the term solidification is used [1, 2]. There is a fundamental connection between these two concepts through the solidification front according to [3]:

![Figure 5: Phase transition of first order: solidification and crystallization.](image)

The interest in the tasks [4 and 5], but always presented in their classic type. Tasks [4 and 5] are used in various experimental techniques [1, 3, 8 and 10] or are the basis of mathematical studies [7, 11, 12, and 13]. The mathematical models of foundry are based on [4 and 5] for example work [8]. The use of tasks has long been a common mathematical basis for the study of first- and second-order phase transitions. The mathematical model (1) used here is the Stefan-Schwarz joint problem from the first half of the 20th century.

Numerical experiments have clearly shown that the presented methodology can be used in 3D printer technology. At least by numerical experiment it is possible to make estimates for the crystallization front [3]. Numerical experiments in this pure type are "easy", but taking into account real contact and the need to use mathematical methods in solid state physics [6, 2] requires many high-level knowledge resources: for example, huge computational resources, mathematics, mathematical physics, computational mathematics and physics, high resolution for quantum level observation.

Numerical experiments draw our attention to the notion of crystallization front as an important common criterion for evaluating heat transfer and droplet size in 3D printer technology. The achievement of high technological characteristics of products made using a 3D printer raise the question of optimization and control.

4. Conclusion

The basic mathematical methodology for creating and optimizing 3D printer technology is Stefan-Schwarz's task.

The crystallization front is an important general control criterion in 3D printer technology as well.

3. References

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Investigation technology manufacture of contact wires of a copper alloy for transport electric network

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Abstract: In this work, we performed virtual and physical studies of the process of forming a contact wire by the method of equal channel angular pressing according to the Conform scheme. As the starting material, low-alloy bronze was used after heat treatment for solid solution. ECAP-Conform was carried out using a pre-treated preform by continuous free bending. The modelling of the technological chain and the study of the VAT of the deformation zone were carried out using the Deform 3D software package. Computer simulations were performed at an initial temperature of 300 °C. The parameters of the SSS in the deformation zone and the force conditions of pressing are determined. An increase in the deformation temperature from deformation heating is established. Verification studies using an extruder ECAP-Conform. Experimental long-length contact wire samples were obtained, their physic-mechanical properties were studied after deformation and after additional hardening heat treatment.

Keywords: COPPER ALLOYS, FEM, ECAP-CONFORM, CONTINUOUS FREE BENDING

1. Introduction

The development of modern high-speed railways is accompanied by a complication of the working conditions of the sliding contact of the wire – current collector pair under conditions of increased speeds and starting currents, as well as additional loads on the wires from 3-4 times increased tensile forces and a more active wave effect1.2. These factors impose increased requirements on operating conditions and wire materials, however, the available drawing technologies are technically complex and time-consuming, require large production areas and a range of expensive equipment for shaping3. Thus, there is an urgent task of obtaining high-strength contact wires with minimizing costs. In this regard, a new combined process was developed for the formation of the contact wire by bending and equal-channel angular pressing according to the Conform scheme, which was investigated using virtual and physical methods of study.

2. Materials and methods

As a material for research, a low-alloyed copper alloys Cu-0.5Cr and Cu-0.5Zr was used. The article presents the study of chrome bronze. The initial billet underwent preliminary thermomechanical treatment, including heat treatment for solid solution and deformation processing by continuous free bending. Virtual studies were carried out by the finite element method using the Deform 3D software package. The initial temperature in the simulation was selected at 300 °C, the impeller rotation speed was 10 rpm.

3. Results and discussion

It was found that during the ECAP-Conform process with the formation of wires in the peripheral region of the deformation zone, deformation heating occurs up to 500-550 °C. It is shown that in the process of deformation, compressive stresses prevail, which, as a rule, positively affects the quality of the resulting product. The degree of accumulated strain in this case reaches e ~ 4-5. Verification studies using an extruder ECAP-Conform. Experimental long-length contact wire samples were obtained (Figure 1), their physicomechanical properties were studied after deformation and after additional hardening heat treatment.

The ultimate tensile strength after shaping was 450 ± 15 MPa. The increase in strength at this stage is associated with the simultaneous occurrence of several structural-phase processes, namely, the refinement of the structure and increase in the density of dislocations, with the simultaneous occurrence of a process of strain-induced decomposition of a solid solution with the formation of fine particles of the second phase. Subsequent dispersion hardening at the aging stage leads to an even more substantial increase in the ultimate tensile strength up to 540 ± 20 MPa. The electrical conductivity after ECAP with shaping is 42 ± 2 % IACS. Aging at 450 °C for 1 hour increases the electrical conductivity to 78 ± 2 % IACS. It should be noted that after aging, the plasticity level is 16 ± 2 %. The study of operational properties and comparison with the requirements of the standard [GOST 55647-2018] revealed that the resulting set of properties exceeds the Russian requirements in the Br2 group for contact wires for high-speed railways. The number of twists was 5, and the number of bends: 4.

4. References


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