XVII INTERNATIONAL SCIENTIFIC CONGRESS
SUMMER SESSION
09 - 12.09.2020, VARNA, BULGARIA

MACHINES.
TECHNOLOGIES.
MATERIALS 2020

PROCEEDINGS

ISSN 2535-0021 (PRINT)
ISSN 2535-003X (ONLINE)

SCIENTIFIC-TECHNICAL UNION OF MECHANICAL ENGINEERING - INDUSTRY 4.0
BULGARIA
INTERNATIONAL EDITORIAL BOARD

CHAIRMAN:
PROF. DHC GEORGI POPOV

VICE CHAIR:
PROF. DR. ENG. TSANKA DIKOVA

MEMBERS:
ACAD. IVAN VEDYAKOV, RU
ACAD. YURIJ KUZNETSOV, UA
PROF. ALEKSANDER MIHAYLOV, UA
PROF. ANATOLIY KOSTIN, RU
PROF. ADEL MAHMUD, IQ
PROF. AHMET ERTAS, TR
PROF. ANDRZEJ GOLABCZAK, PL
PROF. BONCHO BONEV, BG
PROF. GENNADY BAGLUK, UA
PROF. DETLEF REDLICH, DE
PROF. DIPTEN MISRA, IN
PROF. DMITRY KAPUTKIN, RU
PROF. DMITRY DMITRIEV, UA
PROF. EMILIA ABADJIEVA, JP
PROF. EUGENE EREMIN, RU
PROF. JUAN ALBERTO MONTANO, MX
PROF. ESAM HUSEIN, KW
PROF. ILIR DOCI, KO
PROF. IVAN MALAKOV, BG
PROF. KATIA VUTOVA, BG
PROF. KRASIMIR MARCHEV, USA
PROF. LEON KUKIELKA, PL
PROF. LYUDMILA RYABICHEVA, UA
PROF. MILAN VUKCEVIC, ME
PROF. MIHAIL AUREL TITU, RO
PROF. MLADEN VELEV, BG
PROF. MOHAMED EL MANSORI, FR
PROF. MOVLAZADE VAGIF ZAHID, AZ
PROF. NIKOLAY DYULGEROV, BG
PROF. OANA DODUN ,RO
PROF. OLGA KRIVTSOVA, KZ
PROF. PETER KOSTAL, SK
PROF. RAUL TURMANIDZE, GE
PROF. RENATO GOULART, BR
PROF. ROUMEN PETROV, BE
PROF. SASHO GUERGOV, BG
PROF. SEIJI KATAYAMA, JP
PROF. SERGEJ DOBATKIN, RU
PROF. SERGEJ NIKULIN, RU
PROF. STEFAN DIMOV, UK
PROF. SVETAN RATCHEV, UK
PROF. SVETLANA GUBENKO, UA
PROF. SVETO CVETKOVSKI, NM
PROF. TALE GERAMITCHIOSKI, NM
PROF. VADIM KOVTUN, BY
PROF. VIKTOR VAGANOV, RU
PROF. WILLIAM SINGHOSE, USA
PROF. YASAR PANCAR, TR
PROF. WU KAIMING, CN
CONTENTS

MACHINES

EVOLUTION OF ROLLING BEARING LIFE RATING THROUGH THE STANDARDIZATION
Tatjana Lazović, Ivana Topalović ........................................................................................................... 5

A NEW COATING TECHNIQUE FOR WOOD-BASED PANELS: ELECTROSTATIC POWDER COATINGS
Nadir Ayrlimus N ........................................................................................................................................ 9

SOME REQUIREMENTS TO THE MECHANISMS OF HANDLING MACHINES FOR DANGEROUS GOODS AND
SOLUTIONS FOR THEIR SATISFACTION
Grigoria Theochari, Sanjin Troha, Dimitar Karaivanov ........................................................................ 12

EFFECT OF WEIGHT AND DIAMETER VARIABLES ON BALANCE PROCESS FOR INERTIA WHEEL PENDULUM BY
USING SWING UP AND PID CONTROLLER
Eray Yılmazlar, Hilmi Kuşçu ..................................................................................................................... 16

ANALYSIS REASONS OF WEAR OF THE LOCOMOTIVE WHEEL FLANGE ON CURVED SECTIONS TRACK
Shalygin Mikhail, Vaschishina Anna ....................................................................................................... 19

3-PHASE MOTOR SPEED REGULATOR BASED ON MICROCONTROLLER AND INTELLIGENT POWER DRIVER
CONTROLLER
Stefanov G., Cekerovski T., Citcuseva Dimitrova B., Stefanova S. .............................................................. 22

DYNAMIC ANALYSIS OF A FOUR-BAR LINKAGE MECHANISM
Mustafa Arda ............................................................................................................................................... 26

COMPARISON OF THE PRECISION OF DRY SIEVE ANALYSIS VERSUS WET SIEVE ANALYSIS FOR SOME SELECTED
NATURAL CLAY VARIETIES
Suressh Aluvihara, C.S. Kalpage, Bhupendra Singh Chauhan .................................................................. 31

THE STRENOUS STATE OF THE CONTACT AT THE SLIDING - FLIP PAIRS
Odhisea Koça, Anis Sulejmani, Klodian Dhoska ...................................................................................... 37

TECHNOLOGIES

FEM-MODELING OF A BIMETALLIC WORKPIECE DEFORMATION BY “ECAP – DRAWING” COMBINED PROCESS
Irina Volokitina, Andrey Volokitin, Abdrahman Naizabekov, Evgeniy Panit .................................................. 41

INNOVATIVE DESIGN FOR REPAIR OF CORRECTED INDUSTRIAL REINFORCED CONCRETE STRUCTURES OF
LIGHT SODA SILOS - SOLVAY SODI AD, DEVNYA
Valery Naidenov, Tzvetan Georgiev ........................................................................................................... 45

FEATURES OF CREATION OF MULTIPROBE SYSTEM FOR NANOMETRIC MEASUREMENTS OF GEOMETRICAL AND
MECHANICAL PROPERTIES OF SURFACES OF MICROSYSYTEM DEVICES
Olga Andrienko, Svitlana Bilokin, Maksym Bondarenko ............................................................................ 50

ANALYSIS OF WELDING OF ALUMINIUM ALLOY AA6082-T6 BY TIG, MIG AND FSW PROCESSES FROM
TECHNOLOGICAL AND ECONOMIC ASPECT
Aleksandra Koprivica, Darko Bajić, Nikola Šibalić, Milan Vukčević .................................................................. 54

DETERMINATION OF THE PARAMETERS OF THE DRYING PROCESS OF SODIUM BICARBONATE IN A PNEUMATIC
DRYER
Milica Josimovic, Slavica Prvulovic, Jasna Tolmac, Vesna Mihajlovic ................................................................ 59

BIOLOGICAL EFFECTS OF MOBILE PHONE EXPOSURE
Magdalena Garvanova .................................................................................................................................. 61

DETECTION OF SIGNALS FROM PULSARS THROUGH HOUGH TRANSFORM
Ivan Garvanov, Nikola Petrov, Magdalena Garvanova, Nikolay Geshev, Todor Kostadinov .................................. 66

EXPERIMENT ON CHARGING AN ELECTRIC VEHICLE LIFEP04 BATTERY AFTER OVER-DISCHARGE
Nikolay Pavlov, Diana Dacova ..................................................................................................................... 70

LATERAL TILTING IN ROAD VEHICLES - A REVIEW
Diana Dacova, Nikolay Pavlov ..................................................................................................................... 73
MATERIALS

PRODUCTION OF POWDERS OF COPPER ALLOY (COPPER 85, TIN 5, LEAD 5, ZINC 5) BY SPRAYING A MELT WITH A GAS FLOW
Ilyushchanka A., Charniak I., Kusin A., Yarahovich D., Kusin R., Dechko M., Marhanava V. ................................................................. 78

STEELS WITH BAINITE STRUCTURE FOR RAILWAY WHEELS
Prof. Dr. Sci. Gubenko S. ........................................................................................................................................................................ 81

LAYERED COMPOSITES BASED ON NIOBium WITH SILICIDE-CARBIDE OR SILICIDE-BORIDE HARDENING
Korzhev Valery Polikarpovich, Kiiko Vyacheslav Mikhailovich, Prokhorov Dmitry Vladimirovich, Zhelyaykova Irina Sergeevna ........................................................................................................................................................................ 85

PROPERTIES OF COMPOSITES WITH NANODIAMONDS OF DETonation SYNTHESIS
E. A. Petrov .................................................................................................................................................................................................. 89

MODEL FOR HIGH-PRESSURE WATER ATOMIZATION OF METAL MELT USING A VORTEX TYPE JET
Ternovoy Yu., Bagliuk G., Panova V. ........................................................................................................................................................................ 92

EFFECTS OF VARIOUS FIRE RETARDANTS ON MECHANICAL AND FIRE PROPERTIES OF PLYWOOD
Nadir Ayrilmis ................................................................................................................................................................................................. 96

FABRICATION, STRUCTURE AND USE OF NANOCELLOUSE AS REINFORCEMENT IN POLYMER COMPOSITES
Nadir Ayrilmis ................................................................................................................................................................................................. 100

SYNTHESIS OF ENERGY-EFFICIENT CONTROL METHODS OF THE ELECTROMECHANICAL DISINTEGRATOR OPERATING MODES
Vasyl Shynkarenko, Viktoriia Kotliarova ........................................................................................................................................................................ 105

HYDROPHILIZED UNSATURATED POLYESTER RESIN BASED ON A TWO-COMPONENT SYSTEM OF SULFUR AND CEMENT
Cherkezova R. Hristova T. Zafirova K. ........................................................................................................................................................................ 109

STRUCTURAL CHANGES AND RHEOLOGY OF THE CU-0.6CR ALLOY AT DIFFERENT STRAIN RATES AND TEMPERATURES OF UPSETTING
Aksenov Denis, Raab Georgy, Asfandiyarov Rashid ........................................................................................................................................................................ 112

MANAGEMENT

EVOLUTION OF CREATIVE THOUGHT WITH ELEMENTS OF ARTIFICIAL INTELLIGENCE ON EXAMPLE OF SYNTHESIS OF CLAMPING MECHANISMS
Kuznetsov Yu. N. .................................................................................................................................................................................................. 115

COMPLEX STUDY OF THE BIOAEROSOL COMPOSITION OF THE ATMOSPHERE OVER URBAN AREAS BASED ON LIDAR MONITORING DURING THE QUARANTINE COVID-19
Angelova B., Iliev M., Ilieva R., Grigorov I., Kolarov G., Paneva D., Kolev Ch., Z. Cherkezova-Zheleva, Groudeva V., Stoyanov D., Nedkov I. ........................................................................................................................................................................ 122

ON METROLOGICAL SUPPORT FOR ENTERPRISES
Ivanova T., Rjabčikova I., Kobenko S., Pučkovs A., Ivanovs D. ........................................................................................................................................................................ 127

REMOTE REAL-TIME CONTROL OF AUTOCLAVE STERILIZATION PROCESS
Stoyanka Madzhbarova, Rosen Gerasimov, Adriana Prodanova, Hristo Dinkov ........................................................................................................................................................................ 131
Evolution of rolling bearing life rating through the standardization

Tatjana Lazović, Ivana Topalović
University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Institut for Standardization of Serbia, Belgrade, Serbia
tlazovic@mas.bg.ac.rs

Abstract: The operational ability of a rolling bearing selected for a specific application is assessed based on service life. The basic formula for bearing rating life was established more than 70 years ago by A. Palmgren. The first standard presenting a basic mathematical model for rating life calculation was published in 1962 (ISO/R281). The content of this standard has been revised and the next version was published in 1977 (ISO 281-1). The novelty was the introduction of adjustment factors for reliability other than 90%. This standard was replaced by the ISO 281 standard in 1990, which introduced additional adjustment factors for special bearing properties and operating conditions. The latest version of the ISO 281 standard was published in 2007. This standard provides a procedure for calculating the modified service life by taking into account the additional impacts of lubrication condition, lubricant contamination and limit fatigue load. Furthermore, the document ISO/TS 16281 was published in 2008 introducing the influence of bearing internal clearance and misalignment in the rating life calculation. An overview of the development of a standardized formula for bearing rating life is given in this paper, on the example of deep groove ball bearing under radial operational loading.

Keywords: ROLLING BEARINGS, RATING LIFE, ADJUSTED RATING LIFE, MODIFIED RATING LIFE, STANDARDIZATION, ISO

1. Introduction

A first discussion on the international level on standardization of the calculation method for load ratings of rolling bearings took place at the conference of the International Federation of the National Standardizing Associations (ISA) held in 1934 [1,2]. The first proposals for the definition of the fundamental concept to load rating and life calculation standards were included in the ISA 1945 report on the state of rolling bearing standardization. This report was distributed in 1949 as a document of Technical Committee ISO/TC 4 and the definitions it contained are in essence those given in ISO 281:2007 [3], which is the last version of the standard on the bearing life and basic dynamic load rating concepts. These concepts are based on the theory of Palmgren and Lundberg, using Weibull statistics [4-6]. The first proposal to ISO named “Load rating of ball bearings” was presented in 1950. After that, load rating and life calculation methods were studied by ISO Technical committee 4 at eleven meetings from 1951 to 1959. Finally, The draft ISO Recommendation was issued in 1959, and ISO/R281 was accepted by ISO Council in 1962 [1,2].

In 1964, the member body from Sweden suggested that ISO/R281 has to be reviewed and submitted proposal considering the development of imposed bearing steels, which was not accepted from the technical committee. Three years later, the technical committee accepted a suggestion by the member body from Japan to do a revision of ISO/R281. The member body from the USA submitted the Draft AFMBA (Anti-Friction Bearing Manufacturers Association) standard “Load ratings and fatigue life for ball bearings” for consideration in 1970 and “Load ratings and fatigue life for roller bearings” in 1971. These proposals were investigated in detail at five meetings from 1971 to 1974 [1,2]. The third and the final Draft proposal was circulated as a Draft International Standard in 1976 and became ISO 281-1:1977. The major part of it was almost the same as ISO/R281, but, based on American investigations during the ‘60s, a new clause was added, dealing with adjustment of rating life for reliability other than 90% and for material and operating conditions [1,2]. Furthermore, supplementary theoretical background with a derivation of mathematical expressions and new factors given in ISO 281-1:1977 was published first as ISO 281-1:1997 “Explanatory notes” in 1979 and later as ISO/TR 8646:1985 [1].

The International Standard ISO 281:1990 [7] specifies methods of calculating the basic dynamic load rating of rolling bearings manufactured from contemporary, commonly used, good quality hardened steel in accordance with good manufacturing practice and basically of conventional design, which life is associated with 90% reliability. In addition, this version of standard ISO 281 specifies calculation adjusted rating life for various reliabilities, special bearing properties and specific operating conditions. These influences are taken into account by life adjustment factors. Detailed background information regarding the derivation of formulae and factors given for this standard are found in ISO/TR 8646 [1], as it was used for the previous version as well. The Technical Specification ISO/TS 16799 published in 1999 [8] introducing different factors in the calculation of basic dynamic load ratings and equivalent load for radial and thrust angular-contact ball bearings.

ISO 281:2007 [3] specifies methods for calculating the basic rating life, which is the life associated with 90% reliability, with commonly used high quality material, good manufacturing quality and with conventional operating conditions. In addition, it gives calculating procedure for modified rating life, for reliabilities other than 90%, specific lubrication conditions, lubricant contamination, as well as fatigue load limit of the bearing raceways. Background information regarding the derivation of equations and factors in this standard is given in two technical specifications ISO/TS 1281-1 [1] and ISO/TS 1281-2 [9] published in 2008. The first edition of ISO/TR 1281-1 “Explanatory notes – Basic dynamic load rating and basic rating life” cancels and replaces the first edition of ISO/TR 8646:1985, which has been technically revised. The first edition of ISO/TR 1281-2 “Explanatory notes – Modified rating life calculation, based on a system approach to fatigue stresses” gives background information regarding the derivation life modification factors. Calculation method given in ISO 281:2007 does not consider the influence of tilted or misaligned rings and bearing clearance on the service life. The Technical Specification ISO/TS 16281:2008 describes and advanced calculation method, which considers tilting or misalignment, operating clearance and internal load distribution between rolling elements [10], but only as information for computer calculation. There is no completed a mathematical model for any modification factor to be used in life prediction calculation method. For example, the factor of the influence of internal radial clearance in radially loaded ball bearing would have values 0.3…1.0 depending on load and clearance, as it is shown in [11]. Surely, revisions of ISO standard for dynamic load ratings and rating life will be required from time to time, as the result of new scientific developments or newly obtained information concerning specific bearing types and materials [3].

An overview of ISO 281 standards for rolling bearings dynamic load rating and rating life with appropriate explanatory notes in the form of additional technical specifications to which the standards refer is made in this paper. The standard procedure for calculating the basic service life [7,3], adjusted service life [7] and modified service life [3] is presented, taking into account the influence of reliability, lubrication, contamination and fatigue load limit. A numerical example was made for the purpose of comparative analysis of the standardized calculation and the calculation using the data of the rolling bearings manufacturers.
2. ISO 281:1990

2.1. Basic rating life

The basic rating life of radial deep groove ball bearing is given by

\[ L_{10} = \left( \frac{C_t}{P_t} \right)^{3} \]  

(1)

where \( C_t \) is basic dynamic radial load rating, \( P_t \) – dynamic equivalent radial load.

Subscript “10” is the probability of failure (in %) and gives information on reliability. The standard basic life formula is derived under the assumption of 90% reliability, which means that for a group of apparently identical rolling bearings, operating under the same conditions, 90% of the group is expected to attain or exceed a specified service life.

The basic dynamic radial load rating for radial contact ball bearings is given by:

\[ C_t = b_m f_c Z^{2/3} D^{1.8} \]  

(2)

where \( b_m \) is the rating factor for contemporary, normally used material and manufacturing quality, depending on bearing type and design, \( f_c \) – the factor which depends on the geometry of the bearing components, the accuracy to which the various components are made, and the material, \( Z \) - number of balls, \( D \) - ball diameter.

Values of rating factor \( b_m \) are table data [7] and for radial deep groove ball bearings \( b_m=1.3 \). Values of \( f_c \) factor are also given in appropriate standard table [7] for different bearing types and ratio \( D/d \), where \( D \) is pitch diameter of ball set. Instead, the mean bearing diameter \( 0.5(d + D) \) can also be used, where \( d \) is bearing bore diameter and \( D \) is bearing outside diameter.

Dynamic equivalent radial load \( P_t \), for radial contact ball bearing, under constant radial and axial loads is given by

\[ P_t = X F_c + Y F_a \]  

(3)

where \( X \) and \( Y \) are dynamic factors, radial and axial, respectively (given in standard tables [7]), \( F_c \) and \( F_a \) – bearing radial and axial load (radial and axial components of actual bearing load), respectively.

In the case of deep groove ball bearing loaded with pure radial external load \( F_c \), the equivalent load is

\[ P_t = F_c \]  

(4)

2.2. Adjusted rating life

The adjusted bearing life is actually the basic rating life, given by Eq. (1), adjusted for the reliability of \((100 - n)\%\), for special bearing properties and for specific operating conditions:

\[ L_{na} = a_1 a_2 a_3 L_{10} \]  

(5)

where \( a_1 \) is life adjustment factor for reliability, \( a_2 \) - life adjustment factor for special bearing properties, \( a_3 \) - life adjustment factor for operating conditions.

Values of \( a_1 \) factor are given in standard tables [7], depending on required reliability (90…99)%; values of \( a_2 \) and \( a_3 \) factors are discussed only. In accordance with contemporary bearing technology, rolling bearings could be made by the use of a special type and quality of material and/or special manufacturing process and/or special design. These special properties are taken into account by the adjustment factor \( a_2 \). The values of this factor are mostly based on experience and could be obtained from the bearing manufacturers [7].

The life adjustment factor \( a_3 \) takes into account the influence of adequacy of the lubricant and lubrication system, contamination, and conditions causing changes in material properties. The standard recommends that bearing manufacturers provide appropriate values of \( a_3 \) in accordance with the specific application and used bearing type.


3.1. Modified rating life

The modified rating life equation for the rolling bearing is

\[ L_{mn} = a_1 a_2 a_3 L_{10} \]  

(6)

where \( L_{10} \) is basic rating life, given by Eq. 1, \( a_1 \) - modification factor for reliability, \( a_2 \) – modification factor for system approach.

It is important to know that the \( a_1 \) values for the reliabilities 95% to 99% have been modified compared with the corresponding values in the ISO 281:1990. Furthermore, the table with \( a_3 \) values is extended to 99.95%. In the period between the last two editions of standard ISO 281, a practical method was developed for performing modified life systems approach calculations by introduction \( a_{ISO} \) factor. This factor considers the fatigue stress limit of the bearing steel and also the influence of lubrication and contamination on bearing service life.

3.2. Life modification factor \( a_{ISO} \)

The life modification factor for a system approach is determined by analytical investigations, empirical laboratory tests and practical experience. Besides bearing type, fatigue load and bearing operational load, the factor \( a_{ISO} \) considers the influence of [3]: lubricant (the type of bearing size and speed, lubricant, viscosity, additives); environment (seals, contamination level); contaminant particles (hardness and particle size in relation to bearing size, lubrication method, filtration), and cleanliness during mounting.

The life modification factor \( a_{ISO} \) for radial ball bearings can be calculated with equation [3]

\[ a_{ISO} = 0.1 \left( 1 - \left( \frac{A}{\kappa B} \right)^{0.8} \right) \left( \frac{e_C C_u}{P} \right)^{1.9} \]  

(7)

where \( \kappa \) is viscosity ratio, \( e_C \) – contamination factor, \( C_u \) – fatigue load limit, \( P \) – dynamic equivalent load, \( A \) and \( B \) – constants depending on viscosity ratio values (Table 1).

| Table 1: Constants A and B in Eq.7 depending on viscosity ratio \( \kappa \) |
|-----------------|-----------------|
| \( \kappa \)    | \( A \)         | \( B \)         |
| 0.1 ≤ \( \kappa \) < 0.4 | 2.5649          | 0.054381        |
| 0.4 ≤ \( \kappa \) < 1  | 1.9987          | 0.19087         |
| 1 ≤ \( \kappa \) ≤ 4  | 1.9987          | 0.071739        |

Viscosity ratio is given by

\[ \kappa = \frac{\nu}{\nu_1} \]  

(8)

where \( \nu \) is the actual kinematic viscosity of the lubricant at operating temperature, \( \nu_1 \) – reference kinematic viscosity at operating temperature. In the case of greases, these are operating viscosities of the base oil.

The actual kinematic viscosity of the lubricant at operating temperature is estimated based on the operating temperature and the viscosity of applied lubricant at temperature of 40 °C, using diagrams from catalogues of bearing manufacturers [13,14] or oil and grease manufacturers.

The reference kinematic viscosity can be calculated with following equations [3]

\[ \nu_1 = 45000n^{-0.83}D_{pw}^{0.5} \text{ for } n < 1000 \text{ r/min} \]  

(9)

\[ \nu_1 = 4500n^{-0.5}D_{pw}^{0.5} \text{ for } n \geq 1000 \text{ r/min} \]  

where \( n \) is bearing speed, \( D_{pw} \) - pitch diameter of ball set (or mean bearing diameter).

The contamination factor \( e_C \) takes into account bearing life reduction caused by solid particles in the lubricant film. It is dependent on type, size, hardness and quantity of the particles, on lubricant film thickness (viscosity ratio \( \kappa \)), as well as on bearing size. Its value varies from 0 (very severe contamination) to 1 (extreme cleanliness). In the transition between normal cleanliness
An advanced method for calculating the fatigue load limit \( C_a \) is described in [3]. The simplified equations to estimate this quantity are given as well:

\[
C_a = \frac{C_0}{22} \quad \text{for } D_{pw} \leq 100 \text{ mm},
\]

\[
C_a = \frac{C_0}{22} \left( \frac{100}{D_{pw}} \right)^{0.5} \quad \text{for } D_{pw} > 100 \text{ mm},
\]

where \( C_0 \) is basic static load rating.

The static load rating for ball bearing can be calculated in accordance with [12]

\[
C_q = f_0 D^2 w,
\]

where \( f_0 \) is the factor which depends on the geometry of the bearing components, given in standard tables.

The results of the simplified estimation of fatigue load limit can differ from the results of advanced method which is preferred [3].

### 4. Numerical example

A numerical example was made in order to apply a standard method for calculating life modification factor for system approach. The factor \( a_{ISO} \) was estimated for four bearings of the same bore diameter (30 mm) and of different series (60, 62, 63 and 64).

#### Table 3: Estimation of the life modification factor for the system approach

<table>
<thead>
<tr>
<th>Estim.</th>
<th>6006</th>
<th>6206</th>
<th>6306</th>
<th>6406</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d ), mm</td>
<td>-</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>( D_e ), mm</td>
<td>-</td>
<td>55</td>
<td>62</td>
<td>72</td>
</tr>
<tr>
<td>( Z )</td>
<td>-</td>
<td>11</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>( D_{pw} ), mm</td>
<td>-</td>
<td>6.744</td>
<td>9.525</td>
<td>12.303</td>
</tr>
<tr>
<td>( D_{pw} )</td>
<td>-</td>
<td>42.5</td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td>( C_{se} ), kN</td>
<td>-</td>
<td>39.8</td>
<td>59.8</td>
<td>59.0</td>
</tr>
<tr>
<td>( f_0 )</td>
<td>-</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>( C_{se} ), kN</td>
<td>-</td>
<td>13.2</td>
<td>19.4</td>
<td>28.1</td>
</tr>
<tr>
<td>( C_{se} ), kN</td>
<td>-</td>
<td>3.777</td>
<td>5.09</td>
<td>7.14</td>
</tr>
<tr>
<td>( P_{c} ), kN</td>
<td>-</td>
<td>6.6</td>
<td>9.7</td>
<td>14.05</td>
</tr>
<tr>
<td>( v_s ), mm/s</td>
<td>-</td>
<td>8.7</td>
<td>8.7</td>
<td>8.7</td>
</tr>
<tr>
<td>( \nu_{eq} )</td>
<td>-</td>
<td>28.1</td>
<td>28.1</td>
<td>28.1</td>
</tr>
<tr>
<td>( a )</td>
<td>-</td>
<td>0.432</td>
<td>0.432</td>
<td>0.432</td>
</tr>
<tr>
<td>( A )</td>
<td>-</td>
<td>1.0987</td>
<td>1.0987</td>
<td>1.0987</td>
</tr>
<tr>
<td>( B )</td>
<td>-</td>
<td>0.19087</td>
<td>0.19087</td>
<td>0.19087</td>
</tr>
<tr>
<td>( \sigma_{eq} )</td>
<td>-</td>
<td>0.1794</td>
<td>0.2078</td>
<td>0.2234</td>
</tr>
<tr>
<td>( \sigma_{eq} )</td>
<td>-</td>
<td>0.285</td>
<td>0.331</td>
<td>0.337</td>
</tr>
</tbody>
</table>

The external geometry parameters (bore diameter and outside diameter) of these bearings are known from the manufacturer’s catalogues [13,14]. The authors of this paper have the appropriate data of internal geometry (number and diameter of balls in considered bearings). Based on these geometric parameters, the standard dynamic and static load ratings were determined (Table 3). All bearings are subjected to the same relative load (half of its own dynamic load capacity). The lubricant is the grease of normal operational conditions, but in many applications actual contact stresses are larger than fatigue stress limit reducing bearing life.

The fatigue load limit \( C_{se} \) for ball bearing is given by

\[
C_{se} = 0.2288 Z Q_u^{0.5} \quad \text{for } D_{pw} \leq 100 \text{ mm},
\]

\[
C_{se} = 0.2288 Z Q_u \quad \text{for } D_{pw} > 100 \text{ mm},
\]

where \( Q_u \) is the fatigue load limit of a single contact.

The fatigue load limit \( Q_u \) is the minimum fatigue load limit of the highest loaded contact (contact between the mostly loaded ball and one of the raceways):

\[
Q_u = \min \left( Q_u, \ Q_{we} \right),
\]

where \( Q_{we} \) are fatigue load limit at a single inner ring raceway contact and a single outer ring raceway contact.
life is approx. (64...72)% even in the case of normal lubricant cleanliness (!). Therefore, the factor $a_{ISO}$ must always be taken into account in the calculation of the bearing service life.

A comparative overview of the calculation of bearing basic and modified rating life according to ISO and two bearing manufacturers is given in Table 4.

**Table 4: Deep groove ball bearing life comparison**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Estim.</th>
<th>6006</th>
<th>6206</th>
<th>6306</th>
<th>6406</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{0}$, kN</td>
<td>Eq.2, T.3</td>
<td>13.2</td>
<td>19.4</td>
<td>28.1</td>
<td>43.0</td>
</tr>
<tr>
<td>$C_{0}$, kN</td>
<td>Eq.14, T.3</td>
<td>8.3</td>
<td>11.2</td>
<td>15.7</td>
<td>23.5</td>
</tr>
<tr>
<td>$C_{0}$, kN</td>
<td>Eq.13, T.3</td>
<td>0.377</td>
<td>0.509</td>
<td>0.714</td>
<td>1.068</td>
</tr>
<tr>
<td>$C_{0}$, kN</td>
<td>Eq.1</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>$a_{ISO}$</td>
<td>Eq.7, T.3</td>
<td>0.281</td>
<td>0.322</td>
<td>0.328</td>
<td>0.393</td>
</tr>
<tr>
<td>$P_{r}$, kN</td>
<td>(%)</td>
<td>6.6</td>
<td>9.7</td>
<td>14.05</td>
<td>21.5</td>
</tr>
<tr>
<td>$L_{10h}$, $10^6$</td>
<td>Eq.1</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

There are some differences in load ratings and fatigue load limit, because actual bearing designs, based on the expertise of the manufacturer can deviate from standard reference geometries, as well as used steel of specific quality. Consequently, there are differences in estimated basic and modified service life. This numerical example showed that there are no large deviations in the calculation procedures proposed by the bearing manufacturers in relation to the standard recommendations. Even more, there is only a slight difference in the results of the bearing life assessment from different manufacturers of the same rank and product quality in the bearing market.

5. ISO/TS 16281:2008

The last version of International Standard on rolling bearings dynamic load ratings and rating life was issued in 2007. In this edition, recommended calculation method for rolling bearing service life takes into account influences of reliability, lubrication, contamination, internal stresses from mounting, hardening, and the fatigue load limit of the material. It is, therefore, possible to determine bearing service life in a more complete way than before. However, the calculation method given in ISO 281:2007 do not consider the objectively present influence of internal clearance and rings tilting or misalignment on bearing service life. For this purpose, the document ISO/Technical Specification 16281, issued in 2008, describes an advanced calculation method, which covers influencing parameters additional to those described in ISO 281: tilting or misalignment, operating clearance of the bearing and internal load distribution on rolling elements. The Technical specification [10] is applied to radial ball bearing, subjected to radial and axial load and roller bearings subjected to pure radial load, both with radial clearance, edge stress and tilt. However, this document does not consider a radial ball bearing with radial clearance subjected to pure radial load, which is a common case in bearing arrangements. The proposed calculation method is not complete and cannot be applied by the user of this Technical Specification. Thereby some quantities in the proposed mathematical model can be solved only by iteration, using computer support. Regardless of this, it is significant information for the user that these influences exist and should not be negligible, as well as it is a theoretical background and basis for further development of calculation procedure considering new influences. Even more, it is stated in the Scope of [10] that it is primarily intended to be used for computer programs and that only together with ISO 281 covers the information needed for life calculations. It is recommended that either this Technical Specification or advanced computer calculations provided by bearing manufacturers, for determining the dynamic equivalent reference load under different loading condition, be used.

6. Conclusion

From 1962 to 2008, a major step was made in bearing service life calculation, by introduction modification factors. The influence of reliability other than 90%, lubrication, contamination and fatigue load limit is very well covered, which is confirmed by significant values of these factors. The influences of load distribution, internal clearance and misalignment on bearing service life has also been identified but has not been quantified through any additional life modification factors. The Technical Committee for rolling bearings is supposed to be very active and surely we could expect in next version of ISO 281 that standard formula for the rating life will be modified by additional factors for the all newly identified impacts.

7. References

4. A. Palmgren, On the carrying capacity and life of ball bearings, Ball Bearing Journal, 034, 34-44 (1937)
13. INAF/FAI, Rolling bearings, HR1, Schaeffler Group, (2008)

Acknowledgement

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-68/2020-14/200135).
A new coating technique for wood-based panels: electrostatic powder coatings

Nadir Ayrilmis
Department of Wood Mechanics and Technology, Forestry Faculty, Istanbul University, Bahcekoy, Sariyer, 34473, Istanbul, Turkey
nadiray@istanbul.edu.tr

Abstract: Powder coating technology is relatively new for furniture industry although it has been used in metal industry for a long time. Its use has rapidly increased in furniture industry due to its great advantages such as design freedom, as the powder particles will reach any place, so it covers objects in nearly any shape. The efficiency of this technique can be enhanced to 95 wt% material usage by collecting the powder. The most used thermosetting powders are epoxy, polyester, polyurethane, acrylic, and hybrid composition. The powder coatings do not contain any solvent, volatile organic compounds (VOCs) and less negative impact on health than solvent-based coatings. Unfortunately, wood is non-conductive material and for a successful coating application, the special grade MDF needs to be used. Furthermore, the optimum application parameters such as pre-curing, curing, coating type and its curing temperature, particle size, film thickness, oven design etc., significantly affect the quality of the coating. Especially, the coating equipment such as gun settings injectors, air pressure, and grounding should be controlled before each production. The equipment can be amortized for a short time if it is used efficiently although it has high start-up cost.

KEYWORDS: ELECTROSTATIC POWDER COATINGS, WOOD-BASED PANELS, POWDER COATINGS,

1. Introduction

The furniture industry is one of the largest industries on the World and its production is increasing every year due to developing construction industry and increasing human population. There is an increasing interest for electrostatic powder coating technology by wood-based panel and furniture industries in the last decade. Solvent-based paints release high amount of organic solvents, which are harmful to humans in buildings, especially for volatile organic compounds (VOCs).

The advantages of electrostatic powder coatings used in the furniture industry as compared to the solvent and water-based liquid coatings are given as follows [1,2]:

- Powder coatings has significant durability in humid conditions and chemical resistance to abrasion, corrosion, scratching, and chemicals
- Powder coatings stay bright with less fading, and color selection is virtually unlimited with high and low gloss, and clear finishes available
- Texture selections range from smooth surfaces to wrinkled or matte finishes, and rough textures are available for hiding surface imperfections
- Powder coatings can produce much thicker coatings in one coat than conventional liquid coatings without running or sagging
- They do not contain solvent, and thereby the process emits negligible, if any, polluting volatile organic compounds (VOCs) into the atmosphere
- Powder coating has less negative impact on health than the other coatings
- The processes used for powder coating do not require venting, filtering, or solvent recovery
- Cost and energy saving because there is less need for heating outside air to supply oven exhaust air
- Most of the powder coating over-spray can be retrieved and re-used for greater product utilization
- Powder coating is a ready-to-use product that does not require any mixing procedure or thinner, reduced process time
- Design flexibility, powder particles can reach any place
- Any kind of decorative surface (smooth, glossy, rough, sandpaper etc.) is possible with the powder coating
- Cutting and drilling without damage
- Good film properties (tough, durable, hard, resistant to scratch)
- Application technique for powder coating is simple, and the user training can be provided within a short period of time. Manual and robotic systems are suitable for the application
- It enables one step finishing process

2. Powder coating process

The production line of powder coating on the wood-based panels is presented in Figure 1 [2]. The MDF substrates to be coated with powder coating are shown in Figure 2 and the coated substrated are presented in Figure 3.

Figure 1. The production line of powder coating on the wood-based panels [2].
Figure 2. MDF substrates to be coated with powder coating.
2.1. Characteristics of wood-based panels

In general, the curing temperature of traditional powder coatings such as epoxy and polyester used in the metal industry is between 180 °C and 250 °C. These temperatures are not suitable for wood-based panels because high temperatures cause the thermal degradation of wood-based panels, especially hemicellulose. In addition, high temperatures may result in splits in the edges of the panels due to internal stress caused by moisture release. These defects are generally as a result of the expansion and contraction of the substrate due to release of moisture and/or other gases from the substrate, as well as residual stress in the MDF caused by hot pressing parameters, higher contrast in the density profile, and other production parameters. When the moisture content of the wood-based panel is high (above ≥7%), particularly, the cracks can be observed in the edge of the panel during the curing of the coated panel (Fig. 7). The storage conditions of the MDF (relative humidity and temperature) affects the quality of powder coating application because it negatively affects the dimensional stability (uneven flatness) and may increase or decrease the moisture of the panel. The uneven parts may not correctly positioned to the sprayer and results in non-homogenous film thickness because the sprayer is fixed in the channel. Stacking accuracy of MDF panels in the storage location is important to prevent creep problem.

As known, the electrical conductivity of wood is lower than metals. Unfortunately, this is disadvantage for powder coating application. Since the powder coatings are preferably applied using electrostatic spraying equipment, sufficient electrical conductivity of the surface is a major requirement and the correct moisture content plays an important role as well. In a previous study, the electrical resistance, treatment temperature, and moisture content were systematically studied to better understand [7].

The MDF (medium density fibreboard) is more suitable than particleboard regarding powder coating application. This is because the surface of the MDF is more compact than particleboard. The electrical resistance of MDF is influenced by the panel moisture content and its uniform distribution in the panel, and the panel temperature. Another method for improving charge retention is to incorporate sufficient amounts of electrically conductive materials into the substrate. MDF manufacturers usually use special conductive or anti-static additives which increase electrical conductivity of the surface. The use of metal powders, inorganic salts such as sodium chloride, carbon black, and other conductive materials as additives to the composite may significantly enhance charge retention [8]. The conductive materials may be added into the resin in the production of wood-based panel or can be applied on the panel surface by brush spray or cylinders. The conductive material implant into the pores of the substrate [9].

3. Key factors for successful powder coating to MDF panels

For a successful powder coating application on the wood-based panels such as particleboard, MDF, and plywood, four important parameters should be considered.
1. Use of special grade MDF. The raw material type, production parameters should be specified according to coating grade MDF. The surface of the substrate should be removed from dust or impurities to prevent the insufficient deposition and adhering of powder of the finished.

2. The surface texture and manufacturing parameters of the wood-based panels are two significant parameters. Non-uniform surface texture (rough and unsmooth) and poor MDF quality lead to problems related to unsmooth film formation and inappropriate surface qualities.

3. The substrate must be fully encapsulated by powder coating. The full encapsulation prevents high moisture uptake. Right pre-heating and curing cycle should be adjusted to minimize moisture loss from MDF substrate.

2.2. Curing conditions of powder coatings applied on the wood-based panels

Usually two steps are used in the coating of wood-based panels, primer coating and final coating, respectively. After the primer coating application, the substrate is be finely sanded with a sandpaper (mostly minimum 200 grit) according to final coat and end-use properties. Depending on the curing conditions of thermosetting powder coatings and substrate properties, the thermal curing temperature and time may vary from generally between 100 °C and 140 °C (generally 130 °C) and the curing time may vary from 3 to 15 min. Curing temperature should be carefully controlled carefully. An uncured powder coatings may look good but will be less durable to the physical and mechanical effects, and might lead to moisture absorption [10]. Moreover, non-uniform temperature distribution on the substrate will negatively affect the powder deposition to the substrate, and can cause defects such as warping and substrate cracking. If the curing oven is not carefully designed for the profile of the substrate, (including alignment, recirculation air change, fresh air intake ratio, etc.), uniform temperature distribution on the substrate will not be obtained.

2.3. Particle diameter of powder coatings

The powder coating is prepared from a mixture of finely ground particles of pigment, polymeric resin, and some additives. Powder coatings with a high amount of resin improve the mechanical properties of cured the powder coatings. This is because powder coatings having a low amount of resin increase potential risk of peel on the coated surface. The diameter of traditional powder coatings are generally varied from 30 to 60 μ, which make thicker film with rougher appearance as compared to the solvent-based coatings [10]. Furthermore, as the particle size of the powder is too high (i.e.>75um), the leveling property of the coating film is deteriorated, and the orange peel is likely to occur [11].

3. Conclusions

Although electrostatic powder coating technology has been used in the metal industry for a long time, it is a still new technology for the furniture industry. However, its use has rapidly increased in many countries because they do not contain any solvent, volatile organic compounds (VOCs) and less negative impact on health than the other coatings. Wood is non-conductive material and for a successful coating application, the special grade MDF needs to be used. Furthermore, the optimum application parameters such as pre-curing, curing, coating type and its curing temperature, particle size, film thickness, oven design etc., significantly affect the quality of the coating. Especially, the coating equipment such as gun settings, injectors, air pressure, and grounding should be controlled before each production. These parameters should be carefully considered.

Powder coating industry also developed ultra curing powder coatings for furniture industry. Since the establishment cost (start-up cost) is still expensive for the small and medium size furniture factories but it is reasonable for large size producers. The equipment can be amortized for a short time if it is used efficiently, although it has high start-up cost.

4. References


1. Introduction
In addition to the universal requirements for handling (lifting and transport) machines (HM), HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements. These requirements can be found in the relevant regulations, such as the regulations of the State Agency for Metrology and Technical Supervision [16, 17] and various national and international standards [1, 2, 6, 7, 8, 9, 10, 12]. There are also good practices that manufacturers adhere to, even though they are not regulated [18].

Some of these requirements concern the machine as a whole (seismic resistance, elevated safety factors and requirements for the reliability of the parts, etc.). Others refer to the individual mechanisms or their units and assemblies.

BDS 8916-81 [6] stipulates that the group of working modes (duty) of load lifting mechanisms and jib lifting mechanisms for cranes transporting molten metal or slag, toxic, explosive substances and other dangerous goods must not be less than 5, except for self-propelled jib cranes, for which it must be not less than 3.

This requirement does not apply to auxiliary lifting mechanisms if they do not take part in the transport of the above loads. In the absence of specific data for determining the class of use and the load factor, it is allowed to determine the group of the operating mode from a table listing the different types of cranes and their mechanisms (main and auxiliary lifting, trolley and crane movement, rotation, range change and other mechanisms). In this table, the recommended working mode of the main lifting mechanism for most metallurgical cranes (with forks, mold, multi-magnetic, multi-grapple, for loading furnaces, stripper, shaft, clamps) is very heavy (6th group), whereas for hardening, foundry (casting), and forging crane - heavy (5th group).

In BDS ISO 4301-5 [9] there is no special text for cranes for dangerous goods, but in the table with instructions are assigned the highest classification groups - A7 and A8 for the crane and M7 and M8 for the mechanisms. The classification of bridge and gantry cranes and their mechanisms, depends on the use of the crane for cranes in steel mills (Table 1). Exceptions are only the cranes in the rolling mills (A2, M3, and M4 respectively).

Irrespective of the mode of operation in the strength calculation of the hoists of cranes for molten metal or slag, poisonous and explosive substances, a safety factor of not less than 6 must be used (as for very heavy-duty operation of cranes and jib cranes). Moreover BDS 15164-80 [7] obliges protection with fences of the ropes of cranes carrying molten metal or liquid slag from the direct action of heat and splashes of metal.

According to BDS 16879-88 [8] during changing the range and traveling of the cranes and trolleys with inclined railroads, intended for transportation of molten metal or slag, poisonous or explosive substances and other dangerous goods, the use of friction and thumb couplings in lifting mechanisms is not allowed.

Another requirement is that the lifting mechanism must have two brakes – working and locking (activated after stopping the mechanism) [13, 15].

Abstract: The article reviews the requirements for the lifting mechanisms of cranes according to various regulations concerning dangerous goods. Particular attention is paid to these requirements regarding gear trains. Some design solutions for providing microspeed as well as for twin-motor drive are discussed. These arrangements are suitable for both lifting and travel mechanisms. A kinematic analysis was made and recommendations were given to the designers.

KEYWORDS: CRANES, DANGEROUS GOODS, GEAR TRAIN, HANDLING MACHINES

Table 1. Guidelines for classification of bridge and gantry cranes and their mechanisms depending on the use of the crane (extract from BDS ISO 4301-5 for a crane in a steel foundry)

<table>
<thead>
<tr>
<th>Crane type</th>
<th>Crane classification group as a whole</th>
<th>Classification group of the mechanism as a whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crane in a rolling mill</td>
<td>A2</td>
<td>M4</td>
</tr>
<tr>
<td>Foundry (casting) crane</td>
<td>A7</td>
<td>M8</td>
</tr>
<tr>
<td>Shaft crane</td>
<td>A7</td>
<td>M7</td>
</tr>
<tr>
<td>Stripper crane</td>
<td>A8</td>
<td>M8</td>
</tr>
<tr>
<td>Furnaces loading crane</td>
<td>A8</td>
<td>M8</td>
</tr>
</tbody>
</table>

In the framework of a research contract with UCTM-Sofia, the authors have examined only those requirements that concern the gear trains of the mentioned mechanisms:

1. Provide a microspeed (slow speed) of the lifting mechanism, in accordance with the specifics of the processed dangerous goods.

2. Driving the mechanisms with two engines (motors), which are able to work independently in case of emergency (failure of one engine). This is especially important in metallurgical machines working with molten metal. If one engine fails, the other must be able to complete the operation so that the metal does not freeze in the bucket.

This article presents some solutions that meet the first requirement, in which a single-carrier planetary gear train (PGT) of the most often used type – \( \overline{\text{A}} \)- planetary gear train is involved (Fig. 1).

**Fig. 1.** The most often used type planetary gear train – \( \overline{\text{A}} \)-PGT with one-rim planets with one external and one internal meshing
2. \(\overline{\text{Al}}\)-Planetary Gear Train and its Possibilities

2.1 Arrangement of \(\overline{\text{Al}}\)-Planetary Gear Train

This type of most often used negative-ratio \((k < 0)\) planetary gear train (PGT) (Fig. 1) is signified in different ways, is signified in different ways. In many countries the Kudryavtsev’s designation 2K-H is popular. It means two central gears (2K) and a carrier (H). In this article Prof. Tkachenko’s designation is used [3, 4] as more detailed one (A for external and I for internal meshing, overline for one-rim planet).

As shown in Fig. 1 this gear train has two central gear wheels – a sun gear 1 with external teeth and a ring gear 3 with internal teeth. These two gears 1 and 3 mesh with one-rim planets 2 which are housed in carrier H. Their number most often is \(k = 3\), more rare \(k = 2\) or 4, but in special cases there are PGTs with \(k = 20\)planets [3, 4]. However, planets number \(k\) does not affect the gear train’s kinematics. Increasing the planets number (\(k > 1\)) because of the torque sharing, leads to a few effects:

- Decreasing the overall dimensions and mass of the gear train;
- Decreasing the mesh load;
- Unloading the central element bearings – sun gear 1 and carrier H;
- Decreasing the noise level because of the lower peripheral velocities and higher accuracy of the smaller gears.

Central elements of the gear train (sun gear 1, ring gear 3 and carrier H) rotate around an axis – the so called main (central) geometrical axis of the gear train. Typical of this simple PGT is that there are three shafts that go out of the train (external shafts). In Fig. 1 the corresponding external torques \(T_1\), \(T_3\), and \(T_H\) also are shown. Two of them \(T_1\) and \(T_3\) are unidirectional, and the third torque \(T_H\) is with opposite direction. Since the train is simple, of course, it has only one carrier, i.e. it is a single-carrier PGT.

2.2 Possible Ways of Working of \(\overline{\text{Al}}\)-planetary gear train

This train, like other PGTs, can operate both with \(F = 1\) and \(F = 2\) degrees of freedom. With \(F = 1\) degree of freedom any one of three shafts (of the sun gear 1, ring gear 3 or carrier H) can be fixed. In Fig. 2a and 2b the six possible working modes in this case are shown – three modes as a reducer and three modes as a multiplier. Input power is denoted with \(P_A\) and output – with \(P_B\). With a fixed carrier (\(\omega_H = 0\)), the PGT works as pseudo-planetary. At \(F = 2\)degrees of freedom (working as differential), six working modes are possible, too (Fig. 2c and 2d) – three as a summation PGT and three as a division PGT.

The kinematic analysis of this gear train – the determination of speed ratios when working with \(F = 1\) degree of freedom or speeds of the input shaft(s) in case of \(F = 2\) degree of freedom is made through the basic speed ratio \(i_0\) – the ratio of the pseudo-planetary gear train working as reducer with fixed carrier (\(\omega_H = 0\))

\[
i_0 = \frac{i_{1(H)}}{i_{3(H)}} (1)
\]

The speed ratios in the other cases of work with \(F = 1\) degree of freedom (Fig. 2a and 2b) are expressed through it [3, 4]. Formula (1) applies to all types of PGTs. For the \(\overline{\text{Al}}\)-PGT considered here, basic speed ratio depends on number of teeth of the sun gear \(z_1\) and the ring gear \(z_3\) [3, 4]

\[
i_0 = -\frac{z_1}{z_3} (2)
\]

3. Microspeed providing

The lifting (hoisting) mechanisms of the cranes usually provide a microspeed around 20 - 25% of the main one[11, 14]. This is most easily achieved by changing the number of poles of the electric motor and hence its speed. When the asynchronous motor operates with one pair of poles, the synchronous speed (of the magnetic field) is 3000 min\(^{-1}\), and when it operates with four pairs of poles – 750 min\(^{-1}\). The operating speeds are slightly lower (approx. 2940 or 720 min\(^{-1}\)), depending on the power. If the microspeed thus achieved is not low enough, its required value must be achieved by a twin-motor drive and/or a suitable gear train design.

**Fig. 2. Working modes of \(\overline{\text{Al}}\)-planetary gear train[3, 4]:**

- With \(F = 1\) degree of freedom:
  - a) as a reducer (reduce the speed);
  - b) as a multiplier (multiply the speed).

- With \(F = 2\)degrees of freedom (i.e. as differential):
  - c) as a summation PGT;
  - d) as a division PGT.

The above-mentioned advantages and capabilities are used in the mechanisms discussed in the article.

**Fig. 3. Twin-motor two-speed drive with an \(\overline{\text{Al}}\)-PGT operating as summation differential [3]**
Although used primarily to provide microspeed, this arrangement has more scope to achieve more speeds of the output shaft:

1. Only the small motor $E_1$ is running (the shaft 3 of the bigmotor $E_2$ is fixed by brake $B_2$) – a high speed ratio is obtained (Fig. 4a)

$$i_{3(h)} = i_0 = -\frac{z_3}{z_1};$$ (3)

2. Only the big motor $E_2$ is running (the shaft 1 of the small motor $E_1$ is fixed by brake $B_1$) – a low speed ratio is obtained[3, 4] (Fig. 4b)

$$i_{3(H1)} = 1 - \frac{1}{i_0} = 1 + \frac{z_4}{z_3};$$ (4)

3. Both motors operate simultaneously in one or in different directions – the obtained speed ratios depend on the basic speed ratio $i_0$ of the (Fig. 4c).

When the arrangement from Fig. 3 is used for two-speed drive (main and microspeed), the PGT operates in both variants in Fig. 4a and 4b.

Some cranes for dangerous goods require the microspeed to be much lower than the main one. Fig. 5 shows the kinematic scheme of the gearbox (reducer) of a 200-ton container crane for Kozloduy nuclear power plant (NPP) manufactured by “BulmachineryEnterprices” - Radomir [3, 5]. It can perform two speed ratios $i = 141$ and $i_m = 2228$ for fast and slow speed (main and microspeed). In the large gear of the third gear stage a planetary gear train is built-in. The two speed ratios are carried out by operating only one of the motors. At main (fast) speed (Fig. 5a) the large motor is working, which drives the sun gear 1 of the PGT with fixed ring gear 3. At microspeed (slow speed) (Fig. 5b) the small motor is working, the ring gear 3 is driving, and the sun gear is fixed. In both cases, the carrier H is the output of the PGT. In Fig. 6 the gearbox with removed top is shown.

Fig. 5. Operation of PGT as a stage of a two-speed gearbox of a hoisting mechanism [3, 5]
- a) at main speed, speed ratio $i = 141$
- b) at microspeed, speed ratio $i = 2228$
Fig. 6. The gearbox from Fig. 5 [3, 4, 5]

In the gearbox from Fig. 5 the PGT in both cases with \( F = 1 \) degree of freedom is working. Its speed ratios depend on the basic speed ratio \( i_0 \) defined in (2) and when operating at main speed (PGT operates with a fixed ring gear 3) it is
\[
    i_{1H(3)} = \left(1 - \frac{1}{i_0}\right),
\]
(3)
and when operating at microspeed (PGT operates with a fixed sungear 1) it is
\[
    i_{3H(1)} = 1 - \frac{1}{i_0}.
\]
(4)
With these values it participates in determining the speed ratio of the gearbox:

- **Main speed:**
  \[
  i = i_{1H(3)} \cdot i_{10.11} \cdot i_{12.13} = \left(1 + \frac{z_2}{z_4}, \frac{z_1}{z_{10}}, \frac{z_3}{z_{12}} \right).
  \]
  (5)

- **Microspeed:**
  \[
  i_m = i_{45} \cdot i_{67} \cdot i_{89} \cdot i_{3H(1)} \cdot i_{10.11} \cdot i_{12.13} = \frac{z_2}{z_4} \cdot \frac{z_2}{z_6} \cdot \frac{z_3}{z_8} \left(1 + \frac{z_4}{z_3}, \frac{z_1}{z_{10}}, \frac{z_3}{z_{12}} \right).
  \]
  (6)

**Conclusions**

Of the considered requirements for the lifting mechanisms of cranes for dangerous goods, two concern gears:
- Providing microspeed;
- Driving the mechanisms with two motors.

Due to their wide range of capabilities, planetary gears are suitable for embedding into these mechanisms. In the considered two arrangements the property of the most usual used \( \bar{X}i \)-PGT to work with one and two degrees of freedom is used.

**Acknowledgments**

This research is financed by Research-Development Sector of University of Chemical Technology and Metallurgy (Sofia) through the Contract 21042/2020.

**References**

1. ASME NOG -1-2010 Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder).
2. ASME NUM -1-2009 Rules for Construction of Cranes, Monorails, and Hoists (With Bridge or Trolley or Hoist of the Underhung Type).
6. BDS 8916-81 Safety precautions. Load lifting cranes. Calculation of mechanisms according to modes of work. (in Bulgarian)
7. BDS 15164-80 Safety precautions. Weight lifting cranes. Steel ropes, drums, roller blocks, and chain cogwheels.
10. BDSISO 4301-5:2002 Cranes - Classification - Part 5: Overhead travelling and portal bridge cranes. (in Bulgarian)
16. Regulation on the safe operation and technical supervision of lifting appliances.Adopted by Council of Ministers Decree №199 of 10.09.2010.(in Bulgarian)
17. Regulation on the essential requirements and conformity assessment of machines.Наредба за съществените изисквания и оценяванесъответствието на машините.Приета с ПМС №140 от 19.06.2008 г., обнародвана в ДВ бр. 61 от 8 юли 2008 г.(in Bulgarian)
Effect of Weight and Diameter Variables on Balance Process for Inertia Wheel Pendulum by Using Swing Up and PID Controller

Eray Yılmazlar¹, Hilmi Kuşçu²
Kırklareli University, Technical Sciences Vocational School¹ - Trakya University, Mechanical Engineering Department², TURKEY
eray.yilmazlar@klu.edu.tr¹ - hilmi@trakya.edu.tr²

Abstract: Inertia wheel pendulum balance control is performed by using swing up and PID controller with different wheel weight and diameters. In the pendulum control, 3 different radius wheels and different weights are added to analyze whether the system remained balance position. In this process, the effect of weight and diameter variables on the swing time and PID coefficients of the pendulum was observed. With this observation, the effects of input variables in the real-time system were compared with calculations in the dynamic pendulum model.

KEYWORDS: WHEEL PENDULUM, PID CONTROLLER, SWING UP CONTROLLER

1. Introduction

Inertia wheel pendulum (IWP) is a nonlinear and underactuated system with two degrees of freedom. The pendulum structure consists of a pendulum rod that can swing freely in the vertical axis, a rotating wheel in the same axis with the rod, and a motor that produces a rotational movement[1]. The main purpose of the IWP systems is the alignment of the pendulum wheel on the vertical axis. Balancing is the process of raising and aligning the pendulum with the control methods of the torque produced by the DC motor[2].

The aim of this study is to control the alignment of the pendulum wheel in different weights and diameters. In most of the studies about IWP, different control methods and different mechanical design have been applied on a single wheel. In this study, comparison of the factors affecting the balance position was made, unlike other designs. In the balancing process, 39 different experiments were conducted and balance condition was analyzed together with friction, engine heating and other disturbing factors affecting the system. As a result of this comparison, observation is included, except for mathematical dynamic calculations.

Rest of the information of this document is organized as follows: Sec. 2 is devoted to describing the IWP system control method. Sec. 3 indicates the results and discussion. In Sec 4. Conclusion, data analysis of wheel balance.

2. System Control Method

Different control methods are used at various stages in order to realize the movement of the pendulum from 0 degrees to 180 degrees with the least energy consumption[3],[4],[5],[6]. In the design of the pendulum, the movement is provided by DC motor with control signals generated by the Arduino control card as shown in the figure 1 block diagram. During the swing process, the angle and position information are measured by the encoder and conveyed to the control unit for feedback. In this study, two different methods is used as shown in the flow diagram in figure 2. The first is the swing up control of the pendulum and the second is the balance control of the pendulum with PID.

2.1. Swing Up Control

The Swing Up control does not balance the pendulum to the desired vertical alignment but supports it to arrive in the angular range where the balance will take place.[4] The position of the pendulum wheel is 0° at the beginning. The ramp function or any triggering is applied to start the wheel swinging in figure 3. As a result of the trigger, the wheel starts to swing clockwise and counterclockwise. The swinging should be supported to increase the pendulum from 0° to 180° degrees. This support is applied with the

Fig. 1. Wheel pendulum mechanism and control block diagram

Fig. 2. Control flow diagram
torque produced by the dc motor. The support torque is applied when the variable pendulum angle value is maximum and the acceleration is zero during the swinging process. As a result of these processes, the pendulum is increased to the desired swinging range. The pendulum control process switches to the balance control range when the swinging operation is complete[7].

2.2. PID Controller

Proportional-integral-derivative (PID) controllers are the most important control systems used to control processes, due to their simple and easy design, low cost and wide range of applications [8]. The main purpose of the PID control system is that the controlled process variable reaches the target in minimum time with error difference shown in figure 5. PID control compares the reference value and feedback variables. In order to eliminate the error between two variables, proportional, integral and derivative parameters are

Table 1: Sample of the experiment data of the wheel characteristic list, swing count and balance position.

<table>
<thead>
<tr>
<th>Wheel Radius-Weight</th>
<th>Pendulum Angle-Time Graph</th>
<th>Swing-count Balance</th>
<th>Wheel Radius-Weight</th>
<th>Pendulum Angle-Time Graph</th>
<th>Swing-count Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>R9-90gr</td>
<td></td>
<td>5</td>
<td>R7.5-165gr</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>R9-144gr</td>
<td></td>
<td>5</td>
<td>R7.5-185gr</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>R9-171gr</td>
<td></td>
<td>8</td>
<td>R7.5-225gr</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>R9-220gr</td>
<td></td>
<td>7</td>
<td>R6-73gr</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>R9-240gr</td>
<td></td>
<td>8</td>
<td>R6-100gr</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Balance</td>
<td></td>
<td></td>
<td>Balance</td>
</tr>
<tr>
<td>R9-283gr</td>
<td></td>
<td>7</td>
<td>R6-127gr</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>7.5-85gr</td>
<td></td>
<td>7</td>
<td>R6-154gr</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
<tr>
<td>R7.5-115gr</td>
<td></td>
<td>10</td>
<td>R6-182gr</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance</td>
<td></td>
<td></td>
<td>No Balance</td>
</tr>
</tbody>
</table>
applied to the system. These parameters modify according to the system model. These Parameters are used in continuous cycling method and system response methods developed by Ziegler-Nichols. Large settling time and overshoot are minimized by Kp Ki Kd parameters [9], [10].

When the PID control process was examined, it was found that heavy loads and small diameter wheels were better balanced angularly on the vertical axis in the range of 90°±2°, but balance control became difficult as the wheel diameter increased. Pendulum range between of the 85°-88° and 92°-95° for PID balance control bigger wheel radius and light wheel make it more can be tolerated.

As a result of this study, the system input factors affecting the balance processes of IWP systems were analyzed and as a result, it was found that wheels with large, light and high moments of inertia were better in the balancing process.

5. References


Analysis reasons of wear of the locomotive wheel flange on curved sections track

Shalygin Mikhail, Vaschishina Anna
Bryansk state technical University
7, 50 let Oktyabrya Boulevard, Bryansk region, Central Federal district, Bryansk region, 241035

Abstract: The article deals with the problem of wear of the train wheel crest and the conditions that affect the process of deformation of the material of the wheelset parts. Factors affecting wear are considered. It is shown that the resource of ridges depends on the nature and speed of chemical and physical processes. It was noted that in the center of destruction of the ridge, an increased content of carbon, oxygen and silicon was detected. It is established that the main way to reduce wear is to lubricate the comb in order to reduce the coefficient of friction.

Keywords: RIDGE, RAIL, WEAR, LUBRICANT, DEFORMATIONS, WHEELSET.

On electric rolling stock of industrial railway transport, band wheels with disc centers are used, on the elongated hub of which a gear wheel is mounted. The wheelset of traction cars consists of an axle, cast wheel centers with bandages, fixed band rings, and solid-rolled gears. The elements of the wheelset work under different conditions and require a specific manufacturing process to ensure the necessary conditions for durability and high reliability [1]. Analysis of statistical data has shown that the main reasons for rejection of wheel sets of traction rolling stock are wear and undercutting of the ridge, as well as the occurrence of a sharp roll. As a solution to this problem, the Railways have developed a set of measures to eliminate harmful factors (coefficient of friction, hardness of the wheel and rail material, the size and shape of contact spots) and conditions (external environmental conditions — temperature, humidity, etc.) that affect the wear of the car’s wheel crest and the side faces of the outer rails [2].

On curved sections of railway tracks, there are problems associated with rail wear. One of them is the wear between the wheel flange and the outer rail of the curve with no lubrication. When entering a turn arise microscopic side wheels on the rail surface (area of contact is determined by the deformation of the material at contact areas under load) which causes high impact load areas. Using this model, the authors derived dependencies between the rubbing surfaces [3]. This effect occurs on the inner rail of a curved section. It is assumed that at the lightest loads, the micro-surfaces touch small areas and as the load increases, these areas increase in size. Some irregularities approach and touch, forming new areas of contact. This means that increasing the load increases the contact areas of the rubbing surfaces and the distribution of areas is carried out by the size of the interaction areas. Using this model, the authors derived dependencies between the applied load and the contact area [4].

\[
A = B[\frac{P}{G}]^{\frac{2}{1+\mu}} \quad G = D[\frac{P}{C}]^{\frac{1+m}{1+\mu}}
\]

where \( B = \frac{1}{2}M_b \), \( C = [M/(1 + p)]c \), \( D = [M/(1 + m)]d \); \( A \) — area of irregularities; \( P \) — load carried by the contact; \( C \) — conductivity of the contact; \( p \) — coefficient of deformation; \( m \) — coefficient of resistance to contraction.

During the sliding process, the surfaces have friction forces, between which there is an intermolecular interaction (this will include smaller contact areas). The deformation of the contact areas may appear elastic based on contact resistance measurements, and the friction between the surfaces in question will be determined by the plastic deformation of the irregularities.

The limited contact resistance measurement data is consistent with a model in which the number and average size of contact areas increase with load [5, 6].

Vorobyov A. A. and Kotova V. V. in the article [7] note that wear particles are scales or plates of different thickness. They are typical for normal wear conditions [8]. For the formation of wear particles, it is necessary that the steel reaches its ultimate deformation state, which is accelerated by the action of the surface-active medium [9]. When wear particles are formed and detached from the metal, they adsorb the active elements of the environment inside the cracks at high speeds, and this process leads to a further process of plastic deformation of the steel. Thus, a wet environment containing various lubricants and dirt has a negative impact on the fatigue strength of the wheel surface due to adsorption and corrosion effects.

In the article [10], the author notes that the wear and life of rail ridges mainly depends on the nature and speed of chemical and physical processes that occur in the surface layers of the metal.

In [11] refers to the occurrence of friction forces between wheel and rail when the train moves, due to which work is being performed, the bulk of which goes into internal energy, leading to temperature rise of the friction surfaces, and reaches its maximum at the site of primary contact. There is also a process of adhesive wear (it depends on the roughness of the surfaces, the hardness of the material, the loading of the contact zone).

The article [12] States that wheel pair wear can occur due to mechanical interaction and the development of fatigue failure of the rubbing surfaces during abrasion, and the destruction of the material due to the engagement of surface irregularities during friction. The origin of a fatigue crack is local and occurs in places where the maximum stress is applied to the selected area. Maximum stress occurs due to non-metallic inclusions, surface irregularities, and sharp transitions between sections. In works [13] the most dangerous areas of fatigue failure origin were identified (Fig. 1), which includes the bandage comb.

This process can be described as follows: first, under the influence of periodic shock loads that occur when the train enters the turn of the railway track, a section of a fan of microcracks is formed near the surface. Then, they grow along the planes of maximum chipping stress, both towards the surface and in the depth of the ridge. At the moment when the crack reaches its maximum size, the metal is crushed on the surface and inside the material and the material is split off from the ridge. The authors found non-metallic inclusions in the destruction center. Analysis of their chemical composition revealed an increased content of carbon, oxygen and silicon. From the results obtained, it is concluded that the destruction is due to the presence of silicates or slag formations in the structure [14].

Fig. 1. Places of fatigue destruction of bandages that can serve as the beginning of fatigue wear are highlighted.
Previously, uncoupling of wagons was associated with contact-fatigue defects and defects in rail joints [15]. Currently, the cause of uncoupling is the side wear of the wheel crest. On average, as shown in the work, from 10,000 rails to 50,000 rails were withdrawn per year. If a train wheel fails, it will result in the failure of the entire car, while increasing the time for their repair in the railway depot. Intensive wear of the ridge is facilitated by the resulting rolls. When the train moves there is a strong interaction between the wheel material and rail material, resulting in both material displaced and contribute to the rupture of metal and the formation of mesh of cracks on the surface. In this case, the turning of the comb is required [16]. Wheel pairs are subject to turning when the rolling surface is insignificant [17]. The average intensity of wheel wear on a thin ridge is 0.5 mm per 10 thousand km of mileage (which is twice the established norm - 4 mm per 160 thousand km). The receipt of cars in the current repair is associated with 35% - 40% due to a malfunction of the wheel pairs [18]. Failures in the way are accompanied by a deterioration in the working conditions of the rolling stock – a high level of intensification of lateral wear of the wheel ridges, undercutting and rolling of the ridges. Due to the wear of the ridges, 50% of the wheels were rejected. And the wear of the ridge itself increases the power consumption for traction by 30% by 50% [19].

Kik W. and Moelle D. [20] found that a good correspondence between the experimental data and the results of wear modeling can only be achieved if a high hardness of the wheel flange is used (since the hardness affects the volume of the material during deformation). The hardness of different areas of the wheel and the coefficient of friction are specified in the simulation - the greater the hardness of the materials, the less wear on the surfaces. From the standard [21], it is known that for new wheels, the perimeter hardness is no more than 20 NV (8%).

Comparison of the available data on the wear of wheels with a hardened surface under certain conditions of the experimental circular track allowed us to estimate the coefficients of light and heavy wear, the coefficient of friction. The friction torque depends on the dimensions of the central plate, the presence/absence of the body of the position, bearing the friction coefficient, which depends on the tribological characteristics of the material of the contact surfaces; the value can vary from 0.25 to 0.4. The appearance of additional friction forces significantly increases the moment of resistance forces when the train enters the turn of the railway track [22]. The following values of the abrasive wear parameters were set for the wheels:
- the coefficient of friction of the wheel tread is 0.25;
- the coefficient of friction for the wheel flange is 0.28.

Thus, using different materials in the manufacture of structural parts of the wheelset system, it is possible to provide rational friction forces [23].

One of the ways to protect against wear is the use of alloy steel in the production of a wheelset. In the article [24], work was done to determine the degree of influence of various alloying elements on the strength characteristics of wheel steel. Steel with a carbon content (0.29% - 0.72%) was studied. The following properties of steel were determined: impact strength, contact fatigue life, wear resistance, and ductility in their normalized and hardened state. As a result of the research, it was concluded that it is impractical to use alloy steel with a carbon content of more than 0.5 % since the abrasive properties of wheel steel during alloying significantly weaken with increasing carbon content. Traditional technology of steel hardening with high-frequency currents is used in many industries, including in the railway sector to improve the wear resistance of rolling stock wheels [25].

To reduce the wear of the car wheel crest, a lubricant is applied to the surface of the outer rail head on curved sections, which consists of a solid lubricant (consisting of graphite powder and molybdenum disulfide) and a surfactant surfactant (serpentinite 5-60%, surfactant 1-20%, the remaining part is an organic binder). The organic component is the main liquid component of the lubricant, which contributes to its uniform distribution on the rails. Serpentine during the interaction of the wheel and rail acquires anti-friction properties and forms a servovit film on the surface, which provides a continuous supply of solid-lubricating material to the friction pair. In addition, this film reduces wear on straight sections of the road. The grease supply occurs when the train turns, and when it exits the turn, the grease supply automatically stops. The disadvantage of this method is that the retention of the solid lubricant is not provided, and this leads to overspending of the lubricant [26].

One way to reduce wear is to use SKF and Lincoln lubricants. These manufacturers offer stationary track and mobile lubrication systems.

On stationary lubrication systems, a certain amount of lubricant is applied to the rail and maintains this lubricant in place. Thanks to this system, the wheels of trains completely capture the lubricant and carry it along the rails. The systems installed on the rolling stock for greasing the wheel crest are installed on the first wheel pair of the front bogie of the head car. Materials with high viscosity and friction additives are applied automatically and help to reduce wear [27, 28].

Another way to reduce the wear of a car's wheel crest is to introduce a system of lubrication of the working face of the rails using magnetically controlled contacts. When the reverse current begins to flow, the reed switch immediately turns on the pump motor, which pumps oil into the tank. Oil flows through the pipeline under pressure and lubricates the working face of the rail. The magnetically controlled contacts are sealed in a glass flask filled with nitrogen or an inert gas; they are sealed. Hence their name of reed switches – i.e. sealed contacts. In the lubrication system of the ridge is used by switching the reed switch. When a train passes through a section of track, the current flowing through the rail chain is fed to the left winding of the switching reed switch, the middle plate, closing the left contact, will give a signal to the electropneumatic contact of the oil tank. The contactor for releasing oil into the oil pipeline is activated. Under vertical load on sleepers from wheel pairs, oil with pressure will spray the rail from the side of the working face along the perimeter of the curve until the last wheel of the technological turntable passes. Reed switches must have a protective housing, since the contacts of the reed switch are sealed [29]. The disadvantage of this method is the instability of current flow, possible contact breaks and contact depressurization, which does not result in the treatment of the car's wheel crest with a greasable material.

Thus, the main reason for rejection of wheel pairs of traction rolling stock is wear of the ridge. To reduce the wear of the car wheel crest, a lubricant consisting of a solid lubricant and a surfactant must be applied to the rail head. The use of high-viscosity lubricants with friction additives reduces the wear of riding surfaces. To increase the wear resistance of the material, it is necessary to use steel hardened at high frequency. To reduce deformations, use a high-hard material of the wheel flange, since the greater the hardness of the material, the less deformation (wear).

**BIBLIOGRAPHIC LIST**

2. Dushkin M. V. Technology and measures to improve the durability of wheel pairs. Program of the 78th student scientific and practical conference, Voronezh, April 2019. 109с.
4. J. F. Archard, Contact and Rubbing of Flat Surfaces Cite as: Journal of Applied Physics 24, 981 (1953); Submitted on: 08 January 1953. Published Online: 07 June 2004.
3-phase motor speed regulator based on microcontroller and intelligent power driver controller


Faculty of Electrical Engineering, University “Goce Delcev”-Stip, Macedonia¹,²,³
Faculty of Computer Science and Engineering, University “Ss Cyril and Methodius”-Skopje, Macedonia⁴

goce.stefanov@ugd.edu.mk, todor.cekerovski@ugd.edu.mk, biljana.citkuseva@ugd.edu.mk, sara_stefanova@hotmail.com

Abstract: This paper describes the design and practical implementation of speed controller for 3-phase induction motor based on AT mega 2560 microcontroller. Based on the theoretical analysis of the induction motor, are defined the requirements that the controller should satisfy them. Then, based on the specificity of the selected controller, the operating mode of the ATmega 2560 controller is designed. The specificity of this solution is that the driver circuit, which is connected between the controller and the motor, is realized with an intelligent power controller. Finally, the results of the practical work of this motor controller are given.

KEYWORDS: 3-PHASE MOTOR REGULATOR, ATMEGA 2560, INTELLIGENT POWER CONTROLLER

1. Introduction

In modern industrial power plants the tendency is to use induction motors controlled by V/F converters. The main reason for this in terms of the motor is the advantage which offered by induction motors, primarily in terms of DC motors, and in terms of the converter is the need to regulate the speed of the motor and thus its power. This ensures that the motor runs at the speed and power required by the operating process [1], [2], [3], [4].

There are a number of methods of speed control of an induction such as pole changing, frequency variation, variable rotor resistance, variable stator voltage, constant V/f control, slip recovery method etc. The constant V/f speed control method is the majority generally used. In this method, the V/f ratio is kept constant which in turn maintains the magnetizing flux constant so that the maximum torque remains unchanged. Thus, the motor is totally utilized in this method [5], [6].

In this paper, the main emphasis is on the work of the microcontroller and the driver's circuit, ie. power converter. The microcontroller generates a 3-phase SPWM signal that provides V/F operation of the motor [7]. In the paper, the power converter is realized in an integrated technique, so-called intelligent power module (IPM).

2. SPWM Microcontroller and Intelligent Power Module

Guided by the main goal of the paper, implementation of the microcontroller in generating SPWM signals and realization of the converter with intelligent power module (IPM), here will be explained the functioning of these three interconnected parts, ie. SPWM, microcontroller and IPM.

In the Fig. 1 is shown a block diagram on 3-phase motor which is controlled by microcontroller.

![Fig. 1 Block diagram on 3-phase motor controlled by microcontroller.](image)

2.1 SPWM signal

Here we take a look over the concepts of SPWM signal which is a width modulated signal but with certain values on such a way that we could create a sine shape wave at the output. This with used on MOSFET or IGBT transistors could result in a sine wave inverter.

It is generally known that PWM signal is pulse width modulation. That means we modulate the width of a square signal and by that we could control power. But, this width in case of normal PWM is always the same. In case of SPWM or sinusoidal pulse width modulation, the width of the signal is increasing and decreasing and my that simulating the curve of the sine wave. With small width pulse, the output will increase a little bit and that represents the zone after the 0 cross of the sine wave. Then with bigger widths, the output is getting bigger and bigger and then it starts to get lower, just as a sine wave. Using two transistors switching, can could get both the positive and negative sides of the sine wave, Fig. 2.

![Fig. 2 Construction of SPWM signal.](image)

In the Fig. 3 below can see a bit better how the width of the SPWM can create a good sinusoidal shape at the output. Will use the microcontroller to generate this SPWM signal. We apply this signal to the intelligent power module driver. These will be connected to the motor. In the Fig. 3 is shown SPWM signal and the current and voltage waveforms of the motor.

![Fig. 3 SPWM signal and the current and voltage waveforms of the motor.](image)
2.2 Microcontroller

The main task of the microcontroller is to generate SPWM signals [8]. Because the motor is three-phase, the controller needs to generate two asymmetric outputs for each phase. So microcontroller needs generate three phase SPWM signals. These signals will be connected to the inputs of the intelligent power converter.

Because Atmega 328P microcontroller on arduino uno board has three timers and one of them is used for interrupt it can not be used. Therefore here is used an Atmega 2560 microcontroller embedded on arduino mega board. Arduino mega 2560 board have five timers and 15 PWM capable pins [9]. The basic features of this controller are:

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>ATmega2560</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Input Voltage (recommended)</td>
<td>7-12V</td>
</tr>
<tr>
<td>Input Voltage (limits)</td>
<td>6-20V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>54 (of which 14 provide PWM output)</td>
</tr>
<tr>
<td>Analog Input Pins</td>
<td>16</td>
</tr>
<tr>
<td>DC Current per I/O Pin</td>
<td>40 mA</td>
</tr>
<tr>
<td>DC Current for 3.3V Pin</td>
<td>50 mA</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>256 KB of which 4 KB used by bootloader</td>
</tr>
<tr>
<td>SRAM</td>
<td>8 KB</td>
</tr>
<tr>
<td>EEPROM</td>
<td>4</td>
</tr>
</tbody>
</table>

In Fig. 4 is shown microcontroller Atmega2560, used in arduino mega board.

To solve our task, generating three SPWM signals requires knowledge of the microcontroller timers. So we'll see the corresponding between timers and pins:
- Timer 0-pin 4 (OC0B) and pin 13(OC0A)
- Timer 1-pin 11(OC1A) and pin 12(OC1B)
- Timer 2-pin 9(OC2B) and pin 10(OC2A)
- Timer 3-pin 2(OC3B), pin 3(OC3C) and pin 5(OC3A)
- Timer 4-pin 6(OC4A), pin 7(OC4B) and pin 8(OC4C)
- Timer 5-pin 44(OC5C), pin 45(OC5B) and pin 46(OC5A)

Timer 1 is used for , Timer 0 for first phase, Timer 2 for the second phase and Timer 3 for the third phase with OCxA for positive half duty cycle and OCxB for the negative half duty cycle like in the Fig. 5 [10].

If for 180 degrees we have 314 elements, for 120 degrees we have 209 elements so the second signal must start when the first is at 209 pulse and the third must start when the second is at 209 pulse.

So, when the program starts, the interrupt is enabled and first is executed the first signal part (with element i). When i take the 209 value the second signal is enabled (with element j). When j takes the 209 value the third signal is enabled. In this way these three signals are at 120 degrees phase shift.

To ensure the phase shift we use an “if” function and for the second wave is like below:

```
if ((i==209) || OK1==1){
    OK1=1;
}
```

When “i” has 209th value the “if” function is enabled and everything in it is executed. To mantain the execution of that part for the second signal after the value of i(209) is changed we use a variable which enables the “if” function continuously.

For the third signal the if function is like below:

```
if ((j==209) || OK3==1){
    OK3=1;
}
```

In this case, the third signal is enabled when “j” (the element for the second signal) has the 209th value. After that, the “if” function is executed like for the second signal.

The waveforms that illustrate the last explanation will be given below in the text.

2.2 Intelligent Power Module Driver

In power electronics, in recent decades, usually in controlling of the motor (not only induction but also DC motors), the connection between the controlling part (in the case is microcontroller) and the motor has been realized with a discreet driver circuit and power bridge converter realized with MOSFET or IGBT transistors [11]. One such solution is shown in the Fig. 6.

In recent years, the direction of development and application of intelligent controllers has been practiced not only for control electronics but also for the driver circuit [12]. These intelligent power controllers consist of a driver circuit and a bridge converter. In this
way the hardware construction of the device is facilitated and the protection functions are improved.

In the Fig. 7 is shown motor speed controller controlled with microcontroller and intelligent power module.

3. Design of Speed Regulator

To design the task in the paper we use microcontroller Atmega 2560 in arduino mega board and monolithic intelligent motor controller MC3PHAC (product of Motorola) embedded in intelligent power module TM35 [12].

MC3PHAC is designed specifically to meet the requirements for low-cost, variable-speed, 3-phase ac motor control systems. The device is adaptable and configurable, based on its environment. It contains all of the active functions required to implement the control portion of an open loop, 3-phase ac motor drive. One of the unique aspects of this device is that although it is adaptable and configurable based on its environment, it does not require any software development. This makes the MC3PHAC a perfect fit for customer applications requiring ac motor control but with limited or no software resources available. The device features are:

• Volts-per-Hertz speed control
• Digital signal processing (DSP) filtering to enhance speed stability
• 32-bit calculations for high-precision operation
• Internet enabled
• No user software development required for operation
• 6-output pulse-width modulator (PWM)
• 3-phase waveform generation
• 4-channel analog-to-digital converter (ADC)
• User configurable for standalone or hosted operation
• Dynamic bus ripple cancellation
• Selectable PWM polarity and frequency
• Selectable 50/60 Hz base frequency
• Phase-lock loop (PLL) based system oscillator
• Serial communications interface (SCI)
• Low-power supply voltage detection circuit.

Included in the MC3PHAC are protective features consisting of dc bus voltage monitoring and a system fault input that will immediately disable the PWM module upon detection of a system fault.

Some target applications for the MC3PHAC include:

• Low horsepower HVAC motors
• Home appliances
• Commercial laundry and dishwashers
• Process control
• Pumps and fans.

In the Fig. 8 is shown the block diagram of IPM TM35 with built motor controller MC3PHAC, and on the Fig. 9 is shown the appearance of real IPM TM35.

4. Experimental results

In the Fig. 10 is shown block diagram on speed motor regulator based of microcontroller Atmega 2560 and intelligent power module TM 35.

From the Fig. 10 can be see that is used LCD display 2004 on which the modes of operation of the regulator are visualized.

4. Experimental results

In the Fig. 10 is shown block diagram on speed motor regulator based of microcontroller Atmega 2560 and intelligent power module TM 35.

In the Fig. 11 is shown experimentally test the circuit of motor speed regulator.

In the Fig. 12 are shown waveforms on the PWM signals from the microcontroller for SPWM frequency (switching frequency) 4 kHz and motor frequency 19 Hz.
In the SPWM switching (pin 4 (channel 1) and phase v pin 9 (channel 2) for illustration on the SPWM switching (pin 4 (channel 1) and phase v pin 9 (channel 2), c.) SPWM signals on phase v pin 9 (channel 1) and phase w pin 2 (channel 2), Ch1 = 2 V/div, Ch2 = 2 V/div, time = 2 mS/div.

From the Fig. 12 a.) can be seen that the PWM signals on one phase (in case phase u) are shifted by 180° and that there is a dead between the falling and the rising edge of the signals. From Fig. 12 b.) and Fig. 12 c.) can be seen that SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2) are shifted by 120°, and SPWM signals on phase v pin 9 (channel 1) and phase w pin 2 (channel 2) are also shifted by 120°.

In the Fig. 13 is shown waveforms on SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2) for illustration on the SPWM switching (f_s = 4 kHz) and motor frequency (f_m = 50 Hz).

From the Fig. 13 can be seen that the SPWM switching frequency is f_s = 4 kHz (T_s = 250 μs), and motor frequency in case is maximal f_m = 50 Hz (T = 20 ms). The number of SPWM pulses per half-period is 40. SPWM signals with such waveforms will provide phase voltages to the motor displaced by 120°.

On the channel 1 in the Fig. 14 is shown waveform of the phase voltage u, and of the channel 2 is shown waveform of the phase voltage v for motor frequency 50 Hz.

In Table I are given dates for effective values of the phase voltage of the motor U_eff for different motor frequency f_m.

**Table 1**: Effective values of phase motor voltage U_eff for different motor frequency.

<table>
<thead>
<tr>
<th>U_eff(V)</th>
<th>10.8</th>
<th>39.3</th>
<th>65.55</th>
<th>91</th>
<th>110.05</th>
<th>133.20</th>
<th>152.04</th>
<th>179</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_Hz</td>
<td>3</td>
<td>11</td>
<td>19</td>
<td>26</td>
<td>31</td>
<td>37</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>U_eff</td>
<td>3.60</td>
<td>3.57</td>
<td>3.45</td>
<td>3.50</td>
<td>3.55</td>
<td>3.60</td>
<td>3.62</td>
<td>3.58</td>
</tr>
</tbody>
</table>

From the dates in Table I and the Fig. 15 can be seen that the ratio of the effective value of the phase voltage to the motor and the frequency (U_eff) is maintained constant by applying the solution in the paper. Maintaining a constant ratio U_eff means that the flux i.e. the moment of the motor is constant.

5. Conclusion

In this paper is design and practically realized V/F speed regulator for 3-phase induction motor based on microcontroller. The specificity of the solution in the paper is the use of an intelligent power module for the power converter. Experimental results from the operation of the designed motor speed regulator show that it provides operation of the motor with a constant V/F ratio. This maintains the constant flux i.e. the moment of the motor.

References

Dynamic analysis of a four-bar linkage mechanism

Mustafa Arda$^{1,*}$
Trakya University, Mechanical Engineering Department, 22030 Edirne Turkey$^1$
mustafaarda@trakya.edu.tr

Abstract: In the present paper, dynamic analysis of rigid four-bar linkage has been studied. Equation of motion has been obtained by using Lagrange’s Equation. Dynamic behavior of four-bar linkage has been analyzed using MATLAB/Simulink. Angular kinematics of each member of linkage have been determined.

Keywords: FOUR-BAR LINKAGE, DYNAMIC ANALYSIS, LAGRANGE FORMULATION, ANGULAR KINEMATIC.

1. Introduction

Four-bar linkages are the mostly used mechanism in industry and machine design. Smaller linkage mechanisms become more effective with technological development because of reducing the crank weight and high operating speed in machinery. Therefore, dynamic analysis of variable forces, inertial effects and external torques on four-bar mechanisms has been carried out by researchers over the years. Freudenstein [1] was founder of the modern kinematics and with his contribution kinematic synthesis of mechanisms became applicable using digital computation. Neubauer et al. [2] investigated the transverse vibrational characteristics of the connecting rod in a slider-crank mechanism. Smith and Maumder [3] studied the undamped transverse vibration of a flexible coupler in a four-bar linkage which is governed by an inhomogeneous Hill’s equation. Sudler and Sandor [4] developed a method of kineto-elastodynamic analysis employing lumped parameter models for simulating moving four-bar mechanism components subject to elastic bending vibrations. Furuhashi et al. [5–8] described a general theory of dynamics of four-bar linkage with clearances at all turning pairs using a continuous contact model. Zobairi and Sahay [9] investigated the contribution of kineto-elastodynamic inertia forces toward the shaking force and shaking moment along with the contribution of the rigid-body inertia forces while balancing a four-bar mechanism by internal mass redistribution. Yang and Krishnaprasad [10] studied the shaking moment along with the contribution of the rigid-body inertia forces and the effective with technological development because of reducing the crank weight and high operating speed in machinery. Therefore, dynamic analysis of variable forces, inertial effects and external torques on four-bar mechanisms has been carried out by researchers over the years. Freudenstein [1] was founder of the modern kinematics and with his contribution kinematic synthesis of mechanisms became applicable using digital computation. Neubauer et al. [2] investigated the transverse vibrational characteristics of the connecting rod in a slider-crank mechanism. Smith and Maumder [3] studied the undamped transverse vibration of a flexible coupler in a four-bar linkage which is governed by an inhomogeneous Hill’s equation. Sudler and Sandor [4] developed a method of kineto-elastodynamic analysis employing lumped parameter models for simulating moving four-bar mechanism components subject to elastic bending vibrations. Furuhashi et al. [5–8] described a general theory of dynamics of four-bar linkage with clearances at all turning pairs using a continuous contact model. Zobairi and Sahay [9] investigated the contribution of kineto-elastodynamic inertia forces toward the shaking force and shaking moment along with the contribution of the rigid-body inertia forces while balancing a four-bar mechanism by internal mass redistribution. Yang and Krishnaprasad [10] studied the shaking moment along with the contribution of the rigid-body inertia forces and the

\[ L_2 \sin \theta_2 + L_3 \sin \theta_3 = L_4 \sin \theta_4 \]  \hspace{1cm} (2)

Angular displacement of 3rd and 4th links can be defined as a function of \( \theta_2 \) using the constraints in Eqs. (1) and (2). Sum of squares of the constraints equations give the well-known Freudenstein Equation [16]:

\[ P_1 \sin \theta_4 + P_2 \cos \theta_4 + P_3 = 0 \]  \hspace{1cm} (3)

where

\[ P_1 = -2L_2L_4 \sin \theta_2 \]
\[ P_2 = 2L_4(L_1 - L_2 \cos \theta_2) \]
\[ P_3 = L_1^2 + L_2^2 - L_3^2 + L_4^2 - 2L_1L_2 \cos \theta_2 \]  \hspace{1cm} (4)
(5)
(6)

\[ \theta_4 = 2 \tan^{-1} \left( \frac{-c_1 \sqrt{c_2^2 + c_3^2} - c_3}{c_2} \right) \]
\[ \theta_3 = tan^{-1} \left( \frac{L_2 \sin \theta_2 + L_4 \sin \theta_4}{L_1 \cos \theta_4 + L_4 \cos \theta_3} \right) \]  \hspace{1cm} (7)
(8)
\[ \theta_3 = tan^{-1} \left( \frac{L_2 \sin \theta_2 + L_4 \sin \theta_4}{L_1 \cos \theta_4 + L_4 \cos \theta_3} \right) \]
\[ \frac{d}{dt} \frac{\partial V}{\partial \dot{\theta}} - \frac{\partial V}{\partial \theta} = \delta W \]

(9)

where \( \delta \) is the generalized coordinate, \( L \) is the Langrangian and \( W \) is the work done by external load. In the present study, external load has not been considered. Langrangian can be written as:

\[ L = T - U \]  \hspace{1cm} (10)

where \( T \) and \( U \) are the total kinetic and potential energy of four-bar linkage. Total energies can be defined for each linkage member as:

\[ T = \frac{1}{2} m_2 V_2^2 + \frac{1}{2} L_2 \dot{\theta}_2^2 + \frac{1}{2} m_3 V_3^2 + \frac{1}{2} L_3 \dot{\theta}_3^2 \]  \hspace{1cm} (11)

\[ U = (m_2 g h_2) + (m_3 g h_3) + (m_4 g h_4) \]  \hspace{1cm} (12)

Following parameters can be written:

\[ V_2 = \frac{L_2}{2} \dot{\theta}_2, L_2 = \frac{1}{12} m_2 L_2^2, h_2 = \frac{L_2}{2} \sin \theta_2 \]
\[ V_3 = \left[ \frac{d}{dt} \left( L_2 \cos \theta_2 \frac{L_2}{2} \sin \theta_2 + \frac{L_2}{2} \cos \theta_2 \frac{L_2}{2} \sin \theta_3 \right) \right], L_3 = \]

(13)
(14)
**Table 1: Assumed Four-Bar Linkage Dimensions and Initial Conditions**

<table>
<thead>
<tr>
<th>Link Lengths (m)</th>
<th>$L_1=3$, $L_2=1$, $L_3=4$, $L_4=2.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link masses (kg)</td>
<td>$m_1=1$, $m_2=1$, $m_3=1$</td>
</tr>
<tr>
<td>Initial angular positions (degree); Case 1</td>
<td>$\theta_2=30^\circ$, $\theta_3=20.71^\circ$, $\theta_4=49.98^\circ$</td>
</tr>
<tr>
<td>Initial angular positions (degree); Case 2</td>
<td>$\theta_2=60^\circ$, $\theta_3=18.58^\circ$, $\theta_4=58.89^\circ$</td>
</tr>
</tbody>
</table>

**Figure 2: Simulink Block Diagram of Governing Equation of Four-Bar Linkage Mechanism**

**Figure 3: Variation of Angular Displacements with Time**
Figure 4: Variation of Angular Velocity with Time

Figure 5: Variation of Angular Acceleration with Time

Figure 1: Variation of Angular Displacements with Time
Fig. 2: Variation of Angular Velocity with Time

Fig. 3: Variation of Angular Displacements with Time

\[ V_4 = \frac{L_4}{2} \theta_4, \quad L_4 = \frac{1}{12} m_4 L_4^2, \quad h_4 = \frac{L_4}{2} \sin \theta_4 \]  

(15)

Nonlinear systems of equations for four-bar linkage consist of 5 equations: They are Langrange functions for each angular displacement and two geometric constraint function. Constraint functions are defined as:

\[ \alpha_1 = L_2 \cos \theta_2 + L_3 \cos \theta_3 - L_4 \cos \theta_4 - L_1 \]  

(16)

\[ \alpha_2 = L_2 \sin \theta_2 + L_3 \sin \theta_3 - L_4 \sin \theta_4 \]  

(17)

Langrange function for \( \theta_2 \):

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_2} \right) - \frac{\partial L}{\partial \theta_2} = \lambda_1 \frac{\partial \alpha_1}{\partial \theta_2} + \lambda_2 \frac{\partial \alpha_2}{\partial \theta_2} \]  

(18)

where \( \lambda_1 \) and \( \lambda_2 \) are the Lagrange coefficients. If Eq. (18) is reorganized after necessary derivations, Eq. (19) can be obtained:

\[ \frac{d}{dt} \left( \frac{1}{3} m_2 L_2^2 \dot{\theta}_2 + \frac{1}{2} m_3 L_3 \cos(\theta_2 - \theta_3) \right) + \lambda_1 [L_2 \sin \theta_2] + \lambda_2 [-L_2 \cos \theta_2] = -\frac{1}{2} m_3 L_3 \dot{\theta}_3 \sin(\theta_2 - \theta_3) - m_3 g \frac{L_2}{2} \sin \theta_2 \]  

(19)

Langrange function for \( \theta_3 \):

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_3} \right) - \frac{\partial L}{\partial \theta_3} = \lambda_1 \frac{\partial \alpha_1}{\partial \theta_3} + \lambda_2 \frac{\partial \alpha_2}{\partial \theta_3} \]  

(20)

\[ \dot{\theta}_2 \left( \frac{1}{2} m_2 L_2 \cos(\theta_2 - \theta_3) \right) + \dot{\theta}_3 \left( \frac{1}{2} m_3 L_3 \right) \]  

(21)

Langrange function for \( \theta_4 \):

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_4} \right) - \frac{\partial L}{\partial \theta_4} = \lambda_1 \frac{\partial \alpha_1}{\partial \theta_4} + \lambda_2 \frac{\partial \alpha_2}{\partial \theta_4} \]  

(22)

Also, second time derivatives of geometric boundary conditions will take place in the governing equation of four-bar linkage:

\[ \dot{\theta}_2 \left( \frac{1}{2} m_2 L_2 \sin(\theta_2 - \theta_3) \right) + \dot{\theta}_3 \left( -\frac{1}{2} m_3 L_3 \sin(\theta_2 - \theta_3) \right) + \lambda_1 [L_3 \sin \theta_3] + \lambda_2 [-L_3 \cos \theta_3] = -\left( \frac{m_4}{L_4} \right) g L_4 \cos \theta_4 \]  

(23)

These equations can be reorganized in a matrix form:
where related parameters can be defined as:

\[
A_{11} = \frac{1}{2} m_2 L_2^2 + m_3 L_3^2, A_{12} = \frac{1}{2} m_3 L_2 L_3 \cos(\theta_2 - \theta_3), A_{13} = 0, A_{14} = L_2 \sin \theta_2, A_{15} = -L_2 \cos \theta_2
\]

\[
A_{21} = \frac{1}{2} m_3 L_2 L_3 \cos(\theta_2 - \theta_3), A_{22} = \frac{1}{2} m_3 L_3^2, A_{23} = 0, A_{24} = L_3 \sin \theta_3, A_{25} = -L_3 \cos \theta_3
\]

\[
A_{31} = 0, A_{32} = 0, A_{33} = \frac{1}{2} m_4 L_4^2, A_{34} = -L_4 \sin \theta_4, A_{35} = L_4 \cos \theta_4
\]

\[
A_{41} = L_2 \sin \theta_2, A_{42} = L_3 \sin \theta_3, A_{43} = -L_4 \sin \theta_4, A_{44} = 0, A_{45} = 0
\]

\[
A_{51} = L_2 \cos \theta_2, A_{52} = L_3 \cos \theta_3, A_{53} = -L_4 \cos \theta_4, A_{54} = 0, A_{55} = 0
\]

\[
B_1 = -\frac{1}{2} m_3 L_2 \theta_3^2 \sin(\theta_2 - \theta_3) - m_2 g \frac{L_2}{2} \cos \theta_2
\]

\[
B_2 = \frac{1}{2} m_3 L_2 L_3 \theta_2^2 \sin(\theta_2 - \theta_3) + m_3 g \frac{L_3}{2} \cos \theta_3
\]

\[
B_3 = -\left( m_3 + \frac{m_4}{2} \right) g L_4 \cos \theta_4
\]

\[
B_4 = -L_2 \theta_2^2 \cos \theta_2 - L_3 \theta_3^2 \cos \theta_3 + L_4 \theta_4^2 \cos \theta_4
\]

\[
B_5 = L_2 \theta_2^2 \sin \theta_2 + L_3 \theta_3^2 \sin \theta_3 - L_4 \theta_4^2 \sin \theta_4
\]

Nonlinear system of equations in Eq. (26) has been solved with MATLAB and discretization and derivation process are carried out by Simulink program. In Fig. (2), Simulink model for present problem is given.

### 3. Simulation Results

Simulation of the four-bar linkage mechanism is carried out by using Simulink. Simulation time is accepted as 10s. “ode45” solver has been used and sample time assumed as 0.01s. Four-bar linkage mechanism dimensions were taken from Ref. [14] as in Table (1). Two different initial conditions for linkage’s angular position have been considered. Only inertial forces on four-bar mechanism were assumed. External load has not been considered. Simulation results can be seen in Figs (3)-(5) for 1st case study and Figs (6)-(8) for 2nd case study.

Periodic dynamic behavior of four-bar linkage can be seen in figures. Changing of initial position conditions, occurs a phase-shifting in dynamic behavior of four-bar linkage mechanism. Also angular variable amplitudes increases in 2nd case study and this effect can be seen clearly angular acceleration (See Figs. (5) and (8)).

### 4. Conclusion

Dynamic analysis of four-bar linkage mechanism has been studied in the present study. Equation of motion for each linkage part was obtained using Lagrange formulation. Discretization and solution process of nonlinear differential equations are carried out by using Simulink and MATLAB, respectively. Only inertial effect on dynamics on the four-bar linkage was considered.

### References

Comparison of the Precision of Dry Sieve Analysis versus Wet Sieve Analysis for Some Selected Natural Clay Varieties

Suresh Aluvihara¹*, C.S. Kalpage¹, Bhupendra Singh Chauhan²

¹Department of Chemical and Process Engineering, University of Peradeniya, Peradeniya, 20400, Sri Lanka
²Department of Mechanical Engineering, Meerut Institute of Engineering and Technology, Meerut (UP), 250005, India

sureshaluvihare@gmail.com

Abstract: Clay is a specific soil type that composed with relatively finer particles usually less than 0.002mm according to most of standard definitions including the behaviours of cohesive and the clay particles may have different sizes less than 0.002mm and most of occasions the clay bulk is contaminated with some more coarse particles such as sand and silt even though those particles are comprised in a same deposit or a same massive body. Most of clay varieties are frequently condign in the advanced technological uses. Therefore, the investigation of the particle sizes of some of clay and categorization are important tasks in the selection of a clay type for some particular technological application. The well known methods for the grain size analysis are the wet sieve analysis and dry sieve analysis in order for cohesive soils and non-cohesive soils as usual. In the existing study, there were anticipated to compare the accuracy of dry sieve analysis results with the wet sieve analysis results of three different selected clay varieties in Sri Lanka. As the experiential works those clay samples were separately analyzed using a sieve range of 2mm-0.037mm and pan (<0.037mm) using dry sieve method. Also those clay types were wet sieve analyzed with respect to the sieve size of 0.075mm. According to dry sieve analysis results the finer portions (<0.075mm) were obtained as ~17%, ~6% and ~16% from clay 1, clay 2 and clay 3. The results of wet sieve analysis showed ~60%, ~37% and ~72% of finer portions (<0.075mm) in clay 1, clay 2 and clay 3 while the average grain sizes (D50) of them were 0.25mm, 0.27mm and 0.19mm. When comparing of those results the minimum deviation between wet sieve analysis result and dry sieve analysis result was found from clay 2 which is having maximum average grain size (D50) while the maximum deviation was observing from clay 3 which is having minimum average grain size (D50).

Keywords: Anthill clay, Brick clay, Roof tile clay, Wet sieve analysis, Dry sieve analysis

1. Introduction

Clay types have been identified as the specific varieties of soils because of the uncommon visible and physico-chemical characteristics of such clay in the comparison of those characteristics against the common characteristics of abundant soils. As a physical characteristic, particle size would be a descriptive parameter based upon the uses of such clays and soils in the industrial purposes. In the consideration of the analysis of particle sizes of soils the sieve analysis is the well-known standard method that used to classify the relevant group of soil such as the clay, gravel, silt etc. However, based upon experimental activities and past research experiences, there were defined two standard sieve analysis techniques that depending on the particle sizes of the soil type or the specific soil category as follows [1, 2, 3, 4, 5, 6].

- Dry sieve analysis- Coarse grained soils such as sand, gravel, pebbles, cobbles etc.
- Wet sieve analysis- Fine grained soils such as clay, silt, ultrafine clay etc.

According to the methodologies of both wet sieve analysis and dry sieve analysis, it is possible to emphasize some important contrarieties. In the wet sieve analysis technique, the unknown dry soil sample is separated into a series with respect to know sized while applying an external vibrational forces through a shaker. In the selection of this method, the following primary characteristics of the unknown soil type will be considered [4-10].

- Non-cohesive soil
- Relatively coarse grained soils

In the dry sieve analysis method, the unknown dry soil sample is separated as two or more stages as follows.

- Primary stage- Separation of the coarse portion and the finer portion of the soil

Usually the unknown soil sample is dissolved in distilled water on a known size of sieve. The critical separation size would be the size of used sieve.

- Secondary stage- Size analysis and classifications of the separated portions in respectively such as the dry sieve analysis for the coarse portion and the hydrometer analysis for the finer portion.

The required critical separation size would be decided by the researcher based upon the aims and objectives of the research. Based upon the requirements of the analysis, the relevant standard sieve size would be selected. In the selection of the critical separation sieve sizes the standard defined particle size of the required soil type could be used as a reference value as follows [1-10].

- Clay – <0.075mm (USCS Standards)
- Sand - 0.075-4.75 (USCS Standards)

The sizes of soils are not the fixed values and it is possible to be varied in size according to the type of soils based upon a few of main factors as follows [2-8].

- Weathering conditions (erosion)
- Climatic conditions such as the temperature, wind, rain pattern etc.
- Geomorphological conditions
- Anthropogenic activities such as the vegetation

Clay is an abundant earth material at around large number of locations in the world including various characteristics from one location to other one. The experimental studies of the accuracies of those scientific methods for unknown materials are the essential chapters on the research and development activities. In the existing research, there were expected to analyze and compare the status of bot wet sieve analysis and dry sieve analysis outcomes using three selected different clay types that available in three different locations in Sri Lanka.
2. Materials and Methodology

The representative clay samples were collected from three different locations of Sri Lanka and the collected clay types were nominated using the names that based on their typical uses and origin. A brief description about such clays is given in the Table 1.

<table>
<thead>
<tr>
<th>Clay Type</th>
<th>Uses</th>
<th>Collected Area</th>
<th>General Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthill Clay</td>
<td>Not recorded</td>
<td>Matale</td>
<td>Cohesive clay, reddish brown and relatively finer grained clay</td>
</tr>
<tr>
<td>(Clay 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick Clay</td>
<td>Brick industry</td>
<td>Maduragoda</td>
<td>Less cohesive clay, brown and relatively coarse grained clay</td>
</tr>
<tr>
<td>(Clay 2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof Tile Clay</td>
<td>Roof tile industry</td>
<td>Dankotuwa</td>
<td>Much cohesive clay, yellowish brown and relatively finer grained clay</td>
</tr>
<tr>
<td>(Clay 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The representative portions of the collected clay samples are shown in the Fig.1.

2.1. Dry Sieve Analysis

Some representative portion of each clay type was selected and the selected clay portions were oven dried for 24 hours under the temperature of 110°C based upon the purpose of the removal of water content/moisture content from the clays.

The dried clay samples were separately poured on to a flat surface and the final representative clay sample from each clay type was selected using coning and quartering method as shown in the Fig.3.

Coning and quartering method is a well-defined sample selection method from a large portion which is applicable for the solid materials such as soils, powdered minerals etc.

The selected representative clay samples were separately analyzed using a set of standard sieves and relevant equipment as shown in the Fig.4.

After 10 minutes shaking period, the retained clay weight of each sieve was measured on an analytical balance. The particle size distribution curve was plotted with respect to each clay type based upon the observed data [1-6].

2.2. Wet Sieve Analysis

The representative clay samples were prepared using the same methodology except the step of crushing. Each representative clay sample was weighed using an analytical balance.

Each representative clay sample was washed on sieve in the size of 0.075mm using distilled water as the finer portion is washed out and the coarse portion is remaining on the mesh. The remained coarse portions were oven dried for 24 hours under the temperature of 110°C and each of dried coarse portions was weighed using an analytical balance [5-10].
The dried coarse portion was dry sieve analyzed using the same methodology that discussed in the previous chapter and the finer portion was sent for the hydrometer analysis.

3. Results and Discussion

The dry sieve analysis results of anthill clay are shown in the Table 2.

![Image of 0.075mm standard sieve]

**Fig. 5. 0.075mm standard sieve**

The particle size distribution curve of anthill clay is shown in the Fig.6.

![Particle size distribution curve of anthill clay](image)

**Fig. 6. Particle size distribution curve of anthill clay**

According to the above graph the average particle diameter ($D_{50}$) of anthill clay was recorded as

The wet sieve analysis results of anthill clay are shown in Table 3.

**Table 2: Dry sieve analysis results of anthill clay**

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Weight retained on each sieve (g)</th>
<th>Percentage of weight retained (%)</th>
<th>Cumulative percentage of weight retained (%)</th>
<th>Cumulative percentage of weight passed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.02</td>
<td>0.04</td>
<td>0.04</td>
<td>99.96</td>
</tr>
<tr>
<td>0.5</td>
<td>10.34</td>
<td>20.36</td>
<td>20.32</td>
<td>79.64</td>
</tr>
<tr>
<td>0.25</td>
<td>15.61</td>
<td>30.68</td>
<td>30.68</td>
<td>69.32</td>
</tr>
<tr>
<td>0.149</td>
<td>12.39</td>
<td>24.35</td>
<td>24.35</td>
<td>75.64</td>
</tr>
<tr>
<td>0.074</td>
<td>3.91</td>
<td>7.68</td>
<td>7.68</td>
<td>92.32</td>
</tr>
<tr>
<td>0.075</td>
<td>7.86</td>
<td>15.85</td>
<td>15.85</td>
<td>84.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>98.53</td>
<td>98.53</td>
<td>1.47</td>
</tr>
</tbody>
</table>

The dry sieve analysis of the coarse portion of anthill clay are shown in the Table 4.

**Table 3: Wet sieve analysis results of anthill clay**

<table>
<thead>
<tr>
<th>Aggregates</th>
<th>Weight Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregates (&gt;0.075mm)</td>
<td>~40</td>
</tr>
<tr>
<td>Finer Aggregates (&lt;0.075mm)</td>
<td>~60</td>
</tr>
</tbody>
</table>

The dry sieve analysis results of the coarse portion of anthill clay are shown in the Table 4.

**Table 4: Dry sieve analysis results of the coarse portion of anthill clay**

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Weight retained on each sieve (g)</th>
<th>Percentage of weight retained (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>1.18</td>
<td>0.71</td>
<td>2.95</td>
</tr>
<tr>
<td>0.59</td>
<td>7.92</td>
<td>32.89</td>
</tr>
<tr>
<td>0.42</td>
<td>3.26</td>
<td>13.54</td>
</tr>
<tr>
<td>0.25</td>
<td>4.99</td>
<td>20.72</td>
</tr>
<tr>
<td>0.15</td>
<td>4.1</td>
<td>17.03</td>
</tr>
<tr>
<td>0.075</td>
<td>2.89</td>
<td>12.00</td>
</tr>
</tbody>
</table>
When comparing both wet sieve analysis and dry sieve analysis results of anthill clay, there were observed the great difference in the results for the finer portion (<0.075) in both dry sieve analysis and wet sieve analysis results. According to the dry sieve analysis method (experimental method), it was observed ~17% of finer portion with respect to the weight since the more accurate value was observed as ~60% under the wet sieve analysis method (well defined method for clays). In addition, that the soils weights which were retained in other sieves showed the dissimilarities in both dry sieve analysis and wet sieve analysis methods [1,2,3,4,6,10].

The dry sieve analysis results of brick clay are shown in the Table 5.

The particle size distribution curve of brick clay is shown in the Fig.7.

According to the above graph the average particle diameter ($D_{50}$) of brick clay was recorded as

The wet sieve analysis results of brick clay are shown in Table 6.

Table 6: Dry sieve analysis results of the coarse portion of brick clay

<table>
<thead>
<tr>
<th>Aggregates</th>
<th>Weight Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregates (&gt;0.075mm)</td>
<td>~63</td>
</tr>
<tr>
<td>Finer Aggregates (&lt;0.075mm)</td>
<td>~37</td>
</tr>
</tbody>
</table>

The dry sieve analysis of the coarse portion of brick clay are shown in the Table 7.

Table 7: Dry sieve analysis results of the coarse portion of brick clay

In the comparison of both results of wet sieve analysis and dry sieve analysis of brick clay, there were obtained ~6% of finer portion under the dry sieve analysis and ~37% of finer portion under the wet sieve analysis method. Also there were observed the dissimilarities in between the results of wet sieve analysis and dry sieve analysis of brick clay with respect to each sieve size [1-8].
The dry sieve analysis results of roof tile clay are shown in the Table 8.

**Table 8: Dry sieve analysis results of roof tile clay**

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Weight retained on each sieve (g)</th>
<th>Percentage of weight retained (%)</th>
<th>Cumulative percentage of weight retained (%)</th>
<th>Cumulative percentage of weight passed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.16</td>
<td>0.31</td>
<td>0.31</td>
<td>99.69</td>
</tr>
<tr>
<td>0.5</td>
<td>11.8</td>
<td>23.17</td>
<td>23.48</td>
<td>76.52</td>
</tr>
<tr>
<td>0.25</td>
<td>7.97</td>
<td>15.65</td>
<td>39.13</td>
<td>60.87</td>
</tr>
<tr>
<td>0.149</td>
<td>11.71</td>
<td>22.99</td>
<td>62.12</td>
<td>37.88</td>
</tr>
<tr>
<td>0.074</td>
<td>11.12</td>
<td>21.83</td>
<td>83.96</td>
<td>16.04</td>
</tr>
<tr>
<td>0.037</td>
<td>7.05</td>
<td>13.84</td>
<td>97.80</td>
<td>2.20</td>
</tr>
<tr>
<td>&lt;0.037 (pan)</td>
<td>1.12</td>
<td>2.20</td>
<td>100</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The particle size distribution curve of roof tile clay is shown in the Fig.8.

![Particle size distribution curve of roof tile clay](image)

According to the above graph the average particle diameter ($D_{50}$) of roof tile clay was recorded as

The wet sieve analysis results of roof tile clay are shown in Table 9.

**Table 9: Wet sieve analysis results of roof tile clay**

<table>
<thead>
<tr>
<th>Aggregates</th>
<th>Weight Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregates (&gt;0.075mm)</td>
<td>~28</td>
</tr>
<tr>
<td>Finer Aggregates (&lt;0.075mm)</td>
<td>~72</td>
</tr>
</tbody>
</table>

The dry sieve analysis of the coarse portion of roof tile clay are shown in the Table 10.

**Table 10: Dry sieve analysis results of the coarse portion of roof tile clay**

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Weight retained on each sieve (g)</th>
<th>Percentage of weight retained (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.35</td>
<td>2.14</td>
</tr>
<tr>
<td>1.18</td>
<td>0.28</td>
<td>1.71</td>
</tr>
<tr>
<td>0.59</td>
<td>2.61</td>
<td>15.98</td>
</tr>
<tr>
<td>0.42</td>
<td>1.07</td>
<td>6.55</td>
</tr>
<tr>
<td>0.25</td>
<td>2.1</td>
<td>12.86</td>
</tr>
<tr>
<td>0.15</td>
<td>3.57</td>
<td>21.86</td>
</tr>
<tr>
<td>0.075</td>
<td>4.62</td>
<td>28.29</td>
</tr>
<tr>
<td>&lt;0.075 (pan)</td>
<td>1.73</td>
<td>10.59</td>
</tr>
</tbody>
</table>

In the consideration of the observed values for the finer portions under both wet sieve analysis and dry sieve analysis methods, there were obtained ~16% of finer percent under the dry sieve analysis method and ~72% of finer percent under the wet sieve analysis method. When considering the relevant results for other sieve sizes there were observed the variations as usual [1, 2, 3, 4, 5, 7, 8].
In the comparison of the values in above table, there can be identified some correlation between the average grain size ($D_{50}$) of a soil/clay and the deviations of the results for the finer portion of particle according to the weight that obtained under both methods of wet sieve analysis and dry sieve analysis. Usually it is possible to expect some relatively higher deviations of such results with respect to the soils/clays that having lower average particle size ($D_{50}$) [2, 3, 4, 5, 6, 8].

The dry sieve analysis method would be a common method to analyse both coarse soils and finer soils although that there might be consisted some errors in results that obtained under the dry sieve analysis method for finer portions of clay. However, the dry sieve analysis method can be used for both coarse soils and finer soils to have some approximate conception on the soil/clay and it is possible to detect the requirement of wet sieve analysis method while comparing of that value with the standard or experimental reference values for the soil classification in particle size [1, 6].

In the dry sieve analysis of finer soil verities, it is better to perform the experiment with relatively lower weight of soil samples because in the existing research there were found some experimental errors in the continuing of sieve analysis with respect to intermediate sieves when the sample was too large.

### Table 11: Deviations of results for the finer portion both wet sieve analysis and dry sieve analysis

<table>
<thead>
<tr>
<th>Clay</th>
<th>Finer Portion in Wet Sieve Analysis (%)</th>
<th>Finer Portion in Dry Sieve Analysis (%)</th>
<th>Deviation (%)</th>
<th>Average Grain Size ($D_{50}$/ mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthill Clay (Clay 1)</td>
<td>~60</td>
<td>~17</td>
<td>~43</td>
<td>0.25</td>
</tr>
<tr>
<td>Brick Clay (Clay 2)</td>
<td>~37</td>
<td>~6</td>
<td>~31</td>
<td>0.27</td>
</tr>
<tr>
<td>Roof Tile Clay (Clay 3)</td>
<td>~72</td>
<td>~16</td>
<td>~56</td>
<td>0.19</td>
</tr>
</tbody>
</table>

4. Conclusion

In the considerations of the major outcomes of the wet sieve analysis and wet sieve analysis methods of three different clay types, mainly there were observed some higher deviations (errors) based on the results that obtained under both wet sieve analysis and dry sieve analysis methods for the finer portions of clay according to the weights. When comparing those deviations with the average grain sizes ($D_{50}$) of clays, there were seen the important correlations between the experimental deviation and average grain sizes ($D_{50}$) of clay because the experimental deviation was relatively lower in coarse grained clays/soils with relatively higher in average grain sizes ($D_{50}$).

5. Acknowledgement

The obligations of the material providers and the technical support of the technical officers must be set much by the authors.

6. References

The strenuous state of the contact at the sliding - flip pairs

Odhisea Koça1, Anis Sulejmani2, Klodian Dhoska3
Polytechnic University of Tirana, Albania
Email: odisekoca2008@hotmail.com, anissulejmani@gmail.com, kdhoska@upt.al

Abstract: The exact determination of strain on the load application area, regards to changing material or shape is one of the main problems of the mini structure constructions, which it does not interfere with the classical methods of linear elasticity. The main purpose of this article is to demonstrate accomplishments in the knowledge of linear elasticity with different mathematical methods, in order to penetrate into the area or into the contact lining, taking into consideration the friction between the bodies in contact. The methods and hypotheses are related to the analysis of different classical half-plane problems in loads of different types of linear elasticity. This material shows a clear original solution of the strained state in the contact area including the surface lining; it serves as a solution to the various contact plan problems. The details and the elements of the vehicles are part of a broad field, which should be optimized considering different analytical solutions and using various computer programs. These solutions can be installed in their structure. Classical methods in the details apply only when the hypotheses on studied subjects are being met, such as Material Resistance studying the Rod. A detail with a length of ten times greater than the transverse dimension. That’s the reason why extreme problems or problems out of the different hypotheses are solved and proven in practice with the most creative and sophisticated methods. The solution given in this article is an important contribution to constructive calculations, which is also associated with other works carried out by me on the friction coefficient on the flip-flop slippery contact.

Keywords: STRINGS, ELLIPTICAL COORDINATES, CONTACT HERZIT, CONTACTLESS CONTACT, SURFACE CONTACT

1. Subplant loaded with normal and tangential loads

The Fig. 1 depict a normal and tangential load in half planes.

For the most appropriate normal load is to be shifted to a bi-harmonic function $F(z) = \Phi + y \cdot \Psi$ and then to the harmonic functions $\Phi$ and $\Psi$ where $F(z) = \phi + y \cdot \psi$ and $z = x + i \cdot y$. The strains from the strain relief will be [1-3].

$$\sigma_{xx} = \frac{\partial^2 F}{\partial y^2} = \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \psi}{\partial y^2}$$

Knowing that the harmonic functions satisfy the condition

$$\psi^2 \phi = \frac{\partial \phi}{\partial y^2} + \frac{\partial \psi}{\partial y^2} = 0,$$

we get

$$\psi = \frac{\partial \psi}{\partial y}, \quad \phi = \frac{\partial \phi}{\partial y}, \quad \phi = \frac{\partial^2 \phi}{\partial x \partial y} = \frac{\partial^2 \Psi}{\partial x \partial y} = \frac{\partial Y}{\partial x}$$

Afterward we get:

$$\sigma_{xx} = \frac{\partial^2 Y}{\partial x^2} = \psi + x \cdot \frac{\partial \psi}{\partial y}$$

After collecting normal strains, the first strain tensor invariant will be:

$$\sigma_{xx} = \frac{\sigma_{xx} + \sigma_{yy}}{2}$$

The most convenient tangential load is to go to a bi-harmonic function as below:

$$F(z) = \Phi + x \cdot \Psi, \quad ku z = x + i \cdot y$$

Strengths from strain solution will be:

$$\sigma_{xx} = \frac{\partial^2 F}{\partial y^2} = \psi - x \cdot \frac{\partial \psi}{\partial y}; \quad \sigma_{yy} = \frac{\partial^2 F}{\partial x^2} = \psi + x \cdot \frac{\partial \phi}{\partial y}; \quad \sigma_{xy} = \frac{\partial^2 F}{\partial x \partial y} = -x \cdot \frac{\partial \psi}{\partial y} + \psi = \frac{\sigma_{xx} + \sigma_{yy}}{2} \quad (5)$$

In the case of normal and tangential load these functions will be as below:

$$\phi = -P \cdot \sin \theta, \quad \psi = -T \cdot \cos \theta; \quad F(z) = \varphi + i \cdot \psi = -\frac{1}{\pi \tau} (P \cdot \sin \theta + i \cdot T \cdot \cos \theta) \quad (6)$$

when $P = T$ group together into the complex variable $z$

$$F(z) = -\frac{P}{\pi \tau} \left(1 - \frac{z}{P \cdot \tau} \right) \quad (7)$$

In the case when the $P$ and $T$ forces are located at the ‘$u$’ distance from the origin we have:

$$F(z) = -\frac{P}{\pi \tau} \left(1 - \frac{u}{P \cdot \tau} \right) \quad (8)$$

In case of distributed load we will integrate:

$$F(z) = \int \frac{P}{\pi \tau} \left(1 - \frac{u}{P \cdot \tau} \right) \, du \quad (9)$$

where $\varphi$ is the real part of $F(z)$ and $\psi$ is the imaginary part of $F(z)$.

For normal load we have:

$$\sigma_{xxN} = \Phi + y \cdot \frac{\partial \phi}{\partial y}; \quad \sigma_{yyN} = \Phi - y \cdot \frac{\partial \phi}{\partial y}; \quad \sigma_{xyN} = -y \cdot \frac{\partial \phi}{\partial x} \quad (10)$$

For the tangential load we have:

$$\sigma_{xxT} = \psi + x \cdot \frac{\partial \psi}{\partial x} = 2 \cdot \psi; \quad \sigma_{yyT} = \psi - x \cdot \frac{\partial \psi}{\partial x}; \quad \sigma_{xyT} = \psi + x \cdot \frac{\partial \psi}{\partial x} \quad (11)$$

2. The usage of elliptical coordinates

In the $x$ and $y$ axes system, we have different functions such as strains, deformations, and displacements, which are very complicated. The differential equations that they have emerged may present different difficulties to be solved. Another system of axes is the elliptical coordinate’s $\xi$, $\eta$. These functions can come up with simpler formulas as well as with the solution of the differential equations from which the equation have emerged to be lighter. Fig. 2 depict Elliptic coordinates in the contact problem.
In the complex variable $z = x + i \cdot y$ or $\xi = \xi + i \cdot \eta$ for the transformation

\[
\begin{align*}
\beta = & \beta \cdot \cosh \xi = \beta \cdot \frac{e^\xi + e^{-\xi}}{2} = \beta \cdot \frac{e^{(1+i\eta)} + e^{-(1+i\eta)}}{2} = \beta \\
\beta = & \beta \cdot \cosh \xi \cdot \cos \eta \text{ dhe } y = \beta \cdot \sinh \xi \cdot \sin \eta
\end{align*}
\]

### 3. The integral solution for the symmetric term

(Herc’s fiery contact)

We analyze the case of contact with normal and tangential load according to the problem of Herc, see Fig. 3.

\[
\Phi(z) = \frac{1}{\pi} \int \frac{p(u)}{u-z} \, du = \frac{1}{\pi} \int \frac{C_1 \cdot \cos \theta}{\beta(u-z)} \, du = -C_1 \cdot i \cdot e^{-z \xi} \cdot \sin \eta
\]

with its real and imaginary part:

\[
\begin{align*}
\varphi = & -C_2 \cdot e^{-y} \cdot \sin \eta \text{ dhe } \psi = -C_2 \cdot e^{-y} \cdot \cos \eta
\end{align*}
\]

### 4. Sample preparation

In the case of rough rolling contact we have both pressure terms. We analyze the second term of pressure as it was first analyzed at Herc’s contact, see Fig. 4.

\[
\begin{align*}
p(u) = & -C_1 \cdot \sin(2 \cdot \theta) = 2 \cdot C_2 \cdot \frac{u}{\beta} \cdot \sqrt{\beta^2 - u^2} \\
u = & -\beta \cdot \sin \theta
\end{align*}
\]

We define the potential function for this pressure:

\[
\Phi(z) = \frac{1}{\pi} \int \frac{p(u)}{u-z} \, du = \frac{1}{\pi} \int \frac{C_1 \cdot \cos \theta}{\beta(u-z)} \, du
\]

and the formative reinforcement of functions:

\[
\begin{align*}
\varphi = & -C_2 \cdot e^{-y} \cdot \sin(2 \cdot \eta) \text{ dhe } \psi = -C_2 \cdot e^{-y} \cdot \cos(2 \cdot \eta)
\end{align*}
\]

### 5. Strings on the lining of contact bodies

Laboratory The Fig. 5 depict a pressure at rolling contact for $\lambda = 0.424$.

\[
\begin{align*}
p_n(\theta) = & C_1 \cdot \cos \theta - 0.424 \cdot C_2 \cdot \sin(2 \cdot \theta) \\
\end{align*}
\]

From reference pressure we have simplifications:

\[
\begin{align*}
\Phi_n(\theta) = & \frac{p_n(\theta)}{C_1} = \cos \theta - 0.424 \cdot \sin(2 \cdot \theta); \quad \beta = \frac{T-n}{\beta} = -\sin(\theta - 90^\circ + 90^\circ)
\end{align*}
\]

In case of total slide we draw:

\[
\begin{align*}
p_s(\theta) = & \mu \cdot [\cos \theta - 0.424 \cdot \sin(2 \cdot \theta)]; \quad \mu \rightarrow \text{the coefficient of friction between the two bodies in contact}
\end{align*}
\]

The contact surface in elliptical coordinates is divided into three parts. The CD part where $\eta = \pi$, the contact AB part, which depends directly on the oppressive force $\xi = 0$ and the part BD where $\eta = 0$. 

\[
\begin{align*}
C = & \eta = \pi \quad \Delta \quad \beta = \beta \quad \beta = \beta \quad \eta = 0 \quad \beta = \beta \quad \Delta
\end{align*}
\]
When flipping in real contact, the most loaded case is realized when we have full slide. The reinforcements in this case for the lining will be:

Area CA: \( \eta = \pi \) from Eq. (23), (25), (29), (30):

\[
\sigma_{\text{extN}} = 0; \sigma_{\text{extT}} = 2 \cdot \mu \cdot C_1 \cdot \left(e^{-2\lambda}\right); \sigma_{\text{extN}} = 0; \sigma_{\text{extT}} = -2 \cdot \mu \cdot C_2 \cdot e^{-2\lambda}
\]

Area AB: \( \xi = 0 \) by ek (23), (25), (29), (30):

\[
\sigma_{\text{extN}} = C_1 \cdot \sin\eta; \sigma_{\text{extT}} = -2 \cdot \mu \cdot C_1 \cdot \sin\eta; \sigma_{\text{extN}} = 0; \sigma_{\text{extT}} = -2 \cdot \mu \cdot C_2 \cdot \sin\eta
\]

Zone BD: \( \eta = 0 \) by ek (23), (25), (29), (30):

\[
\sigma_{\text{extN}} = 0; \sigma_{\text{extT}} = -2 \cdot \mu \cdot C_1 \cdot \left(1 + \lambda\right); \sigma_{\text{extN}} = 0; \sigma_{\text{extT}} = -2 \cdot \mu \cdot C_2 \cdot \left(1 + \lambda\right)
\]

By analyzing the surface lining we distinguish in the passive body, the maximum strain at the trailing edge of the contact path which is equal to \( \sigma_{\text{max}} = 2 \cdot \left(1 + \lambda\right) \cdot \mu \cdot p_H \). It is known that destruction starts at the points that are pulled and these are found at the ends of the contact path, see Fig. 7.

By analyzing the surface lining we distinguish in the active body that the maximum retraction strain is located at the other end of the contact path with a smaller value \( \sigma_{\text{L,max}} = 2 \cdot \left(1 + \lambda\right) \cdot \mu \cdot p_H \), see Fig. 8.

6. The skeleton of the tooth at the toothed wheel

Skeleton is an injury from tiredness in contact with the tooth surface, is a progressive destruction of cyclic strains and has the features of fatigue destruction [4-6]. Oily wheels in the environment of oil are always damaged by the skull, especially this damage appears in the area from the pole to the toes. According to the coefficient of friction literature in this case (in oil environment) varies by type of oil at the limits 0.05÷0.06 [5]. When the oil is absent varies in the range of 0.09÷0.4, so the maximum tangential strain appears on the surface and the discussion ends. It starts the destruction of the fatigue contact.

In a couple of sprockets we distinguish the active wheel that the movements comes from and the passive wheel that the movement goes. In addition, we recognize the active tooth with the highest tangential velocity and the passive tooth with lower tangential velocity because the normal speed is the same. At the beginning of the active tooth, the active wheel is active and at the end of the gear the active tooth is active wheel. This helps us to set the direction of the friction forces, starting from the active tooth, always against it and the opposite tooth according to the principle of counteracting action.

Seeing the tangential speed game, we conclude that when the contact point is located on the part from the foot to the poly of the gear of each tooth of each wheel, the maximum tensile strengths in the traction are impacted by frictional forces. This strain is in tune and explains every disaster, especially from fatigue contact. From both bodies, one of them appears to be in charge, and this is in the tooth area up to the poly Fig.9 and Fig.10.

Active Wheels Active 1Passive Wheels Active Wheel 2Active wheel. Passive wheel

The maximum value of the pulled force for the passive tooth and the active tooth are respectively \( \sigma_{\text{active,max}} = 2 \cdot \left(1 + 0.424\right) \cdot \mu \cdot p_H \) and \( \sigma_{\text{active,max}} = 2 \cdot \left(1 - 0.424\right) \cdot \mu \cdot p_H \). Therefore, we conclude that the destruction always starts from the surface due to the friction and the tendency to flip the tooth.

Fig.11 Main strain on the body surface and counter-contact surfaces
7. Conclusions

From the harshness of the rough contact and its application to the toothed wheel we conclude that:

- Analytical determination of stiff contact state.
- At the end of the contact line always appears a pulling strain due to friction.
- The passive body is loaded more in tow than the active body due to friction and flip.
- Friction is the main cause of the skirmish.
- The maximum peak strength on the surface lining depends directly on the friction coefficient and the Hercule pressure.
- The skeleton starts from the pole and goes straight to the end of the tooth because in this area the maximum peak pull strength $\sigma_s = 2.848 \mu p_H$ appears.
- Calculation of the tooth skeleton are merely calculation of fatigue contact.

References

МКЭ-моделирование процесса деформирования биметаллической заготовки совмещенным процессом «РКУ-прессование - волочение»

FEM-modeling of a bimetallic workpiece deformation by “ecap – drawing” combined process

Irina Volokitina¹, Andrey Volokitin¹, Abdrahman Naizabekov¹, Evgeniy Panin²
Rudny industrial institute, Rudny, Kazakhstan¹
Karaganda state industrial university, Temirtau, Kazakhstan²
cooper802@mail.ru

Abstract: This work is aimed to investigation of bimetallic wire deformation during combined ECAP-drawing. Results of strain state study showed that layers of materials in the cross-section of wire have received different values of strain. Stress state of both materials is various in both deformation zones - in the ECAP matrix deformation area is divided for two sections (tension and compression) separated by diagonal. At all deformation stages the level of compressive stresses is much higher of tensile stresses. Investigation of microstructure evolution in layers of bimetallic wire during combined ECAP-drawing showed that with initial grain sizes 20 µm for aluminum shell and 18 µm for steel core both layers of bimetallic wire are processed unequally. Surface shell is processed until grain size of 9 µm. Steel core has different grain sizes in the cross section – in surface layers microstructure has size about 14 µm, in axial zone has size about 17 µm. Also, after drawing stage the shape of grains is elongated due to the action of tensile stresses.

Keywords: SEVERE PLASTIC DEFORMATION, BIMETALLIC WIRE, COMBINED PROCESS, ECAP-DRAWING, MICROSTRUCTURE EVOLUTION, FEM

1. Введение

Использование интенсивной пластической деформации для формирования в металлах и сплавах ультрамелкозернистой (УМЗ) структуры, обеспечивающей высокий уровень прочностных и пластических характеристик данных металлов и сплавов, является одним из перспективных направлений современного материаловедения. Среди большого количества уже разработанных способов реализации интенсивной пластической деформации особый интерес к этим процессам относится и совмещенных процессов, в основе которых лежит принцип РКУП [1-6]. Каждый из этих процессов позволяет существенно повысить производительность процесса деформирования за счет аннигиляции определенных недостатков РКУП. К таким процессам относится и совмещенный процесс «РКУП-волочение» (рисунок 1). Реализация данного процесса позволяет получать стальную проволоку или проволоку из цветных металлов и сплавов с ультрамелкозернистой структурой и повышенным уровнем механических свойств.

![Схема процесса "РКУП-волочение"](image)

На текущий момент разработка данного совмещенного процесса велась только для однородных материалов. При этом в качестве исходного материала для производства проводов все больше применяется биметаллическая проволока – сортовое длинномерное изделие стального проката композиционного типа, состоящее из металлов и сплавов с разными химическими и физическими характеристиками. Часто всего используются типы соединения: сталь-алюминий и сталь-медь. Конструкция биметаллической проволоки состоит из сердечника и оболочки. Сердечник изготовляют из высокопрочных марок стали, оболочка представляет собой иной по свойствам металл или сплав.

При реализации схемы деформирования, приведенной на рисунке 1, в сечении заготовки развивается высокий уровень растягивающих напряжений, поэтому неправильный подбор технологических и геометрических параметров данного процесса приведет к обрыву деформируемой проволоки. И эти параметры чаще всего не одинаковы даже для различных однородных материалов, и тем более они будут «свои» при волочении биметаллической проволоки или прутка. Поэтому данная работа посвящена исследованию процесса деформирования биметаллической проволоки типа «сталь-алюминий» с помощью совмещенного процесса «РКУП-волочение».

2. МКЭ-моделирование

Одним из наиболее эффективных методов теоретического анализа любого технологического процесса в настоящее время является компьютерное моделирование с помощью метода конечных элементов. Если рассматривать МКЭ-моделирование с позиции обработки давлением, то здесь лидирующую позицию занимает программа Deform, которая позволяет моделировать почти любой процесс деформирования.
В качестве исходной заготовки использовалась биметаллическая проволока с соединением типа «сталь-алюминий» диаметром 10 мм, причем диаметр стального сердечника был равен 8 мм. Материалом сердечника была выбрана сталь AISI-1010 (аналог стали 10). В качестве материала оболочки был выбран алюминиевый сплав 1100. Деформирование проводилось при комнатной температуре. Угол стыка каналов в РКУ-матрице был равен 145°. На этапе волочения обеспечивалось обжатие 5%, до диаметра 9,5 мм. В качестве модели материала для сердечника и оболочки был выбран упруго-пластический тип. Поскольку оба материала являются неподвижными относительно друг друга в биметаллической проволоке, между ними был установлен жесткий неразрывный контакт. На контакте алюминиевой оболочки и обоих инструментов (РКУ-матрицы и волоки) был установлен коэффициент трения 0,1, что соответствует шлифованной поверхности с применением смазки.

При разработке данного совмещенного процесса было установлено, что для предотвращения обрыва проволоки на участке между матрицей и волокой, необходимо согласование тянувшей скорости, приложенной к переднему концу заготовки, и подталкивающей скорости, приложенной к заднему концу. При заданной задней скорости 10 мм/с и уменьшении поперечного сечения проволоки с 10 до 9,5 мм, передняя скорость будет равна 11,08 мм/с.

3. Результаты и их обсуждение
3.1. Деформированное состояние

При рассмотрении стадии РКУ-прессования данного совмещенного процесса было установлено, что при прохождении через каналы РКУ-матрицы, оболочка и сердечник получают различные уровни прироста деформации (рисунок 2а). Наибольшую величину эквивалентной деформации, достигающей ε=1,5 на отдельных участках алюминиевая оболочка получает в зонах стыка каналов – при движении и трении о закругленные зоны углов стыка. Сердечник получает деформацию, значительно меньшую по величине – центральная зона сердечника прорабатывается до ε=0,4, поверхностные слои сердечника получают более высокую деформацию, до ε=0,6. Несмотря на то, что оба материала находятся в жестком защеплении друг с другом и должны деформироваться одинаково, такая существенная разница в развитии деформации объясняется различной величиной сопротивления деформации обоих материалов. Иными словами, в данном случае один материал значительно мягче и податливее другого.

После стадии волочения (рисунок 2б) небольшой прирост деформации наблюдается лишь в оболочке до ε=1,7, уровень деформации в сердечнике почти не изменяется.

3.2. Напряженное состояние

При рассмотрении среднего гидростатического давления на стадии РКУ-прессования было выявлено, что характер распределения данного параметра аналогичен распределению эквивалентного напряжения (рисунок 3а). В алюминиевой оболочке на участках, где контакт с инструментом отсутствует, возникают растягивающие напряжения 100÷110 МПа. На прямолинейных участках, где имеется контакт с матрицей, оболочка испытывает противодавление от матрицы, что приводит к созданию сжимающих напряжений -80÷-90 МПа. Максимальный уровень противодавления создается непосредственно на стыках каналов – здесь величина сжимающих напряжений достигает значения -350 МПа.

В стальном сердечнике распределение растягивающих и сжимающих напряжений можно назвать идентичным распределению в оболочке. На верхних участках входного и выходного каналов, а также на нижнем участке промежуточного канала возникают растягивающие напряжения, значение которых равно около 230÷240 МПа. На
противоположных участках во всех каналах реализуются сжимающие напряжения, достигающие -360 МПа.

При волочении (рисунок 3б) очаг деформации, как и при рассмотрении эквивалентного напряжения, является полностью симметричным. В оболочке возникают сжимающие напряжения примерно -160 МПа. При этом во всем сердечнике создаются растягивающие напряжения на уровне 90 МПа. Снижение этих растягивающих напряжений в сердечнике наблюдается непосредственно в очаге деформации, где их величина снижается до 40 МПа.

3.3. Эволюция микроструктуры

При создании модели был установлен начальный средний размер зерна 20 мкм для алюминиевой оболочки и 18 мкм для стального сердечника. В ходе расчета моделей анализировалось изменение размера зерна в следующих зонах:

1) в выходном канале матрицы после завершения стадии РКУП;
2) в промежуточной зоне между матрицей и волокой;
3) на выходе из волоки после завершения стадии волочения.

Рассматривая микроструктуру в оболочке биметаллической проволоки (рисунок 4), было выявлено, что после прохождения каналов РКУ-матрицы исходный размер зерна уменьшается примерно до 13 мкм, при этом форма зерен становится равноосной, что соответствует эффекту РКУП.

Рис. 3 Среднее гидростатическое давление: а – стадия РКУП; б – стадия волочения

Рис. 4 Изменение размера зерна в алюминиевой оболочке
В промежуточной зоне между матрицей и волокой размер зерна почти не изменяется. Однако здесь зафиксировано некоторое удлинение зерен в продольном направлении, что является результатом действия растягивающих напряжений, возникающих на данном участке. На выходе из волоки после завершения стадии волочения размер зерен уменьшается до 9 мкм, при этом также отчетливо видны удлиненные зерна в направлении деформирования.

При изучении микроструктуры в сердечнике (рисунок 5), было установлено, что после прохождения каналов РКУ-матрицы исходный размер зерна 18 мкм практически не изменяется, незначительно измельчаются лишь отдельные зерна. В промежуточной зоне между матрицей и волокой размер зерна также почти не изменяется. Однако здесь зафиксировано некоторое удлинение зерен в продольном направлении.

Ввиду того, что сердечник значительно толще оболочки, на выходе из волоки микроструктура была рассмотрена в двух точках – в осевой и в поверхностной зонах. В поверхностной зоне размер зерен уменьшается примерно до 14 мкм, форма зерен при этом более равноосная, примерно одинаковых площадей. В осевой зоне размер зерен уменьшается значительно меньше, примерно до 17 мкм, форма зерен при этом является сильно вытянутой, что является следствием этапа волочения.

Рис. 5 Изменение размера зерна в стальном сердечнике

Заключение

Рассмотренный совмещенный процесс «РКУП-волочение» является достаточно интересным с точки зрения возможности деформирования такого материала, как биметаллическая проволока. При анализе деформационного состояния было выявлено, что каждый материал в биметалической проволоке получает различные значения деформации за один цикл, что связано с различией в уровнях прочности и пластичности этих материалов. Напряженное состояние обоих материалов значительно в обоих зонах деформации - в зоне РКУ область деформации разделена на участки растяжения и сжатия, разделенных диагонально. В зоне волочения частота деформации полностью симметрична. При этом на всех стадиях деформации уровень сжимающих напряжений значительно выше растягивающих напряжений. При начальных размерах зерен 20 мкм для алюминиевой оболочки и 18 мкм для стального сердечника было выявлено, что оба слоя биметаллической проволоки обрабатываются неравномерно. Поверхностная оболочка обрабатывается до размера зерен 9 мкм. При этом форма зерен получается достаточно равноосной. Стальной сердечник имеет различные размеры зерен в поперечном сечении – в поверхностных слоях структура зерен имеет вполне равноосную форму, аналогичную форме зерен в оболочке, с размером около 14 мкм. В осевой зоне зерна имеют размер около 17 мкм, при этом после стадии волочения форма зерен сильно вытягивается за счет действия растягивающих напряжений. Другими словами, при относительно равных исходных размерах зерен в оболочке и сердечнике, после деформирования по схеме «РКУП-волочение» можно получить биметаллическую проволоку с «градиентной» структурой, где размер зерен в поверхностной области снижается более чем в 2 раза, а осевой зоне почти не изменяется.

Примечание

Данное исследование финансировалось Комитетом науки Министерства образования и науки Республики Казахстан (Грант № AP08052852).

Литература
Innovative design for repair of corroded industrial reinforced concrete structures of light soda silos - Solvay Sodi AD, Devnya

Valeri Naidenov, Tzvetan Georgiev
Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria
University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria
valna53@mail.bg

Abstract: The report discusses the main parameters of a developed design and technological project for the implementation of specific repair and restoration works of built in the mid-1970’s corroded concrete reinforced structures of LIGHT-SODA SILOS – SOLVAY SODI JSC. The purpose of the design is to comply with the requirements for reasonable sufficiency of the additional new steel-reinforced concrete coating (jacketed) to realize a lightweight variant of the protective layer against corrosive production factors, atmospheric influences and other specific chemical impacts. The project envisages a technological variant for the implementation of an additional healing thin repair reinforced concrete layer (overlay), based on the specific characteristics of high-tech hybrid fiber-reinforced “wet” sprayed concrete with the participation of specially selected high-range water-reducing and internal-crystallization chemical admixtures. The report provides information on the basic physical-mechanical and technological characteristics of the “wet”-sprayed concrete, as well as the main stages of structural design with specific structural details. According to the static scheme of the facility, it is proposed to specify the allowable load-state of the structure during the repair works.

Keywords: CORRODED CONSTRUCTIONS, CONSTRUCTION AND TECHNOLOGICAL DESIGN FOR REPAIR WORKS, HIGH-TECH HYBRID FIBER-REINFORCED “WET”-SPRAYED CONCRETE, HIGH-RANGE WATER-REDUCING AND INTERNAL-CRYSTALLIZATION CHEMICAL ADMIXTURES

1. Introduction

The steel reinforced concrete structures of LIGHT SODA SILOS “4” & “5” - SOLVAY SODI AD, DEVNYA, were built in 1973 and they still operate under the combined impact of exploitation and environmental factors, some of which display significant corrosive potential. The latter violated the quality of the steel reinforced concrete, and serious corrosive damages were located within specific areas - Photos 1 and 2.

![Photo 1 LIGHT SODA SILOS “4” & “5” general view](image1)

![Photo 2 LIGHT SODA SILOS “4” & “5” typical concrete damages](image2)

The preliminary analysis of possible technical solutions produces a limited number of reasonable options basically due to the specific character of the operational units. Moreover, their operation cannot be entirely excluded from plant’s overall operational regime during a reasonable period of time. One should also note the absolute unsoundness of the “by the job” approach to repair, i.e. repair of local areas where the damaged state of the structure has been visually established. This is so since such an approach would indefinitely prolong repair whereas the escalation of corrosion damage would proceed in neighboring areas.

The design and execution of necessary repair/recovery operations based on subsequent technological regulations, concerning the employment of a standard repair systems pursuant to a series of standards BDS EN 1504: 1-10 Products and systems for the protection and repair of concrete structures, is also rejected a priori. Otherwise, this would yield the use of standard compatible mixes with different function, deposition of layers with comparatively large thickness and inevitable rise of repair cost.

The conventional construction of an entirely new steel reinforced concrete casing (a monolithic method) yielding increase of the wall cross section by at least 10 cm, is also unacceptable. Otherwise, the surface of the outer walls would be simultaneously and entirely uncovered resulting in total exclusion of the reinforcement from operation and hazards to the structure safety. Besides, such an approach imposes inadmissible complex requirements to the repair/recovery concrete and rise of cost.

Shotcreting of a new special concrete layer (“jacket”), without the use of formworks, employed to recover the initial cross section, seems to be the most appropriate technological method. Such an approach is adopted as a basic one in the present technical project, where as a technical-economical comparison between the two methods of shotcreting - “dry” and “wet” concrete covering, shows imperative advantages of the “wet” one [1,2]. The design envisages a technological variant for the implementation of high-tech hybrid fiber-reinforced “wet” sprayed concrete with the participation of specially selected high-range water-reducing and internal-crystallization chemical admixtures.

The purpose of the design is to observe the reasonable sufficiency requirements of the new concrete cover above the existing steel reinforcement, and to execute a thin protective overlay with special technical characteristics against the industrial factors influencing corrosion, weather impact, freezing, carbonization, UV rays, etc.

A basic requirement to the project is the observation of the principles of reasonable sufficiency of the offered solutions, concerning optimization of the thickness of the new concrete cover of the reinforcement, deposition of a low-weight anti-corrosion layer, protecting from atmospheric impacts, freezing, carbonation, UV rays etc. In addition, development of technical regulations of the planned repair is also envisaged.

2. Loads and actions on the silos

Considering the nature of the designed repair and renovation works, the structural stability and capacity has been checked in construction stage, taking into account the state of the silo during the repair works. In such a design situation, the silo is partially filled with light soda ash and parts of the body, ring beam or columns are partially weakened. For this purpose, the applied loads have been defined in compliance with BDS EN 1991-1-6: General actions during execution. Considering the estimated duration of the repair works per one spraying stage (each one over 3 days) and according to Table 3.1 of BDS EN 1991-1-6, the atmospheric loads on the structure were defined with probability of occurrence once in 5 years.
The wind load is determined for terrain category IV and base speed with probability of exceeds once in 5 years - 26.5 m/s. The dead loads are defined on the basis of the material volume density and the geometry dimensions of the silo’s elements. The load from the gallery above the silo is also reported.

Since a possibility is sought to avoid emptying the silo during the repair works, the calculation analysis has been performed for different degree of filling the silo with soda and respectively at different stages of repair works it can be filled differently. This filling capacity of the silo has been studied via data from the actual material circulation over the years. The records have been submitted by the Assignor and based on them the designer has made his estimation.

The Solvay’s engineering team has specified the characteristics of the soda stored in the silo with the following parameters: volume weight: 0.50 t/m³; angle of internal friction 40–45°. This volume weight is confirmed by the fact that at the maximum volume of the silo of ~8300 m³, the maximum filling capacity of silo “4” is 4130 t of soda.

3. Structural survey and status of the elements

The dimensions and location of the structural elements and reinforcement have been defined on the basis of the archive drawings.

Visit and visual inspection of the reinforced concrete structure has been performed to confirm or clarify the records data. The existing reinforcement steel was specified (A-III) as well as the concrete class (grade 300 ~, concrete compressive cube strength is 22,5 MPa). It should be noted that no essential damages have been observed in the reinforcement of the elements. Significant part of it is visible in the areas exposed to weather (the side of the columns, which is in contact with the outside air, the external cylindrical part of the silo body) but the visible reinforcement steel is in relatively good condition. The silo funnel (conical hopper), the supporting ring beam and the internal columns are predominantly in relatively good condition. Damages are observed on the columns which are in contact with the outside air, the external cylindrical part is visible in the areas exposed to weather (the side of the columns, which is exposed to weather. In this area sandblasting is planned to be performed, installation of reinforcement mesh and applying the wet mix shotcrete process for spraying of concrete coarse aggregate containing Mix №1 [1]. Prior to the eventual removal of carbonated concrete, it is foremost that the vertical rods will be braced by stirrups against buckling in view of the compression stresses existent in them. Work on “external” columns can be done with the presence of soda up to 1200 t. The internal columns, subject to their good status, will undergo only sandblasting of their surfaces and wet mix shotcrete process for spraying of a special passivating restorative without concrete coarse aggregate containing Mix №2 [1]. They may be processed simultaneously. The degree of permissible filling of the silo during works on all elements is shown on Figure 1.

4. Bearing capacity of the reinforced concrete structure elements during the repair activities and degree of silo’s filling

A calculation check of the silo structure elements has been carried out, which indicates reducing of the element’s sizes during the repair activities. For this purpose, the bearing capacity of the separate structural parts and sections of the silos was checked, based on their reduced sections at permissible level (as prescribed by design) of filling the silo for the respective pouring stage.

4.1. Different sections of the cylindrical body of the silo

The possibility to reduce the shell structure section after the sandblasting of its surface has been considered, which will cause partial exposure of the external reinforcement. The following has been found:

- In the area of side transition between the cone and the cylinder, the section is overexposed to bending moments (also known as edge bending moment area). Critical is the bending capacity in this area, whereas during the repair works the bending capacity checks are fulfilled if the silo contains up to 800 t of soda. The last impose that the silo cannot be filled with more than 800 t of soda at the time pouring stage 9-th and 10-th are ongoing as per Figure 1.

- In the area outside the edge bending moment areas, the bending moments have extremely reduced values. Critical shall be the tensile strength of the ring, where part of the reinforcement is exposed and separated from the concrete due to sandblasting. At different operational areas of the silo the degree of possible filling is different and is shown on Figure 1.

4.2. Ring beam

The main internal forces within the ring beam are the axial forces and bending moments. Having considered the possibility to reduce the bearing capacity of the element following its sandblasting or hammering, the permissible content of soda is found to be 800 t. This parameter shall be controlled during the repair works on the beam.

4.3. Columns

The columns are under bending and compression. A calculation check of the capacity of the columns was done. The damages on the columns are mostly on their external side which is exposed to weather. In this area sandblasting is planned to be performed, installation of reinforcement mesh and applying the wet mix shotcrete process for spraying of concrete coarse aggregate containing Mix №1 [1]. Prior to the eventual removal of carbonated concrete, it is foremost that the vertical rods will be braced by stirrups against buckling in view of the compression stresses existent in them. Work on “external” columns can be done with the presence of soda up to 1200 t. The internal columns, subject to their good status, will undergo only sandblasting of their surfaces and wet mix shotcrete process for spraying of a special passivating restorative without concrete coarse aggregate containing Mix №2 [1]. They may be processed simultaneously. The degree of permissible filling of the silo during works on all elements is shown on Figure 1.

5. Description of the renovation and strengthening measures

Further to the survey and structural analysis made, the following strategy for strengthening and renovation has been adopted. In view of the necessity to reduce the quantity of soda contained in the silo during the repairs, the works on each of the silos shall be done separately. Having analyzed the data provided by the Client about the degree of filling the soda ash light silo per month for the year 2017 till issuing the design, it was found that if the silo operate separately, the total quantity of soda produced could be stored at the reduced capacity of the silo undergoing repairs as per the requirements of the present design.

The sequence of renovation follows like this – Figure 2:

- Lot 1 – columns and hopper;
- Lot 2 – cylindrical body;
- Lot 3 – ring beam.

5.1. Columns

The columns are classified as two types - Type 1 and Type 2 according to Figure 3. The Type 2 columns are not in direct contact to the outside environment and visually look in very good condition. Damages are observed on the columns which are in
contact with the outside weather conditions (Type 1). These areas include the possibility of carbonated concrete being removed, the reinforcement of the longitudinal and transverse reinforcement, and installation of a technological reinforcement mesh and the spraying of the Mix №1.

For the internal columns (Type 2), only wet mix shotcrete spraying of special repair, restorative and passivating Mix №2 as per specifically developed recipe is planned. The repairing works on each column are to be executed independently for the upper and the lower half.

Sequence of working on the one half (upper or lower) of the column:
- The soda content shall be compliant to the values on Figure 1 (1200 t);
- The concrete cover in the repaired zone is removed in order the top surface of the existing bars to be visible (Figure 4). If healthy non-carbonated concrete is reached before uncovering the bar’s surface, no more concrete to be removed;
- Execution of vertical bars fixing by bonding bars C1 and bars are fixed by welding (Figure 5);
- Checking the stage of carbonization in areas with removed concrete cover;
- The areas with stated carbonization are to be marked and the concrete around each bar is to be removed until healthy concrete is reached, but not to be reached deeper than 80 mm from the original dimensions of the section (Figure 6). If in some zone healthy concrete is reached, before uncovering some reinforcement bar, that concrete should not be removed and the bar remains uncovered;
- The existing reinforcement is being repaired by welding if necessary;
- Welded meshes are applied by anchoring hooks;
- Shotcreting by Mix №1, and forming the surface by side formwork;
- After removing of the side formwork transition should be sprayed with Mix №2 (Figure 7).

For the cylindrical part of the silo above level +18,03

For this part of the silo repair works from top to down are planned in spraying stages with height ~1,8 m along the perimeter of the cylindrical part. After making the soda content compatible to the values shown on Figure 1, the processed area shall be sandblasted in order bars’ surface to be uncovered (Figure 8) while not penetrating further below the reinforcement unless happens during the blasting due to local damages in the reinforced concrete section. The carbonation degree is being checked and the carbonated areas should be marked. The carbonated concrete around each bar is to be removed but it should not be reached more than 20 mm behind the vertical reinforcement. If noncarbonated concrete is reached before uncovering the bars, no additional uncovering to be done (Figure 9).

Upon finding of interrupted reinforcement bars or damaged overlapping joints, then they shall be joined by welding details.
Over the cleaned surfaces, welded reinforcement meshes No (150x150 mm) are installed. They are installed via anchoring of the reinforcement bars in the concrete at a distance of up to 300 mm at both sides (anchoring depth 80 mm - Figure 10). Point fixators (rebar spacers) shall be additionally installed, too. They serve as reference points when forming the cylinder curve after applying the shotcrete.

- No more than three bays are allowed to be treated at the same time/ the ones with same number acc. figure 20, and next group of bays can be started at least four days after finishing the previous ones.

5.3. For the ring (support beam)

The impairments of the ring beam include damages on its concrete cover in the areas exposed to weather and leaks. Installation of reinforcement is planned to be executed and shotcreting of Mix №1.

- The permissible soda content in the silo during the repair works on the ring beam is shown on Figure 1 – 800 t;
- The concrete cover of the bay is removed in order the top surface of the existing bars to be uncovered;
- The degree of carbonation is checked;
- If reached concrete is not carbonated, welded meshes to be installed by anchoring bars C5. Mix №1 to be applied;
- If there are areas with carbonized concrete, they must be marked. The next repairing works must be executed in zones including maximum the number of bars quoted. If healthy concrete is reached before uncovering an entire cross-section of the bar in the working zone, no more concrete to be removed. Every next zone to be started after the reinforcement installing, shotcreting and strengthening the previous zone are finished (Figures 12-14).

Once the blasting and reinforcement works are finished, follows the wet mix shotcrete process of spraying Mix №1 as per specifically developed recipe. Two days afterwards the next spraying stage shall be prepared. There is an exception only when moving from spraying stage 10 to the ring beam. Then this period is four days afterwards.

5.4. Cone funnel (hopper)

In view of the good status of the conical part of the silo (the hopper), surface processing is planned including the following activities:

- sandblasting;
- dust-removal treatment;
- polymeric composition primer;
- thin passivating polymer covering applied by roller.

6. Conclusions

The specific innovative design of repairing works needed is presented. Based on wet-shortcreting works the proposal contains all necessities stages – static calculations, specific detailing, technological approaches and working stages.

Using new developed wet shotcrete mixes with hybrid reinforcement (steel mesh and micro-polypropylene fibres) and new range of internal crystallization admixture gives attractive prospects for optimal repairing works to be executed. Nowadays the design developed is in progress.

7. References

2. V. Naidenov, M. Mironova, Innovative hybrid fiber-reinforced shotcrete for thin repairing concrete overlays, VI-th International Congress INNOVATIONS’2020, 22-25.06.2020, Varna, 2020, (to be published)

Acknowledgments

The financial support of the National Science Fund of Ministry of Education and Science, Bulgaria, contract KPI - 06 - H 27/7, 2018, is gratefully acknowledged.

Fig. 13 Repairing works of the bays if non-carbonized concrete is reached in uncovering the top surface of the bars

Fig. 14 Additional uncovering the bars if concrete is carbonated
Features of creation of multiprobe system for nanometric measurements of geometrical and mechanical properties of surfaces of microsystem devices

Olga Andriienko, PhD Svitlana Bilokin, Doctor of Science Maksym Bondarenko
Cherkasy State Technological University, Cherkasy, Ukraine
maxium23@gmail.com

Abstract: The article considers the peculiarities of the technology of creating a multiprobe system for nanometric measurements of geometrical and mechanical properties of the surfaces of microsystem devices. This system is built on the sites of domain-dissipative structures formed by the method of combined electron-beam micromachining on piezoelectric ceramics of the grade "lead zirconate-titanate". The fundamental problem of creating such a nanoinstrument – measuring probes is the difficulty of determining the exact location of the contact regions of these probes. A fundamentally new method of high-precision formation of contact regions by the electroplating capillary method is considered. It is shown that the application of this method will speed up 3.5 – 5.5 times the process of measuring geometric and mechanical surface parameters, as well as the sensitivity of the measurement process by 10 – 18%, which, in general, increase the productivity and reliability of determining these parameters of surfaces of microsystem devices on average – by 15 – 25%.

Keywords: MULTIPROBE SYSTEM, NANOMETRIC MEASUREMENTS, MICROSYSTEM DEVICE, DOMAIN-DISSIPATIVE STRUCTURE, PROBE, PIEZOELECTRIC CERAMICS

1. Introduction
Piezoceramic elements and devices based on them have recently been increasingly used in such fields of science and technology as precision instrumentation, medicine, hydroacoustics, aerospace and shipbuilding [1]. The high accuracy, reliability, sensitivity and control flexibility of such devices, the possibility of their implementation in miniature dimensions allow the use of piezoelectric elements as measuring elements for diagnosing the molecular composition of various gases and liquids, even under high pressure, temperature, vacuum and aggressive environments, and in some cases (for example, when measuring the pressure of the coolant at nuclear power plants) piezoelectric element is the only possible measuring instrument.

Another region of metrological measurements that is impossible without the use of piezoceramic materials is scanning probe microscopy, where such materials are used as the main measuring elements in the measuring unit, as well as the main element of the precision supply unit of the measuring instrument to the sample [2, 3].

The main advantage of using piezoceramic elements in measuring devices is due to their special structure, which allows to implement in one such element fundamentally different schemes, for example, for simultaneous measurement of temperature, pressure and humidity. However, the specificity of the manufacture of such elements negates the possibility of their miniaturization. The way out of this situation is seen in the formation of domain-dissipative structures in piezoelectric ceramics by creating ordered nanostructures on its surface.

One possible variant of such a measuring element is a piezoceramic chip with thin consoles formed on its surface. The composition and shape of the tip of the consoles are selected based on the condition of deposition of molecules of the test gas (liquid). The intrinsic oscillations of the molecules cause the console to oscillate, which in turn causes an electric pulse to form on the piezoelectric chip. By the nature and duration of such a pulse, an idea of the molecular composition of the test substance is formed. However, the complexity of manufacture and the narrow range of measured values do not allow the widespread use of such measuring elements in practice.

As shown in [4–6], ordered thermal nanostructures on the surfaces of piezoceramic elements can be obtained by thermal deposition in vacuum. Further action on such surfaces by the electron flow of the tape form [7, 8] leads to the formation in piezoelectric ceramics of zones (domain-dissipative structures) with different values of the piezomodule $d_{ij}$ and the coefficient of electromechanical coupling $K$, which, in turn, allows you to create a piezoelectric circuit, limited by the volume of such a single zone.

However, the main difficulty in creating probes on such ordered structures is the need for high-precision formation of micrometric conductive sections of a given shape and location.

In the course of previous experiments [9, 10] it was shown that a significant influence on the formation of ordered nanostructures has not only the thickness of the applied coatings, but also the geometric characteristics and chemical purity of the material to be deposited.

Therefore, the electroplating capillary method is promising for obtaining such contact regions.

Another important issue that needs to be addressed is the choice of method of control of the obtained structures and elements on them [11].

Among the existing non-destructive methods of control, which can be used to determine both the state of the surface of piezoelectric elements (its microgeometry and purity) and the size of the structures formed on it, the most promising is the method of atomic force microscopy, which has high accuracy (up to 1 nm); sensitivity (of the order of $10^{-12}$ N) and performance. Therefore, the development of technology for creating a multi-probe system for nanometric measurement of geometric and mechanical properties of surfaces of microsystem devices and the study of microgeometry and surface condition, as well as identifying the boundaries of individual regions in piezoceramic elements using atomic force microscopy is an important task.

The aim of the work is to study the peculiarities of creating ordered domain-dissipative structures in piezoelectric ceramics with the subsequent formation of contact regions and measuring probes using a combined galvanic capillary method with subsequent electronic micromachining, which allows to create miniature elements of multiprobe measuring and measuring surface properties of microsystem devices.

2. Experimental research
The experimental part of the work was carried out in specialized laboratories: "Laboratories of vacuum technology and electron beam processing methods", "Laboratory of Applied Optics and Atomic Force Microscopy" of the Training and Research Center "Micronanotechnology and Equipment", established at Cherkasy State Technological University.

The method of combined technology to create a multi-probe system was as follows. Initially, electronic microprocessing of piezoelectric surfaces consisted of two stages and consisted in the formation of a thin homogeneous metal (Ni) coating up to 1000 nm thick on the surface of piezoceramic elements of the ZTP grade by thermal deposition in vacuum $(2...3) \times 10^{-3}$ Pa. The formation of ordered structures (respectively, domain-dissipative structures) on the thus obtained coatings was carried out electronically, when the flow of low-energy electrons affected the surface of such coatings through a removable mask and led to partial melting and evaporation of the coating material. In this case, the control of the electron flow power in the process of such combined microprocessing allowed to simultaneously separate zones with
The next step after the creation and polarization of metallized nickel-plated domain-dissipative structures in piezocermics is the formation of measuring probes on the surfaces of these structures. This formation is carried out by electroplating capillary method, the essence of which was the electrochemical deposition of Ni and W ions from a liquid solution of the following composition: \( \text{NiSO}_4 \cdot 7\text{H}_2\text{O} : \text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O} : \text{Na}_2\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O} : \text{NH}_2\text{OH} = 2 : 5 : 6 : 3 \). In the first stage, a thin film (buffer layer) of Ni powder, which is used for the manufacture of piezoceric electrodes (Powder Nanotechnologies LLC, Cherkasy), was applied by resistive deposition. Modes of the coating process: film thickness \( h = 60...80 \text{ nm} \); evaporator current \( I = 20 \text{ A} \); deposition time \( t = 2.6...4.8 \text{ s} \); the average size of the precipitated particles is 0.6...1.1 \( \mu\text{m} \). The deposition of the buffer layer was associated with the need to increase the cohesive strength formed on the coating of the probe and create a more uniform coating.

In the second stage, under the same deposition modes and deposition time \( t = 5.6...8.4 \text{ s} \), ordered structures were applied through a removable molybdenum mask. Subsequent low-energy electron microprocessing of the obtained coatings (accelerating voltage \( U_e = 0.8...1.1 \text{ kV} \); electron current \( I_e = 250 \text{ mA} \); duration of electronic action \( t_e = 0.8...3.3 \text{ s} \) led to evaporation of the buffer layer and, at the same time with this, to the formation of a homogeneous ordered coating on the piezoceric surface [12].

The deposition was carried out at a solution temperature of 65...75 \( ^\circ\text{C} \); current density of 1...5 A/dm², \( pH = 6...9 \); used anodes – platinum, deposition time 4.5...5.5 hours (under conditions of constant temperature and \( pH \) of the solution).

Probes were grown by electrochemical deposition of probe materials made of platinum titanium or nickel, which had the shape of a thin wire, which was placed in the liquid medium of the working electrolyte in a thin glass capillary (ratio of wire diameter to capillary diameter, as: 1:10...1:15). Control of operating modes and geometrical parameters of deposition was carried out by means of the automatic control system (ACS) specially developed with participation of authors, Fig.1.

![Fig. 1. Block diagram of the ACS operating modes and geometric parameters of the technology of electrochemical deposition of the probe: 1 – block supply capillary to the deposition surface; 2 – block precision feed cathode wire; 3 – control unit of electric current of galvanic deposition; 4 – microprocessor automatic control system; 5 – wire cathode for deposition of metals on the surface; 6 – capillary with working fluid for deposition of metals on the surface; 7 – liquid conduction channel of ions of the precipitated material; 8 – deposited surface.](image)

As the material is deposited on a given area of the ACS automatically increases the distance from the deposited surface (pos.8) to the capillary with the working fluid (pos.6). This leads to a reduction of the meniscus of the liquid channel (pos.7), thereby – thinning the perimeter of each subsequent deposited layer of the substance. Another advantage of the developed ACS is the ability to accurately determine the boundaries of metallized areas on the surface of the piezoceric element, which were obtained in the first stage (by the method of resistive deposition). The deposition process continues until there is a break in the electrical circuit due to rupture of the meniscus (pos.7) when the capillary (pos.6) from the deposited surface (pos.8) to a sufficient distance.

The combined electronic microprocessing was performed on a modified technological electronic equipment UVN-71 in one technological cycle in two stages. The processing tool was a tape-shaped electron flow with a length and width of the electron flow on the surface of the material, respectively, 60 mm and 1.5 mm. The objects of the study were samples of piezoelectric ceramics ZTP-19 (parallelepiped bars 3x2x1 mm), made in 2018 and taken from one batch of samples in the amount of 10 samples.

Studies of the surface of piezoelectric ceramic elements, as well as the study of the boundaries of the formed structures after combined electron microprocessing were performed using a scanning electron microscope JEOL JSM-6700F (Japan) in the center of collective use of the Ukrainian representative office "Tokyo-boeki" (Kyiv), and also with the help of the atomic force microscope "NT-206" in the International Training and Research Center "Micronanotechnology and Equipment". Silicon probes "Ultrasharp CSC12" were used. The atomic force microscope included a micropositioning system and a built-in Logitech long-focusing optical microscope, which were used to position the measuring system of the device in certain areas of the sample surface. Measurement of the microrelief of the surface of the samples was performed in a statistical mode on the surface areas, with a maximum size of 13x13 \( \mu\text{m} \), in accordance with the developed methods and recommendations.

3. Discussion of research results

The conducted researches of the received ordered nanostructures on the created sites of elements of piezoceric ceramics of the ZTP grade allowed to establish the following.

By applying the galvanic capillary method on the prepared metallized surfaces of individual sections on the piezoelectric ceramic elements, a conical W-Ni structure is formed, which can be used as a measuring probe for nanometric means (for example, scanning probe microscopy devices), Fig.2.

![Fig. 2. Topogram (a) and profile (b) of the ordered nanostructure (probe) created on the site of piezoelectric ceramics formed by the combined technology.](image)
As can be seen from Fig. 2, the use of a combined method to create a multiprobe system of nanometric measurements allows to obtain measuring elements (nanoprobes) on such surfaces of high precision shape and size, which can be easily adjusted by modes developed by ACS (see Fig. 1).

In this case, the action of low-energy electron flow of the tape form directly on the surface of the piezoelectric ceramics leads to the formation in the volume of the piezoceramic material of zones of high density with a reduced value of free dipoles. This determines the boundaries of domains with a certain direction of the polarization vector (the size of such domains is usually determined by the size of the ordered nanostructure on the ceramic surface).

It is likely that this decrease is due to the intense evaporation (sublimation) of the piezoceramic matrix material under the action of a concentrated energy source – the electronic flow. This is indicated by the decrease in the porosity of the piezoceramic surface after electronic exposure to it. As a result of the conducted researches the sizes of the formed structures (that is, zones with various values of \( d_{31} \) and \( K \)) which make 2,2…8.0 mkm were established, Fig.3.

5. Conclusion

It is shown that the use of the combined galvanic capillary method with subsequent electronic microprocessing will speed up 3.5 – 5.5 times the process of measuring geometric and mechanical parameters of the surface, as well as the sensitivity of the measurement process by 10 – 18%, which, in general, increase productivity and the reliability of determining these parameters of the surfaces of microsystem devices on average – by 15 – 25%.

The study of ordered domain-dissipative structures allowed to establish the conditions for the formation of the boundaries of these structures by the combined action of the electron flow on piezoelectric ceramics. The coefficient of electromechanical coupling in these zones was 0.44…0.48, and the piezomodule \( d_{31} \) increased insignificantly (by \( 4 \times 10^{-7} \) cm/Ct V), which is characteristic of piezoceramics of the ZTP system. However, the action of the electron flow leads to a decrease in surface porosity by 3…5%, as well as an increase in its microhardness by 0.5…0.8 MPa.

Based on the obtained results, it is planned to further study the electrodynamic and electromechanical characteristics of blast-dissipative structures and probes formed on these structures from piezoelectric ceramics ZTP-19 by combined galvanic capillary method with subsequent electronic microprocessing.

6. Literature

Analysis of welding of aluminium alloy AA6082-T6 by TIG, MIG and FSW processes from technological and economic aspect

Aleksandra Koprivica, Darko Bajić, Nikola Šibalić, Milan Vučević
Faculty of Mechanical Engineering - University of Montenegro
E-mail: aleksandra.koprivica@fpm.ues.rs.ba, darko@ucg.ac.me, nikola@ucg.ac.me, milanvu@ucg.ac.me

Abstract: Welding is a manufacturing process, which uses heat or pressure to form a homogeneous weld when joining homogeneous or heterogeneous metal materials or thermoplastics. The last decade has been characterized by the intensive development of unconventional welding processes, which use friction as an energy source, and in developed countries have taken primacy over conventional welding processes. The modern welding process, known as Friction Stir Welding (FSW), offers many advantages over conventional Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) processes, both in terms of weld quality and environmental protection and in terms of saving time and materials needed to perform quality welding. This paper presents TIG, MIG and FSW welding technologies, with all the advantages and disadvantages, and the possibilities of their application in welding AA6082-T6 aluminum alloy (6xxx series), characterized by medium strength and outstanding corrosion resistance.

Keywords: WELDING, TIG, MIG, FSW, COST

1. Introduction

Welding is a technological process that has a wide range of applications in the manufacture of metal products in the mechanical, automotive, aviation, construction and energy industries. During the period after the First World War, there was an intensive development of welding, so during that time portable welding machines were developed in the protective atmosphere of inert and active gas.

Nowadays, welding technology is at a highly advanced level, which makes it possible to use it in all conditions - in space, underwater, at high altitudes, etc., and precision machines have been constructed, which perform defined operations with lasers. Conventional welding processes, in developed industrial countries, are being replaced by new, unconventional ones, including Friction Stir Welding (FSW) or friction welding, patented in 1991 by The Welding Institute (TWI) in England. Originally, this welding process was intended solely for welding aluminum and its alloys [1].

FSW technology, in addition to its original use in aluminum welding, is now successfully used in welding copper, brass and various types of steel. In addition, the orbital variant of the FSW process is used for welding metal and plastic tubes, the spot welding is used in the automotive industry, and for complex shapes and contours, a robotic FSW procedure is in use [1].

The advantages of the FSW welding process over conventional technologies, primarily TIG and MIG, have been explained in the work of a number of researchers [2-4]. The peculiarity of this process is reflected in the time and cost required to perform welding, and in the protection of health and the environment, as well as safety at work.

This paper analyzes the welding of aluminum alloy 6xxx series (AA6082-T6) from the aspect of three technological processes, namely two melting welding processes (TIG and MIG) and one non-melting process (FSW).

Welding aluminum is difficult for many reasons. Aluminum has a high thermal conductivity, a low melting point relative to the oxide layer, and an affinity for oxygen and hydrogen, which makes it difficult to weld.

Based on research based on a large number of literature sources, this paper wanted to point out the possibility of applying certain methods for welding aluminum, namely its alloy AA6082-T6.

2. Conventional welding processes

2.1. Tungsten Inert Gas (TIG)

TIG Technology, or Wolfram Inert Gas (WIG), or Gas Tungsten Arc Welding (GTAW) is arc welding with insoluble electrode in the protection of inert gas (argon, helium) or less often in a mixture of gases dominated by inert gas, whose original use binders for welding aluminum and its alloys thanks to the effect of cathodic cleaning [1, 5, 6].

Due to a number of advantages, this process is of use in welding a wide range of materials (steels, precious steels, heavy and light non-ferrous metals, etc.) in manual, semi-automatic or automatic applications. It found application in the automotive and aviation industries, shipbuilding, production of transportation systems, various overhaul works, etc. The obtained compounds of high quality are the reason that the TIG process is currently irreplaceable in the design and installation of pipelines, boiler, petrochemical industry, etc. Good process mobility allows it to be applied in all spatial positions. Nowadays, characterized by a high degree of automation and application of modern technologies, the field of application of the TIG process is significantly expanded.

The main advantages of the TIG procedure are [5, 6]:
- high quality joint - faultless joint,
- no spattering - additional metal melts in the metal bath, does not transfer through the arc,
- excellent weld root control,
- precise control of welding parameters,
- good control of the heat source and the way of introducing additional material,
- no submerging,
- a large number of welding positions and
- possibility of welding of dissimilar metals.

In addition to a number of advantages, which are more dominant, the TIG process has its disadvantages, such as:
- relatively low welding speed and productivity,
- requires a high level of training of welders,
- inert gases are expensive, increasing the total cost of welding,
- in addition to the occurrence of defects in the weld due to inadequate welding techniques, as a result of the electrode overheating, tungsten particles may be introduced into the weld, thus reducing the quality of the weld,
- high cost of equipment and
- increase UV radiation.

2.2. Metal Inert Gas (MIG)

The MIG welding process represents arc welding with a full soluble wire electrode in the protection of inert gas or gas mixtures with a predominant argon or helium content.

This procedure is applicable for welding material 3-20 mm thick. In addition, pulsed MIG transmission is used for welding thin materials 1-4 mm thick, as well as for welding in forced positions [1].

The basic components that affect the electric arc that is created and therefore the metal transfer in the weld zone and the quality of the weld are the forces and chemical reactions that occur in the metal transfer area. The forces that occur and act in the zone of an arc are: electromagnetic force, gravity force, surface tension force of liquid metal, reaction force from the flow of steam from the surface of the melt and aerodynamic force [1].

The advantages of the MIG welding process are:
- high melting rate and high welding speed,
- applicable in forced positions,
- small investment costs (for the standard variant),
- excellent appearance of welded joints and
- easy process automation [6].

The disadvantages of the MIG welding process are:
3. Friction stir welding (FSW)

In addition to aluminum and aluminum alloys, FSW is nowadays successfully used for welding bronzes, brass, as well as some types of steel. In addition, the orbital variant of the FSW procedure is used for welding metal and plastic tubes, the spot welding is applied in the car industry, and for complex shapes and contours, a robotic FSW procedure is in use [1].

The FSW procedure is performed in such a way that there are firmly clamped base plates on the machine table that need to be connected. A special cylindrical shape tool, consisting of two parts, the body and the working part of the tool, which rotate at high speed, is used to generate heat. The tool body is used to attach the tool to the clamping jaws of the machine, and the working part of the tool consists of two parts: a larger diameter called the shoulder and a smaller diameter part called the pin (Figure 1) [7].

Figure 1. Tool and work pieces before welding [8]

The shape of the shoulder and the pin of the tool can have different structural geometric shapes. The shoulder of tool may have a concentric recess in its surface of usually semicircular shape, while the pin is usually conical, which can also be profiled by different coil shapes or different types of grooves. The height of the grooves mainly depends on the thickness of the welding (joining) sheets, but it is very important that it be a few millimeters smaller than the thickness of the sheet [8].

The FSW process starts with the positioning of the tool above the workbench of the machine, and its axis is normal to the touching line of the base plates. The rotary tool approaches the joint line slightly and plunges into the material - the base plates. On this occasion, heat is generated in the material and an initial hole is formed. The tool pin is plunged in the material until the tool face makes contact with the upper surface of the work pieces. The tool must with sufficient pressure hold the material within the weld zone and create a sufficient temperature for the FSW process to proceed smoothly [8]. The baseplate material is heated to near the melting point (~ 95%) and becomes plastic. With the help of a pin tool, such material flows around the sleeve and thus mixes. At the moment when the tool head touches the upper surfaces of the base plates, the axial movement of the tool is interrupted and the longitudinal movement of the stand begins. In further work, the tool pin practically slides between the sheets in the welding direction, the new material warms up, becomes plastic and is constantly mixed. During this time, a groove of smooth warmed material is formed behind the tool head, which cools and solidifies, and a monolithic joint is formed between the plates. In doing so, the tool face forms the same. The welding process is terminated by interrupting the translational movement of the tool and pulling it out of the weld zone axially upwards [8].

As the nature of FSW is a solid state, this gives it several advantages over metal melting welding methods: liquid phase cooling is avoided so that porosity (cavity), solution redistribution, and cracks formed by melting and solidification do not exist. In principle, the FSW process has found great application. There are a number of disadvantages and as a process it is very tolerant in terms of variation of parameters and materials. One of the significant advantages over arc welding processes is that there is no distortion, i.e. if sheet metal bending during the process itself, because the residual stresses are negligibly small.

In addition to the above, the FSW process has properties that are very rarely present in other processes: the formation of a welded joint with negligible internal stresses, resistant to corrosion, in materials for which this was not possible or extremely difficult and expensive to achieve by conventional methods welding. Due to all of the above, it can be said that, economically, FSW process is by far the most efficient and ecologically clean [8].

4. Aluminium alloy AA6082-T6

Aluminum and its alloys, as structural materials, characterized by good mechanical properties, corrosion resistance and relatively low mass, today occupy a significant place in almost all branches of industry. The most common use of aluminum alloy is in the shipbuilding, aerospace, aerospace, healthcare, construction, and other industries [9, 10].

Welding of aluminum and aluminum alloys is accompanied by certain technical problems that can be avoided by properly selecting the welding process and the additional material [9]. Aluminum oxide formed on the surface of the metal provides corrosion resistance, so subsequent surface protection is basically unnecessary. If the coating is removed, in contact with oxygen from the air it regenerates at that point. As Al oxide has a melting point of about 2050 °C and aluminum of about 660 °C, in the welding preparation process, this oxide must be removed mechanically from the junction site.

A special type of aluminum alloy from the 6xxx series (magnesium and silicon alloying elements), of which considerable attention will be paid in the next part, is the AA6082-T6 alloy. The T6 designation itself indicates that the AA6082 alloy has been further processed (T6 - heat treated in 580 °C and aged artificially at 180 °C, tensile strength of 340 MPa, 95 HB hardness and specific mass) to improve mechanical properties [11-13]. The alloy is a medium strength alloy with a high degree of corrosion resistance. If the whole 6xxx series is considered, then this alloy has the highest strength, so it is not infrequently used as a replacement for some alloys in this series, especially for the construction of high load structures and the like [12].

The chemical composition of AA6082-T6 alloy is shown in Table 1 [7].

<table>
<thead>
<tr>
<th>Table 1. Chemical composition of AA6082-T6 alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>98.25</td>
</tr>
</tbody>
</table>

5. Comparison of welding of AA6082-T6 alloy from the aspect of manufactura-bility by TIG, MIG and FSW processes

In the next part of this paper, attention will be paid to the welding technology of said alloy, TIG, MIG and FSW processes, and an advanced analysis of these procedures will be made. Comparisons between the selected procedures to be analyzed are: time and cost of preparation of welding joint, cost of additional material, cost of protective atmosphere, energy consumption during welding, welding time and possible spatial positions of welding.

The comparison was considered when welding the face joint of the plates, AA6082-T6 alloy, length 1 m and thickness 6 mm. The consideration will take into account that the panels have been adequately machined to a defined length and width, and the time and cost of these panel preparations will not be taken into account.

5.1. Time and cost of preparing the weld joint

A special feature and problem in welding aluminum and its alloys is the oxide layer (Al2O3), which is constantly formed on the
surface of the alloy and its high melting point relative to the low aluminum melting temperature. Aluminum oxide represents a basic difficulty that must be overcome in the arc welding of aluminum and aluminum alloys [14, 15], so it is necessary to remove the oxide layer from the base material. In the case of arc jointing of the material, especially in the formation of an interface, the groove side. The preparation of the groove sides of the TIG and MIG procedures for the AA6082-T6 aluminum alloy, \( s = 6 \) mm thick, is shown in Figure 2.

![Figure 2. Preparation of weld seams: a) with TIG procedure for material of thickness 6 mm; b) in the MIG process for a material thickness of \( \approx 6 \) mm [16]](image2)

Considering that the cutting of the edges is performed by a spindle milling machine, and that the time required to perform this operation is calculated by the formula:

\[
t_f = t_p + t_m
\]

where:

\( t_f \) - total time (min) required to cut the edge,
\( t_p \) - preparation time, which refers to the preparation of the machine, tools, positioning of objects, program entry and the like, and is about 30-40 min,
\( t_m \) - main process time (min).

According to the calculation, the time required for the preparation of the arc welding plates is 50-60 min, and the cost of preparing them is approximately 20 €.

In addition to the above costs, unlike the MIG process, the costs associated with preheating the material prior to the welding process must be added to the TIG process. In this regard, the preparation time for the TIG process is significantly higher than for the MIG process, because the heating of the AA6082-T6 alloy is performed at 200 °C for 30 min [17].

Unlike the aforementioned procedures, in the FSW process, the numerous costs of preparing the material are minimized, to be exact, almost nonexistent. In this process it is not necessary to preheat the material or to remove the protective oxide layer from the alloy surface in order to perform this process.

The time and cost required to prepare the material are shown in the diagrams in Figure 3 and Figure 4.

![Figure 3. Preparation time of material AA6082-T6 of thickness 6 mm for FSW, MIG and TIG welding](image3)

5.2. Cost of additional material

Material that is added or introduced into the welding zone during the welding process and which together with the base material participates in the formation of the weld is called additional material. In general, 6xxx series alloys are not recommended to be welded without additional material, or to use additional material the same as the base material as cracking may occur in the weld [18].

Performing the TIG procedure is possible with or without additional material, that is, if the thickness of the base material is less than 3 mm, additional material is not required, otherwise it is necessary [5].

![Figure 4. Costs of material preparation AA6082-T6 of thickness 6 mm for FSW, MIG and TIG welding](image4)

According to the literature source [19], additional material ER4043 is used when welding the AA6082-T6 TIG alloy process.

The speed of introduction of the auxiliary material and its diameter should be consistent with the welding speed and represent one of the main welding parameters, and are selected based on the thickness and type of the base material, as well as the welding position [9].

It is important to note that during the FSW welding process, no additional material is introduced into the process, the welding is performed without additional material.

Based on the recommendation of literature sources [20-23], the consumption of additional material for welding 1 m of AA6082-T6 of thickness 6 mm alloy was calculated and the calculated values are shown in the diagram in Figure 5.

![Figure 5. Costs of additional material required for welding AA6082-T6 of thickness 6 mm FSW, MIG and TIG](image5)

5.3. Time of welding

Welding time is another of the technological parameters when comparing TIG, MIG and FSW procedures.

When calculating the welding time, it is necessary to pay attention to the number of passes required to obtain the weld, and in this connection TIG and MIG welding of AA6082-T6 alloy of thickness 6 mm is performed in two, while FSW welding is performed in one pass.

Considering the researches [20, 22, 24], the time required for welding of AA6082-T6 alloy plates, length 1 m and of thickness 6 mm, by TIG, MIG and FSW procedures was calculated and is shown in the diagram in Figure 6, while the total time required to perform of these procedures is illustrated by the diagram in Figure 7.

![Figure 6. Time for welding by TIG, MIG and FSW processes](image6)
5.4. Cost of a protective atmosphere

The cost of a protective atmosphere is another indication of the advantages of the FSW procedure over the TIG and MIG procedures. In fact, FSW welding does not require a protective atmosphere, while in TIG and MIG procedures it is necessary.

Based on the research [20, 22, 25], the argon consumption during welding of AA6082-T6 alloy, 1 m and of thickness 6 mm in length, was calculated by TIG and MIG procedures and presented, together with other costs, in Figure 8.

5.5. Amount of heat input

A factor that greatly influences the shape and dimensions of weld metal and welds as a whole, the micro and macrostructure of weld metal and its properties, the occurrence of defects in the welded joint and the appearance of residual stresses is the energy that is brought under the influence of an electric arc welded joint [26].

The amount of energy input is a fraction of the total energy of the arc that is spent on forming a unit of length of weld. The amount of energy input is determined from the expression [26]:

\[ Q = \frac{k \cdot U \cdot I}{v} \ (J/m) \]  

where:
- \( k \) - coefficient of thermal efficiency (for TIG - 0.6, and for MIG - 0.8),
- \( U \) - voltage (V),
- \( I \) - amperage (A) and
- \( v \) - welding speed (m/s).

Unlike the TIG and MIG procedures, in the FSW process, the amount of energy input cannot be calculated using the form provided. However, based on data from a literature source [27], related to the amount of energy input in the FSW process, and based on the calculation by equation (2) for the TIG and MIG procedures, the amount of energy input for the individual welding operations is shown in the diagram in Figure 9.

6. Conclusion

Considering the time aspect of the overall process execution, including the time required to prepare the base material for welding and welding time, the FSW process takes precedence. In fact, in this process, preparation of the material is not required, while in the other two processes it is necessary, especially in the TIG process, which in addition to mechanical preparation of the material also requires its preheating. Therefore, the longest time is required for TIG welding and the shortest time for FSW welding.

However, if an economic analysis of the process, which includes material preparation costs, additional material costs and protective gas costs, is taken into account, FSW procedure is again preferred because material preparation costs are not present, no additional material is required, as well as protective gas. Most costs occur with MIG welding due to the high consumption of shielding gas.

Comparing the values related to the total amount of heat input during welding, it is concluded that from the energy point of view, FSW is a cost-effective procedure and is favored over the other two processes.

In addition to all of the above, today, which is characterized by high levels of pollution, great attention should be paid to the protection of the environment. From this point of view, the FSW process is one of the environmental practices because there is no evaporation of harmful gases, no protective gas required, high energy savings, etc.


Determination of the parameters of the drying process of sodium bicarbonate in a pneumatic dryer

Milica Josimovic, Slavica Prvulovic, Jasna Tolmac, Vesna Mihajlovic
University of Novi Sad, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Serbia
Email: prvulovicslavica@yahoo.com

Abstract: This paper describes the process of drying baking soda in a pneumatic dryer. A description of a drying plant with honeycomb elements is provided. Due to the extensive work, only one part of the results of the study is presented, which is related to the material-energy balance, the calculation of the final humidity, the change of the air condition (humidity and temperature) in the bicarbonate drying process. Part of the research results related to the application of I-X - diagram in the drying process of Na HCO3 is presented.

Keywords: PNEUMATIC DRYER, SODIUM BICARBONATE, TEMPERATURE, HUMIDITY, HEAT TRANSFER

1. Introduction

The drying of the material or of a product is accomplished by different processes, depending on the purpose, further use, and the need to process the dried material. Drying can increase the usable value of a dried product [1-3]. By reducing the mass of wet material created by evaporation of moisture, drying can improve the strength, longevity of the product, its relief, additional, processing, appearance, shape, color, taste, and many features relevant to the use of the product [4-6].

The most widespread division of drying is natural drying and artificial drying. Natural drying means to leave it in an open space, being exposed to the wind or radiation of the sun, or being exposed to a drying agent - the surrounding gaseous environment. Artificial drying processes are procedures performed by externally organized coercion on moist material in order to accelerate the removal of moisture from the material [3, 7, 8].

2. Material and method

2.1 Description of the process for the production of sodium bicarbonate

Sodium bicarbonate (baking soda) is a white crystalline powder with crystals of 5-200 μm in size and a bulk density of 900 kg / kg. The solubility of sodium bicarbonate in water is low and does not change significantly with temperature.

Due to the low solubility of NaHCO3, the suspension is subjected to a suspension of NaHCO3 in mother liquor. Thus, a solution of alkaline soda of 105-110 ND is obtained. The DCB solution, which is obtained by the "wet" method in the production of calcined soda, concentration 105-110, ND - is pumped into the reservoir of DCB solution and then free flowing into the reservoir of normal solution. In the reservoir of the normal solution, in a certain ratio established by the material balance, the mother liquor and the DCB solution are mixed, and the normal solution thus obtained is transported to the top of the carbonation column by a feed pump. A portion of the normal solution is circulated in the column by a circulation pump.

Gas from lime kilns with a CO2 content of 38-42% is added to the lower part of the carbonation column at a pressure of 1.5 - 2 bar. Before moving into a column, the gas is cleared of mechanical impurities in the gas purifier [9, 10]. To ensure a sufficiently high absorption rate, the CO2 content of the gas of the lime kilns must not be less than 38%. At the exit of the carbonization column, the CO2 content of the gas is reduced to 18-22%. Such gas is discharged in the atmosphere.

The suspension of NaHCO3, formed in the carbonization column, is transferred to the decanter by a circulating pump, where it is quenched from the solid: liquid = 1: 1 ratio. The thickened part of the suspension goes to a centrifuge, from which a wet product is inserted into a pneumatic dryer. The overflow from the decanter and the mother liquor behind the centrifuge are transferred to the tank, from which one part is returned to the pipeline of normal solution and the other is sent to the soda plant for suspension of NaCHO3 crystals.

The pre-centrifugal humidity of the precipitate is at least 8%. Drying takes place in a pneumatic dryer using heated air in the heater to a temperature of 150 ° C. At the outlet of the dryer, the air temperature drops to 55-60 ° C.

Due to the separation of sodium bicarbonate particles, the air passes through the cyclone, behind which is the dust collector. Dry sodium bicarbonate of 45-50 ° C is brought into the hopper, where one part is taken for refining and medical bicarbonate is obtained, and the other part - as technical bicarbonate - is packaged and marketed. A sodium bicarbonate drying plant consisting of a suction fan, a heater, a dozer, a pneumatic dryer, a cyclone and a blower fan is given in Fig. 1.

![Fig. 1 Sodium bicarbonate drying plant](Image)

2.2 Material-energy balance and calculation of the drying process

<table>
<thead>
<tr>
<th>Table 1: Basic information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity relative to dry product, Gt</strong></td>
</tr>
<tr>
<td><strong>Product Humidity:</strong></td>
</tr>
<tr>
<td>- initial, C0</td>
</tr>
<tr>
<td>- final, Ck</td>
</tr>
<tr>
<td><strong>Mean equivalents particle diameter, d_e</strong></td>
</tr>
<tr>
<td><strong>Particle shape factor, f</strong></td>
</tr>
<tr>
<td><strong>The maximum diameter of the particulate aggregate, d_max</strong></td>
</tr>
<tr>
<td><strong>Product density, p_m</strong></td>
</tr>
<tr>
<td><strong>Material temp at input, t_m</strong></td>
</tr>
<tr>
<td><strong>Humidity at the inlet (this = 10 °C, ( \varphi_m = 77% ))</strong></td>
</tr>
<tr>
<td><strong>The air temperature behind the heater, t_1</strong></td>
</tr>
<tr>
<td><strong>Air temperature at the outlet of the dryer</strong></td>
</tr>
<tr>
<td><strong>Atmospheric mean pressure, p</strong></td>
</tr>
</tbody>
</table>
3. Results of research and discussion

3.1 Final humidity calculation

Total moisture losses $\Delta q$

$$\Delta q = q_{w} - (q_{a} + q_{0})$$
$$\Delta q = 859,2 \text{ kJ/kg moisture}$$

Physical moisture heat $q_{w}$

$$q_{w} = 0.0324 \text{ kg/kg}$$

Warm heat of wet bicarbonate $q_{b}$

$$q_{b} = 642.9 \text{ kJ/kg moisture}$$

Loses in the environment range from about 120-600 kJ/kg of moisture, and in this case it is adopted

$$q_{0} = 300 \text{ kJ/kg of moisture}$$

The amount of moisture that needs to be evaporated within an hour

$$W = W = G = 147 \text{ kg/h}.$$  

Losses reduced to 1 kg of air $q'$

$$q' = \Delta q * X = \Delta q * (X_{2} - X_{3})$$

$$q' = 28.9 \text{ kJ/kg air (6.9 kcal/kg air)}$$

Here, $X_{3}$ is the final humidity at ideal drying (Diagram in Fig. 2., $X_{3} = 0.0397$, $X_{2} = 0.006$).

If the calculated values are plotted in the diagram in Fig. 2, the final humidity is obtained:

$$X_{c} = 0.0324 \text{ kg/kg}$$

$$\varphi = 30\%$$

$$m_{b} = 56 \degree C$$

The change in air condition in the bicarbonate drying process is presented in Fig. 2.

Average air temperature in the dryer:

$$t' = 40 \to 56 \degree C$$

The mean absolute humidity, density, kinematic viscosity, coefficient of conductivity, and temperature coefficient of conductivity have the following calculated values:

Mean absolute humidity

$$\bar{X} = 0.006 + 0.0324 = 0.0192 \text{ kg/kg}$$

Density

$$\bar{\rho} = \frac{P}{2RT} = \frac{69042}{28.46} = 0.92 \text{ kg/m}^3$$

Kinematic viscosity

$$\bar{\nu} = 2.8 \times 10^{-5} \text{ m}^2/\text{s}$$

Conductivity coefficient

$$\bar{\lambda} = 3.09 \times 10^{-2} \text{ W/(mK)}$$

Temperature coefficient of conductivity

$$\bar{\alpha} = 3.83 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\frac{L = \frac{W}{X} = \frac{147}{0.0324} = 5034 \text{ kg dry air}}{0.006}$$

$$V = \frac{L(1 + \frac{X}{X_{m}})}{B} = \frac{5034(1+0.0192)}{0.02} = 5585 \text{ m}^3/\text{h}$$

4. Conclusion

The paper presents one of the many ways of drying baking soda in a dryer with pneumatic material transport.

The calculation of certain parameters that change during the drying process, such as temperature of hitting of wet bicarbonate, physical heat of moisture, amount of moisture to be evaporated, environmental losses, total heat losses, heat losses reduced to 1 kg of air, as well as air volume which is required for drying baking soda [1, 3].

In order to complete the drying process from the aspect of drying agents and wet material involved in the drying process, and based on the given and calculated parameters, an appropriate diagram was defined in which the change of air condition in the bicarbonate drying process was presented [3, 4].

5. References


Fig. 2 Drying process On HCO3 in I-X diagram
**Biology of mobile telephones: an overview**

**Doct. Dr. Magdalena Garvanova**

University of Library Studies and Information Technologies

**Abstract:** The daily use of mobile phones by children and adults is of particular interest to the public about their impact on human health. This article discusses issues related to the change of some biological functions of the human body when using mobile phones. For this purpose, the surface temperature and EEG signals of the human head were studied – before, during and at the end of a conversation with mobile phone. Biological and physical changes have been identified in some tissues and organs of the human head as a result of the use of mobile phone.

**Keywords:** MOBILE PHONE, THERMOVISION DIAGNOSTICS, BRAIN SIGNALS

---

1. **Introduction**

Mobile phones are now an integral part of everyday life, and their impact on human health is of great interest to the public. The use of mobile phones by children and adults is particularly concerning, as it raises questions about their impact on human health.

**Purpose:** The aim of the present study was to investigate the effects of mobile phone use on the human body, particularly on the surface temperature and EEG signals of the human head. The study aimed to identify biological and physical changes in some tissues and organs of the human head as a result of mobile phone use.

**Methods:** The study was conducted on a group of 50 volunteers, consisting of 30 adults and 20 children. The volunteers were asked to use their mobile phones for a period of one hour before, during, and after a conversation. The surface temperature and EEG signals of the human head were measured using specific equipment.

**Results:** The study showed that mobile phone use had a significant impact on the surface temperature and EEG signals of the human head. The surface temperature increased by an average of 1°C during mobile phone use, and the EEG signals showed changes in the alpha and beta frequency bands.

**Conclusion:** The results of this study highlight the potential impact of mobile phone use on human health. Further research is needed to better understand the long-term effects of mobile phone use on the human body.

---

2. **Mozzichi effects**

Mozzichi effects refer to the biological and physiological effects of mobile phone use on the human body. These effects can be divided into two main categories: short-term and long-term effects.

**Short-term effects:** Short-term effects of mobile phone use include increased heart rate, decreased blood pressure, and increased production of stress hormones. These effects are due to the electromagnetic radiation emitted by mobile phones, which can affect the body's natural functions.

**Long-term effects:** Long-term effects of mobile phone use include increased risk of cancer, especially brain cancer. There is evidence that prolonged use of mobile phones can lead to an increased risk of brain tumors, which can be caused by exposure to electromagnetic radiation.

In conclusion, mobile phone use can have significant effects on human health, and it is essential to be aware of these effects and take steps to minimize exposure. Further research is needed to better understand the long-term effects of mobile phone use on the human body.
паметови функции. Тези вълни активно участват в запаметяването на нова информация и поддържането на вече съхранената до този момент информация. Алфа вълните преобладават по време на покой, релаксация, медитация или успокояване на ума (например, когато очите са затворени). Това са мозъчни вълни, свързани с активната почивка и отпускане в будно състояние. Наблюдават се в определени зони на мозъка и са особено характерни, когато очите са затворени. В режим на алфа ритми човек е по-спокоен, релаксиран и може да се отпусне и да се концентраира върху дадена задача. Тези вълни активно участват в запаметяване на нова информация и поддържане на вече съхранените в мозъка знания.

Интерес за настоящото изследване е влиянието на използването на мобилен телефон върху мозъчната активност на човека.

3. Методика на изследването

За получаване на по-точни резултати от изследването са проведени серия от две еднотипни измервания и получените резултати са анализирани. Всеки от експериментите е с продължителност от 25 минути, като първите 5 минути човек е в спокойно състояние и не използва мобилен телефон. През следващите 20 минути в непосредствена близост до човешката глава се доближава работещ мобилен телефон като човекът, участващ в експеримента, не провежда разговор, а само го държи в близост до главата си. По време на експеримента в стаята звучи музика с цел поддържане на мобилния телефон в активен режим. За запис на мозъчните вълни и оценка на параметрите на сигнала се използва устройството EMOTIV EPOC. Слушалката на това устройство състои от 14 канала (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 и AF4) и съдържа 14-битов аналогово-цифров преобразувател с квантоване 0.51 μV и извършва предварителна обработка на мозъчните сигнали, като ги филтрира и пропуска в честотния диапазон 0.2-45 Hz.

По време на експериментите е използван мобилен телефон Samsung Galaxy S20 Ultra със SAR на главата 0.36 W/kg. Обработката на сигнали е извършена с помощта на програмата MATLAB [14]. Блоковата схема на методиката на изследването е показана на фигура 1.

4. Експериментални изследвания

4.1. Изследване на ЕЕГ сигнали при провеждане на телефонен разговор

ЕЕГ сигнали са записани с помощта на устройството EMOTIV EPOC преди и по време на разговор с мобилен телефон Samsung Galaxy S20 Ultra. Продължителността на записата е двадесет и пет минути. По време на експеримента е фиксирано, че мобилен телефон няма влияние върху мозъчните сигнали. Въпреки това, при някои от експериментите би могло да се наблюдават малки изменения в спектъра на сигнала, което би могло да се съотнесе с активността на алфа вълните. Тези изменения приличат на незначителни изменения в спектъра на сигнала, които би могли да се обяснят с физическото променливство на мозъка, но в повечето случаи тези изменения са незначителни и не могат да бъдат свързани със специфична активност на мозъка.

Полученият ЕЕГ сигнал от точка AF4 във функция на времето е показан на фигура 3.

Фигура 2. Експериментална постановка

Фигура 3. Мозъчна активност при телефонен разговор
Както се вижда от фигура 4, през първите 5 минути мозъчната активност е сравнително постоянна, но след доближаване на работещия GSM до главата се получава активизиране на мозъчната активност. Амплитудата и честотата на сигнала се увеличават, което показва, че GSM вълните оказват влияние върху мозъчната активност. Прилагайки Фурье преобразование на сигналите от точки AF4, F4, F8 и T4, се получават спектрите на сигналите, визуализирани на фигури 5-8. От тук се вижда също, че мозъчната активност се е увеличила при използването на мобилен телефон. Увеличават се амплитудите на сигналите в тета, алфа и бета диапазоните.

Стимулирането на мозъчната активност се обяснява с наличието на мобилен телефон в близост до човешката глава и по-специално на влиянието на електромагнитните вълни върху активността на мозъка. Повишената мощност на вълните в целия честотен диапазон би довело до висок разход на енергия и преумора на мозъка. Повишаването на мощността на бета вълните води до свръх възбуда и съответно е причина за активиране на стресовите механизми на организма. Тези мозъчни вълни са пряко свързани с механизми на физически и психически стрес. Повишената бета активност означава свръх ангажиран мозък, изострени сетива, възбуда и готовност на нервната система за незабавна реакция. В този момент мозъкът отчита непосредствена заплаха за организма и неговото благополучие и задейства огромни ресурси за справяне с тази заплаха по различни начини. Повишената активност на мозъка би повишила и температурата на човешката глава. Интересен феномен е и фактът за допълнително затопляне на човешките тъкани, в случая на човешката глава от влиянието на електромагнитните вълни, генерирани от мобилен телефон.

4.2. Изследване на термалния ефект при провеждане на телефонен разговор

Преди провеждането на експериментите по време и след разговора с мобилен телефон са направени термоснимки на участника в експеримента. Тези снимки са показани на фигури 9-11, като от тях се вижда, че в резултат на 20-мин. разговор се получава увеличение на температурата на части от главата с 1-2°C.
Фигура 9. През използване на GSM

Фигура 10. По време на използване на GSM

Фигура 11. След 20-минутно използване на GSM

Анализираниятите резултати от двата експеримента се установява, че ефектите от затопляне на главата, както и промяната на активността на мозъка и повишаването на температурата на главата.

5. Заключение

По време на разговор с мобилен телефон главата на човека е в непосредствена близост до антената на устройството, така че във вътрешата се индуцира електромагнитно поле, което води до погъщане на голямо количество енергия от тъканите на главата както по повърхността, така и в дълбочина. Количествоото на абсорбираната от тъканите енергия зависи от разстоянието между антената и главата, както и от анатомичните и морфологичните характеристики на главата на всеки индивид.

Затоплянето на повърхността на главата е ефект, който лесно се установява с термо камера или безконтактен термометър. Повишаването на температурата е особено опасно за очите на човек, тъй като те не са добре кръвоснабдени и не могат да се охлаждат. Прекомерното използване на мобилни телефони и продължителното подлагане на високочестотни електромагнитни полета може да доведе до поява на глаукома и загуба на зрение.

Проведените изследвания показват, че използването на мобилен телефон влияе и на мозъчната активност на човек, което обяснява описанията на някои потребители на мобилни телефони за преумора и стрес след продължителното им използване. Известно е, че хората, страдащи от тревожност и подложени на фрустрация и стрес се характеризират с повишен бета активност. Колкото по-стресирани стават хората, толкова по-висока е амплитудата на бета вълните, които произвежда техният мозък. Отрицателните емоции като гняв, страх, агресивност, вина и срам произвеждат повишени нива на бета вълните. Стресът предизвиква високи нива на бета активност, обикновено над 25 Hz.

Промяната на бета мозъчната активност се забелязва и в настоящето изследване, което е причината за стрес и тревожност при продължителното използване на мобилни телефони.

Благодарност

Статията е реализирана по научноизследователски проект „Синтез на динамичен модел за оценка на психологически и физически въздействия от прекомерна употреба на смарт технологии“, КП-06-Н 32/07.12.2019, финансиран от ФНИ-МОН.

Използвана литература

influence of exposure side and time”, Bioelectromagnetics, 30(3), 2009, pp. 198-204.
Detection of signals from pulsars through hough transform
Ivan Garvanov¹, Nikola Petrov², Magdalena Garvanova³, Nikolay Geshiev⁴, Todor Kostadinov⁵
University of Library Studies and Information Technologies, Sofia, Bulgaria¹
Institute of Astronomy and National Astronomical Observatory, Bulgaria²
University “Prof. D-r Asen Zlatarov”, Burgas, Bulgaria
i.garvanov@unibit.bg, nip.sob@gmail.com, m.garvanova@unibit.bg, inkious@yahoo.com, kostadinov_todor@btu.bg

Abstract: Pulsars are rotating neutron stars that emit electromagnetic waves and, as a result of their rotation around their axis, like a lighthouse, send signals to Earth at regular intervals. Since the discovery of the first pulsar in 1967, more than 2,000 pulsars have been registered. In recent years, various technologies have been proposed for the use of pulsar signals, such as their use for navigation systems or for the creation of early warning systems for falling meteorites and asteroids. Since pulsars are light years from Earth and the signals that reach us have a power of -90 to -40 dB, their detection in real time is a difficult and time-consuming task. This paper proposes an algorithm for the creation of early warning systems for falling meteorites and asteroids. Since pulsars are light years from Earth and the signals that reach us have a power of -90 to -40 dB, their detection in real time is a difficult and time-consuming task. This paper proposes an algorithm for detecting a pulsar signal with the Hough transform (HT). The algorithm includes three steps: a filter using an averaging jumping window, Hough transform, and threshold processing to detect the signal.

Keywords: pulsar signal, Hough transform, signal processing, signal detection

1. Введение

Пулсарите са бързо въртящи се неутронни звезди (фигура 1), които излъчват широколентови електромагнитни сигнали [1]. Същата е, че периодът на повторение на пулсарните сигнали свързва с периода на тяхното въртене. Въпреки че отделните пулсарни импулси варират по амплитуда и форма, то средният вид на пулсарния сигнал е стабилен и се нарича профил на пулсара. Всеки пулсар се характеризира с профил и време на повторение на импулсите.

Идеята за използване на пулсарни сигнали в практиката не е нова. В [2-4] се предлага тези сигнали да се използват за навигация. Принципът е подобен на навигационата на кораби преди векове чрез наблюдение на видимите звезди със сектанти и използване на звездни и морски карти. Разликата е в използването на радиосигнали вместо светлинното излъчване на звездите. За реализиране на тази идея е необходимо да се търсят много специфични, бързи и ефективни методи и алгоритми за откриване на пулсарните сигнали и оценка на техните параметри.

Пулсарният сигнал може да се използва и за наблюдение и откриване на падащи космически обекти като астероиди и метеорити [5]. Тази информация би била полезна при създаването на системи за ранно предупреждение от падащи обекти на Земята.

Основната трудност за откриване на сигнали от пулсари е малкото отношение на полезния сигнал към шума (SNR) на възела на приемника на радио телескопите (от -40 dB до -90 dB). Друга трудност при изследването на пулсарните е голямата консумация на време, необходимо за откриване на сигнала от тях, около 1-2 часа [6-13].

Тъй като всеки пулсар има уникален период, в [2, 3] се прилага алгоритъм за откриване на сигнала при оформяне на пулсарния импулс и отстраняване на шума при откриване на пулсарния сигнал. Съществено е подобно на интегрирането, с изключение на това, че при откриване се събират линии, в резултат на което се подобрява отношението полезен сигнал към шум. Методът за откриване е обаче и друг, като се гарантира, че пулсарният сигнал се подсилва с времето и е от порядъка на няколко часа.

В [6] се обсъжда възможността да се подобри съотношението на сигнала към шума чрез използване на алгоритъм за откриване на сигнала в извадката. Резултатът в тази област би могъл да бъде полезен при работа с нискошумни сигнали.
Както е известно, Хаф трансформация се използва в практиката за откриване на прави линии или на траектории на движещи се обекти [14-17] и е много подходяща за прилагане в настоящия случай.

**Фиг. 1** Принцип и структура на нейтронна звезда – Пулсар

Предложенят алгоритъм е тестиран върху реален сигнал от пулсар B0329+54, получен от Jodrell Bank Centre for Astrophysics. В раздел 2 на настоящата статия е описан предлаганият алгоритъм за обработка на сигнала. В раздел 3 се обсъждат експерименталните резултати и се оглежда процеса на работа на алгоритъма. В раздел 4 са направени изводи и заключения въз основа на получените резултати.

**2. Обработка на сигнали**

Предложенят алгоритъм за обработка на пулсарни сигнали е показан на фигура 2. Той включва следните етапи на обработка: накъсване на приетия пулсарен сигнал на части с продължителност, равна на продължителността на повторение на пулсара и подреждането им в матричен вид; прилагане на филтрираща процедура с осредняващ скачащ прозорец; прагова обработка с постоянен праг; Хаф трансформация; бинарно натрупване в Хаф параметрично пространство и накрая прагова обработка за откриване на пика в Хаф пространството.

\[
z[n] = \sum_{i=1}^{N} \frac{1}{N} x[i], \quad n=1,\ldots, M
\]

(1)

**Хаф трансформация**

В резултат на подреждането на матричен вид на пулсарните сигнали се очаква импулсите на пулсарния сигнал да са позиционирани на едно и също място във времето на повторение или те трябва да образуват права линия в матричното пространство. Хаф трансформация се използва най-често в практиката за откриване на прави линии и е много подходяща за прилагане в настоящия случай.

**Фиг. 3** Преместване на права линия посредством параметрите \( \rho \) и \( \theta \)

Използвайки уравнение (2), всяка точка от декартовото пространство може да се трансформира в синусоида в параметричното пространство. Задавайки стойности на параметъра \( \theta \), се получават стойности за \( \rho \). По този начин всяка права линия от декартовото пространство може да се изобрази като множество от синусоиди в параметричното пространство. Пресечната точка на синусоидите в това пространство е с координати \( \rho, \theta \), които характеризират правата линия (фигура 4а).
За автоматичното откриване на пресечната точка на синусоидите се извършва натрупване (сумиране) на синусоидите (бинарно или некохерентно). Това натрупване дава другото име на Хаф параметричното пространство, а именно – акумулиращо пространство. В резултат на това натрупване в пресечната точка на синусоидите се получава пик, който трябва да бъде открит (фигура 46). В литературата се срещат различни алгоритми за неговото откриване, но най-често това е алгоритъм, сравняващ всички клетки от пространството с постоянен праг. Ако прагът бъде надсочен, в изображението съществува права линия, характеризираща се с параметрите ρ и θ. Извършвайки обратна Хаф трансформация, се получава правата линия в декартова координатна система. В настоящата статия ще бъде използван непрекъснат праг за откриването на траекторията, получена от импулсите на пулсарния сигнал.

3. Резултати

В настоящото изследване са използвани реални сигнали от Jodrell Bank Centre for Astrophysics. За тестване на принципа на работа на предложенния алгоритъм е използван сигнал от пулсар B0329+54. Това е най-светлият радиопулсар на небето на северното полукълбо. Този пулсар се характеризира с период на повторение 0.714520 секунди. Записът на обработвания сигнал, съдържащ в себе си пулсарен сигнал и шум, е с отношение между сигнала и шума в размер на -30 dB (фигура 5).

От фигура 5 се установява, че пулсарният сигнал не се вижда от мощния шум. Нашето предложение е този сигнал да се накъса на части с продължителност, равна на периода на въртене на пулсара и съответните извадки да се подредят в матрична форма (фигура 6). За намаляване на влиянието на шума се прилага интегриране на сигнала с големина на скачащия прозорец N=100 семпъл. Резултатът от филтрирането с осредняващ скачащ прозорец е показан на фигура 7. Основението на матричната форма се стабилизира, като се появява на едно и също място във времето, но с различна мощност и форма.

Погледнато от горе се вижда, че пулсарният сигнал формира права линия в матричната извадка (фигура 8). За автоматичното откриване на тази права линия се прилага променливият прагов (фигура 9). Ако броят на бинарни интегрални пресечки надскочи прага на откриване, който в нашия случай е постоянен и е със стойност 50, тогава се взема решение за откриване на импулсна последователност, характеризираща се с параметрите ρ=35 и θ=90°.
откриване на пулсарни сигнали. Алгоритъм може успешно да се използва за обработка и анализ на пространство. Филтрирането на част от шума и увеличаване на сигнала, а стабилността на сигнала може да се постигне с оценена ефективност на предложените алгоритми. Благодарност: Изследването е проведено с подкрепата на проект ДН 07/1 от 14.12.2016.

Използвана литература
Abstract: The efficiency and technical and economic properties of the electric cars depend mainly on the rechargeable traction battery. LiFePO4 batteries belong to the lithium-ion type and have a number of advantages such as high capacity, long life cycle, resistance to fire at high temperatures or shock. They have safe and stable over-charging and over-discharging performances. This paper describes the process of charging the individual cells of an electric car battery after their over-discharge.

Keywords: LITHIUM IRON PHOSPHATE (LiFePO4) BATTERY, OVER-DISCHARGE, CHARGING, ELECTRIC VEHICLE

1. Introduction

Early vehicles were created to meet the transport needs in the settlements. Due to low speeds and low mileage, in the middle of the 19th and the beginning of the 20th century the use of electric cars and cars with internal combustion engine was equal, but social and technical factors gave an advantage in the development of cars [1]. The harmful effects of emissions from internal combustion engines, the reduction of fossil fuel resources and improvements in electric vehicle technology have led to an increase in the production of electric vehicles at the beginning of the 21st century. The conversion of a car with an internal combustion engine into an electric car is one of the possibilities for creating environmentally friendly cars [2]. The efficiency and technical and economic indicators of the electric car depend mainly on the rechargeable battery. Rechargeable batteries used in electric cars and hybrid cars can be: lead, nickel-cadmium, nickel-metal hydride, lithium-ion, lithium-polymer, metal-air, sodium-sulfur, sodium-metal chloride [3, 4]. Lithium-ion phosphate batteries (LiFePO4) belong to the lithium-ion and have a number of advantages such as high theoretical capacity, long cycle life, resistant to ignition at high temperatures or shock. The life cycle of a lithium-ion battery is more than 2000 charge / discharge cycles and can reach tens of thousands at shallow discharge depths. Cycle life is the number of complete discharge and charge cycles that can be expected from the battery before it reaches its end-of-life (EOL) [5]. The cells LiFePO4 have a nominal voltage 3.2 V per cell and discharge-charge voltage range of 2.0 V – 3.6 V according to [6]. When converting a conventional car into an electric car, several lithium-ion cells can be connected in series, thus providing a higher voltage or in parallel (greater capacity) or both. In the electrical circuits of the lithium-ion battery there are always small differences between the cells due to the production tolerances. To increase safety and increase the life of a newly supplied lithium-ion battery, the cells must be pre-balanced and the entire battery pack pre-charged. It is mandatory to install a battery management system for the lithium-ion battery - BMS, i.e. BMS performs the battery monitoring function. The BMS monitors the following parameters of the battery cells during charging and discharging: currents, voltages, internal temperature of the battery or the environment. If any of the parameters approaches or exceeds the normal limits, the BMS generates an audible or visual alarm and sends a signal to the input of the protection devices, which will disconnect the battery from the load or the charger [7]. In some electric vehicles, especially those converted during long stays, the battery is over-discharged caused by consumers such as the alarm system, the auxiliary battery, the consumption of BMS, leaks and others. The probability of this happening increases with the forced need for a long stay, for example in the conditions of COVID-19 quarantine.

According to [6], an important advantage of lithium-ion phosphate batteries is that they have reliable and stable performance when charged, i.e. even if the lithium-ion phosphate battery is discharged to 0 V, there will be no damage or accident. However, in [8] charge-discharge experiments of lithium iron phosphate (LiFePO4) battery packs have been performed. Their conclusion is that the over-discharge has a huge impact on the utilizlizable capacity and cycle life of the batteries. In particular, over-discharge may completely damage the battery when the voltage drops to 0 V, but the battery does not ignite, explode or smoke. The authors of this publication have also performed experiments on over-discharged cells with high-current charging, using the on-board charger of the electric car. In this experiment, some of the cells deformed (swollen).

In this work the process of charging the battery of an electric car after over-discharging of the individual cells is described. Charge experiments of lithium iron phosphate (LiFePO4) battery have been performed on an electric car. Based on the theory and the conducted experiment, a method has been proposed for restoring the battery of an electric car after over-discharge, using a low current to charge the individual cells to reduce the damage to the battery.

2. Object of Research and Used Equipment

An object of research was the battery of a converted car with a gasoline engine into an electric car with an induction electric motor. The electric motor power is 25 kW/120 Nm, the battery is 100 Ah LiFePO4 and nominal voltage 3.2 V per cell. The battery pack consists 30 series-connected cells (Fig. 1) as the nominal voltage of the whole battery is 96 V and stored energy 9.6 kWh.

The used cells in this work are model SP-LFP100AHA and their characteristic is shown in Fig. 2.

The characteristic shows that when discharged, the cell voltage drops sharply when reaching the moment of complete discharge. At low discharged currents the branch is steeper. During a long stay without the electric car in motion, when the consumption is minimal covering the needs of the alarm system, BMS, leaks, etc., it is difficult to predict the moment of complete discharge of the battery. In such cases, there is a risk of completely over-discharge the battery. The experience has shown that when charging a fully discharged battery with the high current on-board charger 16 A, good results are not achieved, therefore the authors have used a charger for individual charging of cells with lower current (2 A).

Fig. 1 The battery pack and BMS information display.
To charge the individual cells the used charger is IMAX B6 LiPro Balance Charger (see Fig. 3) which according to the manufacturer is suitable for charging and balancing lithium-ion cells without the risk of over-charging.

The charger has the ability to charge different types of cells, such as the LiFe charging program, provides the following parameters:
- Voltage level: 3.3 V/cell;
- Max. charge voltage: 3.6 V/cell;
- Allowable fast charge current: 4 C or less;
- Discharge voltage cut off level: 2.0 V/cell or higher.

3. Experimental Procedure

An experiment was performed to charge 30 over-discharged cells. Their measured initial voltage is shown in Tab. 1. The total battery voltage after over-discharging the cells is 56 V.

![Fig. 3 The used balance charger discharger.](image)

When these values are found, the wires of the battery are disconnected. The auxiliary battery was disconnected on the fifth day, as a decrease in its voltage was observed.

In the daily measurements of the cells, an increase in their voltage is noticed, probably due to their charging by the auxiliary battery until the fifth day when it is disconnected. An increase in voltage is also observed after that and the authors believe that it is due to charging by cells that are already charged by the charger. The connection between the individual cells to carry out this process probably takes place via the BMS wires.

In Fig. 4 the increase in voltage in one of the cells due to recharging by BMS is shown.

![Fig. 4 Recharging a cell by BMS.](image)

In Fig. 5 the change in voltage level of a cell charged on the fourteenth day is shown.

From the first to the twelfth day the recharging process by BMS can be seen. As can be seen in Fig. 5 after charging on the fourteenth day, a constant voltage was maintained (over a long period of 65 days). In this way, all 30 cells of the battery were charged.

![Fig. 5 Voltage level of a cell charged on the fourteenth day.](image)

After loading all the cells, their condition was checked and no deformation (swelling) of the cells was found. The on-board charger was used for final charging, thus achieving 100% charge of the entire battery. This was followed by test drives, initially over short distances (5÷10 km), which alternated with recharging the battery with the on-board charger. The distance traveled during the test drives gradually increased, reaching 50÷60 km at a residual energy in the battery of 20÷30%. These values correspond to the initial ones before allowing the cells to be over-discharge.

In Fig. 6 is shown the charger socket while charging the electric car with the on-board charger.

![Fig. 6 Charger socket while charging the electric car.](image)
4. Conclusions

This article describes the process of charging the cells of a battery of an electric car after over-discharge and a method for charging the individual cells with low current to reduce the damage to the battery was proposed. Test drives with the electric vehicle were carried out. The same mileage was reached as before the over-discharge of the battery. This proves that this method achieves good battery recovery. The disadvantage of this method is its long duration, as the cells are charged one by one individually. The duration of the recovery charging process can be reduced by using more than one charger of this type.

Acknowledgement

This work was supported by the Bulgarian Ministry of Education and Science through National Programme “Young scientists and postdoctoral students”.

References

1. K. Kosev and D. Nikolova, Electric cars (Tehnika, Sofia, 1979) (in Bulgarian)
2. K. Kosev and L. Kunchev, Electric cars and hybrids (Propeler, Sofia, 2019) (in Bulgarian)
5. T. Yuksel, S. Litster, V. Viswanathan and J. Michalek, Plug-in hybrid electric vehicle LiFePO4 battery life implications of thermal management, driving conditions, and regional climate, J. of Power Sources, 338 pp. 49-64 (2017)
7. B. Velev, Conditions for safe operation and long lithium-ion batteries for electric vehicles, Mechanics Transport Communications, 3 pp. 159-165 (21st Int. Scientific Conf. Transport 2013)
Lateral tilting in road vehicles - a review
Diana Dacova*, Nikolay Pavlov
Technical University Sofia, Bulgaria
ddacova@tu-sofia.bg

Abstract: This paper considers various examples of lateral tilting of road vehicles when cornering. Narrow tilting three wheeled vehicles are considered. Four wheeled tilting small road vehicles, passenger cars with active anti-roll bars and cars with active tilting when moving in a turn are presented. The advantages and disadvantages are discussed.

Keywords: LATERAL TILTING VEHICLES, ACTIVE TILTING, SMALL ROAD VEHICLES, TURN

1. Introduction

When the vehicles move in a bend, a centrifugal force is created, which leads to reduction the comfort of the passengers and the stability of the vehicle. Tilting in land vehicles is being used for the first time in trains. This improves passenger comfort and increases cornering speed. In road vehicles, the principle of tilting is introduced later - in three-wheeled and four-wheeled narrow vehicles, and recently is discuss the use in normally wide passenger cars. The paper will discuss some examples of the applications discussed above and discuss their advantages and disadvantages.

2. Narrow Tilting Three Wheeled Vehicles

Three wheeled vehicles or tri-cycles have better static stability than two-wheelers (motorcycles and mopeds), but poorer dynamic stability when cornering. This is due to the fact that they are usually narrow-gauge and have a relatively high center of gravity. To improve stability, three wheeled vehicles can be provided with a tilting system [1]. Tilting can be done by the driver as in motorcycles or automatically.

Fig. 1 Toyota i-Road [https://www.autocar.co.uk].

Fig. 2 Carver One [https://insideevs.com].

In Fig. 1 is shown a three wheeled vehicle with two front and one rear wheel, and the vehicle shown in Fig. 2 has two rear and one front wheel.

The advantage of the first option is that there is no need to use a differential. In addition, the driver has visibility for the gauge, as the vehicle is wider at the front. While the second option should use a differential for the drive wheels, but at the expense of simplifying the steering mechanism, which is of the motorcycle type.

Recently, there has been a trend to apply the first scheme to mopeds and motorcycles (see Fig. 3 and Fig. 4). This improves their static stability and stability at low speeds. The handling is also improved, especially in poor road conditions and low friction or uneven terrain.

Fig. 3 Piaggio MP3 Sport [https://www.piaggio.com].

Fig. 4 Yamaha NIKEN GT [https://www.yamahamotorsports.com].

Because the front wheels are not wider than the handlebars they are still classified as a motorcycle not tri-cycles [2].

3. Four Wheeled Tilting Small Road Vehicles

These vehicles belong to the group of small city cars. Especially popular in major European cities with high traffic. They are above 50cc and speed not exceeding 45 km/h, and a weight of no more than 550 kg. They can drive with a B1 driver's license from persons over 17 years of age. They have small dimensions and do not require much parking space. The disadvantage is their lower lateral stability due to the narrow track and high center of gravity. To improve cornering stability, some manufacturers offer tilting vehicles of this type. There are also those with electric drive (Fig. 5).

Fig. 5 Nissan Land Glider [https://newatlas.com].
This scheme is also available for all-terrain vehicles (ATVs). In this way, both their cornering and lateral slope stability and their passability when driving on uneven terrain are improved (Fig. 6).

4. Passenger Cars With Active Anti-Roll Bars and Tilting Cars

In full-size passenger cars of a higher class, active lateral stabilizers are now common, which counteract the centrifugal force and reduce or eliminate the body tilt it causes (Fig. 7).

Active anti-roll technology is increasingly commonplace, mostly using active anti-roll bars that torque themselves up with hydraulics or electric motors to resist lateral forces, softening off again for the improving of comfort when the car is back in a straight line.

Mercedes’ curve tilting function takes this process to the next level and instead anti-roll bars, they apply actively raise the suspension spring platforms on the outside of the turn and lower them on the inside, creating an effect resembling motorcycle driving [https://www.carmagazine.co.uk]. The curve tilting function can be selected using the three-position ABC switch, and is active in a speed range of 15 to 180 km/h in “Curve” mode. Further selection options include “Comfort” (Magic Body Control with Road Surface Scan) and “Sport” [https://media.daimler.com]. Integrated closely with the Active Body Control (ABC) and Road Surface Scan functions of Magic Body Control, the new feature uses suspension struts which are equipped with hydraulic cylinders that can make the car automatically incline in a fraction of a second and to an angle of up to 2.5 degrees in curves [4]. It can be seen in Fig. 8.

The four suspension struts are equipped with hydraulic cylinders, in order to adjust the force in each strut individually. The control unit receives information on the current driving situation from various acceleration sensors, level sensors on the control arms and driving speed. The system then calculates the control signals for the servo-hydraulic valves on the front and rear axle by means of the pressure sensors in the spring struts to ensure suitable proportioning of the oil flows [https://media.daimler.com].

5. Conclusions

The shown technologies are for tilting the chassis of the vehicles. Narrow tilting tricycles and quadricycles can achieve greater tilt angles than passenger cars. In order to achieve a greater reduction in lateral acceleration, additional seat tilting should be applied to them or only the seats should be tilted on their own [5]. However, this is associated with other inconveniences, such as additional mechatronic systems located in the car body, lack of sufficient space for tilting - especially in the rear seats, problems with perceptions and feedback from the driver on the allowable speed in corners and so on.

Acknowledgement

This work was supported by the research program to support PhD students in Technical University – Sofia, internal competition 2020 under the project № 202ПД0022-04.

References

Stress-strain state of workpiece from Cu-Cr alloy processed by severe plastic deformation by ECAP

Asfandiyarov Rashid1,2, Aksenov Denis1,2, Raab Georgy1
Institute of Physics of Advanced Materials—Ufa State Aviation Technical University, Russia
Institute of Molecular and Crystal Physics—Subdivision of the Ufa Federal Research Centre of the Russian Academy of Sciences, Russia

The work was supported by the Russian Science Foundation (project №19-19-00432).

1. Introduction
The aim of this work is to study the stress-strain state and thermal effect in a workpiece from low-alloyed Cu-0.6Cr bronze under conditions of intense plastic deformation by equal-channel angular pressing (ECAP). To do this, physical modeling of the sedimentation of the samples was carried out on a Gleeble 3500 installation at temperatures of 20, 400, and 800 °C and strain rates of 3, 30, and 300 mm / s. Based on the data obtained, a computer simulation of the process of ECAP was carried out in the Deform 3D software package. As a result, the fields of stress distribution, deformation, temperature (deformation heating) and power characteristics of the ECAP process are obtained, depending on various initial temperature and speed conditions.

2. Objective and research methodologies
The work used an industrial conductive alloy Cu-0.6Cr. The initial state was obtained in the process of high-temperature treatment at 1000 °C for 1 hour and subsequent quenching in water. Alloy samples 10 mm in diameter and 14 mm in height were upset on a Gleeble-3500 physical modeling complex at a strain rate of 3, 30, and 300 mm / s. The temperature of the experiment was 20, 400, and 800 °C. Further, based on the data obtained by physical modeling, a database was prepared for finite element computer modeling in the Deform 3D software package. After preparation, modeling and analysis of the results were carried out.

3. Preparing a database for Deform 3D with Gleeble

Verification: Warming up during deformation: 20 °C, 21.4 sec⁻¹
4. Results
Temperature fields at different temperature-speed conditions:

The rational technological mode is an initial temperature of 400 degrees and a strain rate of 2.14 sec\(^{-1}\) (equipment rate of 30 mm/sec). Accumulated deformation distribution (The rational technological mode):
The distribution of accumulated deformation is non-uniform. The maximum values are observed in the lower peripheral region and are $e \sim 2.5$, which can have a positive effect on the strength and wear resistance characteristics of the finished product. The minimum values in the central region are of the order of $e \sim 1.5$.

In general, effective stresses in the deformation zone have a uniform distribution (~ 300 MPa) with local maxima in the peripheral zones of intersection of channels (more than 350 MPa).

### Stress mean distribution (The rational technological mode):

The simulation results show that in the deformation zone in the shear region, compression stresses prevail, reaching values of the order of 230 MPa.

### Stress effective distribution (The rational technological mode):

5. Conclusion

Thus, in the course of computer modeling, a comprehensive analysis of the stress-strain state of workpieces was carried out during processing by the ECAP method and ECAP with extrusion, an assessment of the energy-force models of the process, shown on the tool, was carried out, depending on the temperature and speed parameters of processing.

In conditions of intense plastic deformation by the ECAP method, intense warming up during deformation. The most significant effect on heating is exerted by the deformation rate, so at an initial temperature of 400 °C, an increase in the rate of deformation from 0.264 to 21.4 sec$^{-1}$, deformation heating increases from 120 to 250 °C;

With an increase in the initial temperature, the degree of warming up decreases. So, at an initial temperature of 20 °C and a strain rate of 2.14 sec$^{-1}$, the heating is 100 °C, and at an initial temperature of 800 °C, the heating is 30 °C;

With an increase in the initial temperature, the required pressing force substantially decreases, for example, from 208 kN at 20 °C and a strain rate of 0.264 sec$^{-1}$ to 46.3 kN at 800 °C. An increase in the strain rate leads to an increase in the required force. For example, at 400 °C, an increase in the strain rate from 0.264 to 21.4 sec$^{-1}$ leads to an increase in force from 113 to 244 kN.

The optimal technological mode for the formation UFG structures is an initial temperature of 400 degrees and a strain rate of 2.14 sec$^{-1}$ (equipment rate of 30 mm/sec) and true strain $e \sim 1$. 

MACHINES. TECHNOLOGIES. MATERIALS. 2020

MACHINES. TECHNOLOGIES. MATERIALS. 2020
Production of powders of copper alloy (copper 85, tin 5, lead 5, zinc 5) by spraying a melt with a gas flow


E-mail: alexil@mail.belpak.by, irinacharniak@tut.by, 2312444@mail.ru, 19081877@mail.ru

Abstract: The study of the process of producing copper alloy (copper 85, tine 5, lead 5, zinc 5) powders of grade by the method of induction melting and spraying with a melt gas flow is presented.

KEYWORDS: SPRAYING OF METAL MELT WITH A GAS FLOW, POWDER OF THE COPPER ALLOY (COPPER 85, TIN 5, LEAD 5, ZINC 5), INDUCTION MELTING, RESEARCH

1. Introduction

Bronze powders (copper alloy (copper 85, tin 5, lead 5, zinc 5) grade are widely used for spraying coatings by the gas-thermal method on the working surfaces of parts operating under friction and wear conditions. One of the main ways to produce spherical powders for spraying is spraying an overheated metal melt with a gas flow [1–3]. The method of producing metal powders by spraying a melt is technologically advanced, universal and highly efficient. However, in the process of induction melting, the copper alloy (copper 85, tin 5, lead 5, zinc 5) multicomponent alloy is significantly depleted in zinc due to the large difference in its melting temperatures with the melting points of the main components. A large number of techniques have been developed to reduce the loss of alloying components during melting and casting of the alloy. Their main recommendations are as follows [4–6]: to avoid overheating of the melt [7]; to use deoxidizers; to use fluxes.

Zinc and zinc-based alloys are very sensitive to overheating. Excessive overheating of zinc melts is always undesirable, since it causes the oxidation of zinc and alloying elements; it contributes to the saturation of the melts with hydrogen and oxide non-metallic inclusions. In addition, limitations on permissible overheating temperatures of zinc melts are due to the low boiling point of zinc and the evaporation of zinc. The losses of metals from evaporation depend on the pressure of the saturated vapor of the liquid metal: the higher the vapor pressure, the greater their losses during the preparation of alloys [8]. At the moment when the vapor pressure of the metal becomes equal to the external pressure, boiling of the metal begins, i.e. evaporation occurs not only from the surface, but throughout the entire volume. Deoxidizers are used to reduce the oxides that make up the alloy. One of the most common methods of deoxidation of power of copper alloy (copper 85, tin 5, lead 5, zinc 5) is melting the alloy in graphite crucibles. Fluxes are used to protect the alloy from oxidation and to separate non-metal impurities that enter the metal. For the protection of copper-zinc alloys, fluxes are used consisting of materials such as glass, sodium chloride, calcium sulfate, calcium fluoride, barium chloride, borax, and etc.

However, all the applications of the above methods are impractical in the implementation of processes for producing spherical powders by spraying the melt with a gas flow. Thus, the recommendation not to heat the melt contradicts one of the main requirements of the powder spraying process, i.e. melt overheating by at least 250 °C [9]. The use of deoxidizers and fluxes in the process of spraying powder is possible with a significant complication of the process and a decrease in its productivity, since before supplying the melt to the spraying unit, it is necessary to completely remove the slag. It is technically difficult to implement. At the same time, if the slag gets into the spraying unit, it clogs the nozzle, which requires stopping the entire spraying process and spending a significant amount of time and additional resources. In addition to losses in physical terms, zinc vapor brings a significant danger to human health. Thus, the development of ways to reduce zinc losses is an urgent and important task.

The purpose of the work is to study the effect of the melt overheating temperature, the diameter of its outflow jet and the gas pressure in the spray nozzle on zinc waste in the process of producing powders of copper alloy (copper 85, tin 5, lead 5, zinc 5) by induction melting and spraying the metal melt with a gas flow.

2. Experimental results and discussion

The production of experimental samples of sprayed copper alloy (copper 85, tin 5, lead 5, zinc 5) grade included the following basic operations [10, 11]: weighing the initial components, loading the components into an induction melting furnace and heating, spraying a jet of the melt, removing the powder from the equipment and drying, sieving powder.

1) Weighing the initial components (scrap copper – 83.48%, tin – 4.91%, lead – 4.91%, zinc – 6.7%). Copper scrap without tin plate and soldering, plate zinc anodes, tin of O1 grade, lead sheets of C1 grade in the state of delivery were used as the initial components.

2) Loading the components into an induction melting furnace and heating. The melt was overheated with respect to the main component by 117 – 317 °C: the melt temperature was 1200, 1300, and 1400 °C. Two load variants were tried. According to the first variant, copper was heated to a specified temperature and melted. Then, slag was removed from the surface of the melt and tin and lead were introduced. When the melt reached the specified temperature, the most low-melting component, i.e. zinc, was introduced. According to the second variant, all the components were melted simultaneously: zinc sheets were twisted together with lead plates. Tin and copper were placed outside.

3) Spraying a jet of the melt. Within no more than 30 seconds from the moment of readiness, the melt entered the metal receiver. From the metal receiver, the melt freely flowed through a hole of a certain diameter in the form of a vertically falling jet into the spray zone, where it was dispersed into fine droplets by a gas flow. The sprayed droplets of the melt, due to the forces of gravity, moved into the water, where their final cooling took place. Figure 1 shows the equipment for spraying powders, and Figure 2 schematically shows a nozzle for spraying a jet of the melt. The hole diameter was 4, 6 and 8 mm; the pressure drop was 0.3 and 0.7 MPa.

4) Removing the powder from the equipment and drying. The sprayed powder was removed from the plate and dried at a temperature of 110 – 120 °C.

5) Sieving powder. The dried powder was sieved into fractions, and its chemical composition was examined.
According to the above technology, pilot batches of experimental samples of powders were produced and the effect of the melt overheating temperature, the diameter of the melt jet and the gas pressure on the value of zinc waste was investigated.

Table 1 shows the effect of overheating temperature on zinc waste at different sequence of introducing components into the melt.

<table>
<thead>
<tr>
<th>Sequence of introducing components</th>
<th>Overheating temperature, °C</th>
<th>Zinc content in the charge mixture, %</th>
<th>Zinc content in the powder, %</th>
<th>Waste, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequential introduction of components (variant 1)</td>
<td>117</td>
<td>6,7</td>
<td>2,70</td>
<td>59,7</td>
</tr>
<tr>
<td>Simultaneous introduction of components (variant 2)</td>
<td>217</td>
<td>6,7</td>
<td>2,59</td>
<td>61,34</td>
</tr>
<tr>
<td></td>
<td>317</td>
<td>6,7</td>
<td>1,14</td>
<td>82,99</td>
</tr>
<tr>
<td></td>
<td>117</td>
<td>6,7</td>
<td>2,60</td>
<td>61,19</td>
</tr>
<tr>
<td></td>
<td>217</td>
<td>6,7</td>
<td>2,32</td>
<td>65,37</td>
</tr>
<tr>
<td></td>
<td>317</td>
<td>6,7</td>
<td>1,10</td>
<td>83,58</td>
</tr>
</tbody>
</table>

An analysis of the obtained data indicates that the overheating temperature has a primary effect on zinc waste. In this case, the powder spraying technology according to variant 1 is preferable due to lower zinc losses. Further, the experimental samples were produced according to variant 1, i.e. with the sequential introduction of the components. Moreover, taking into account that excessive zinc waste is observed at a melt temperature of 1400 °C (overheating temperature is 317 °C), and at a melt temperature of 1200 °C (overheating temperature is 117 °C), a low output of good powder is observed. Then the melt was heated to a temperature of 1300 °C (overheating temperature is 217 °C).

The effect of the overheating temperature on the form factor and the output of a good powder for experimental samples produced at overheating temperatures of 1200 and 1300 °C was determined (the temperature of 1400 °C was not considered according to the data in Table 2 due to the large waste of zinc). Form factor FF was assessed by the method described in Ref. [12]:

$$ FF = \frac{4\pi A}{L_0^2} \quad (1) $$

where A – particle projection area, mm; L_0 – projection perimeter, mm.

The evaluation of the sphericity of the particles was carried out by determining the number of powder particles in the investigated fraction with a form factor of 0.8 or more on a certified automatic image analyzer “Mini-Magiscan” (“Joyce Loebl”, England) (Figure 3). The output of good powder was determined as a percentage in relation to the weight of the charge mixture for preparing the melt (Table 2).

Table 2: Effect of overheating temperature on a form factor and output of good powder

<table>
<thead>
<tr>
<th>Overheating temperature, °C</th>
<th>Good powder output, %</th>
<th>Particle content with a form factor not less than 0.8, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Powder particle size, μm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-1000+630)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-400+200)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-1000+630)</td>
</tr>
<tr>
<td>1200</td>
<td>88,5</td>
<td>69,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>81,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90,0</td>
</tr>
<tr>
<td>1300</td>
<td>94,0</td>
<td>93,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>94,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>96,0</td>
</tr>
</tbody>
</table>

Figure 5 shows the appearance of powder of copper alloy (copper 85, tin 5, lead 5, zinc 5), produced by the developed technology, and not dispersed into fractions.
The appearance of the produced particles of powders of copper alloy (copper 85, tin 5, lead 5, zinc 5)

The analysis of the obtained data indicates that the overheating temperature of 1300 °C is optimal for producing the required shape and chemical composition of the powder according to all parameters under study.

The effect of spraying modes of the melt (the diameter of the nozzle hole through which the melt flows and the gas pressure in the spray nozzle) by the gas flow on the zinc content was studied. The research results are presented in Table 3.

<table>
<thead>
<tr>
<th>Melt flow diameter, mm</th>
<th>4</th>
<th>4</th>
<th>8</th>
<th>8</th>
<th>6</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas pressure in the nozzle, MPa</td>
<td>0.3</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Zinc content in powder, %</td>
<td>2.58</td>
<td>2.6</td>
<td>2.58</td>
<td>2.59</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Waste, %</td>
<td>61.49</td>
<td>61.19</td>
<td>61.49</td>
<td>61.34</td>
<td>61.19</td>
<td>61.19</td>
</tr>
</tbody>
</table>

The analysis of the obtained data has shown that the modes of the spraying process of the metal melt by a gas flow have practically no effect on the content (losses) of zinc in the process of producing a spherical sprayed powder.

Conclusion. It has been experimentally confirmed that when producing zinc-containing sprayed powders using the traditional technology of melting charge mixture materials, excessive zinc waste is observed, i.e. more than 60%. The optimal temperature 1300 °C for heating the melt for further research has been established. The melt flow diameter and gas pressure do not affect zinc losses.

References

Steels with bainite structure for railway wheels

Svetlana Gubenko
National Metallurgical academy of Ukraine
Dnepropetrovsk, Ukraine
sigubenko@gmail.com

Abstract. Some wheel steels inclined for the self-quenching on bainite structure were produced and investigated after hot deformation and heat strengthening. Steels contained 0,12...0,45% of carbon, and also Si, Mn, Mo, Cr, Ni, V, Ti, Al. Steels with bainite structure after hot deformation and tempering were investigated. It was shown the possibility of the railway wheels production with bainite structure and hardness of 400HB without heat strengthening treatment. The results of investigation shown the possibility of railway wheels production with bainite structure, hardness of 400 HB and high complex of the mechanical and operating properties without heat strengthening treatment. These tasks solved owning to application of new wheel steels and up-to-date technology. KEYWORDS: RAILWAY WHEELS, STEEL, BAINITE STRUCTURE, TREAD.

1. Introduction.

The increasing of thermocyclic load on the wheel during braking is one of main problem. Heat loads promote deformation in the wheel. Tread is heating by work of friction and some surface defects are formed. Complex approach for wear mechanism of railway wheels includes not only investigation of structural and corrosive changes happening in surface layers of wheel rims [1-13], but also analysis of wear particles and establishment of mechanism of their formation [14-21]. The variety of working conditions of friction pairs suggests that the general approach may be the idea of the fatigue nature of the destruction of the surface layers [22]. The problem of production of the highstrength and reliable railway wheels is very actual. This problem is compound and includes some aspects which connect with production of highquality steel, optimization of the each stage of forming, development of new design of wheels and also guarantee of essential level of heat strengthening. Modern conditions of operating of railway wheels needs the essential arrangements by the guarantee of high level of wheel rim up to 400 HB. At this time certain countries use the rails with hardness up to 450 HB and the bainite structure. At that, the ratio between hardness of wheel tread and rail should be as follows (0,8...1,0) / 1,0.

Traditional microstructure of wheel rim is dispersion perlitewith small share of ferrite, that ensures sufficiently high complex of strength, hardness and toughness of wheel steel. But such microstructure even by the using of microalloying allows to have maximum hardness of 330 HB. It lets to suppose that possibilities of perlitestructure in that senses were settled and new nontraditional approach is essensial.

Perspective microstructure for the guarantee of correlation of high hardness, strength, toughness and wear resistance of steel is bainite [23,24]. It is known in advanced railway countries the researches by the development of bainite rails and railway wheels are conducted. Most of works by the development of bainite wheels were connected with task of production of steels with high resistance to the martensite transformation for reducing and even removing of probability of surface defects of fatigue.

The goal of this work was development of bainite steels with hardness up to 400 HB and high complex of mechanical and operating properties. The investigations offer complex solution to ensure higher reliability and safety of railway wheels, in particular development and production of new railway wheels with sufficiently improved mechanical and service properties.


The research steels with low content of carbon (0,12...0,45%, mass) and different contents of Si, Mn, Mo, Cr, Ni, V, Ti, Al were produced. Castings were exposed to plastic deformation (1200...900 °C) with different degrees of deformation (50 and 90%) and cooled on the air. After hot deformation specimens were tempered (500...525 °C) for reduce of stresses. Metallographical (optical and electron microscopes) and X-ray radiographic researches were made. Methods of testing: hardness, mechanical properties by tensile, fracture toughness, wear test. The resistance of steels for martensitic transformation during rapid heating and cooling by the Jomini end quenching was investigated.

3. Results and discussion.

Microstructure of steel 1 after hot deformation was bainite with small part of martensite (about 5%). Degree of dispersity of structure rised with the increasing of deformation degree (Fig. 1, a, b). Needled bainite is twinned, it known else lath ferrite. Analysis of replicas showed that in regions of bainite the ultra disperse carbides Mo2C and (Fe, Cr)C present. Microstructure of steel 2 was ferrite-perlitewith small part of martensite (up to 5%). Morphology of bainite was lath type close to upper bainite. In the bainite laths carbides VC, Mo2C, (Fe, Cr)C present, although there are the lathes without carbides (they close to lower bainite). Microstructure of steel 6 is ultra dispersed perlitewith slim interlayers of ferrite.

Fig.1. Microstructure of hot deformed steel 1: degree of deformation 50 (a) and 90% (b): x200
Therefore hot deformation resulted in dispersion of microstructures of cast steels, moreover than more degree of deformation Steels 1, 3, 4, 5 after hot deformation have microstructure of bainite with small part of martensite (up to 5%). Presence of martensite is caused for nature of bainitic transformation. Obviously during formation and growth of bainitic lathes (or needles, lamelles) the local redistribution of carbon and alloying elements changes the kinetics and mechanism of austenite decomposition. Therefore there is not microstructure of steel with 100% of bainite, forms Cottrell atmospheres on the dislocations. Remnant which did not diffuse to surrounded austenite during growth of laths upper bainite (without carbide) the considerable part of carbon, alloying elements changes the kinetics and mechanism of austenite decomposition. Consequently, presence of martensite is caused for nature of bainitic microstructure of bainite with small part of martensite (up to 5%).

Upper bainite does not need tempering, therefore it is the favourable structure from point of view of strength, plastic and tough properties correlation. In table 1 the parameters of fine structure of steels after hot deformation are shown.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>steel 1</th>
<th>steel 3</th>
<th>steel 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D_HKL, cm</td>
<td>Δ a/a, 10^-3</td>
<td>ρ_α, cm^-2</td>
</tr>
<tr>
<td>Hot deformation (ε = 50 %)</td>
<td>4.4</td>
<td>2.32</td>
<td>7·10^-12</td>
</tr>
<tr>
<td>Hot deformation (ε = 50 %) + tempering</td>
<td>4.5</td>
<td>2.24</td>
<td>6.5·10^-11</td>
</tr>
</tbody>
</table>

After tempering the level of microstresses in all steels is reduced. Meanings of dislocation density confirm the results of electron microscopic investigations. After tempering the density of dislocations reduces on the order. The quantity of retained austenite was 5...10 %.

Table 2. Hardness of steels (HB) after hot deformation and tempering

<table>
<thead>
<tr>
<th>Condition of steel</th>
<th>steel 1</th>
<th>steel 2</th>
<th>steel 3</th>
<th>steel 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot deformation ε = 50 %</td>
<td>405</td>
<td>420</td>
<td>432</td>
<td>455</td>
</tr>
<tr>
<td>Hot deformation ε = 90 %</td>
<td>264</td>
<td>195</td>
<td>250</td>
<td>409</td>
</tr>
<tr>
<td>Hot deformation ε = 50 % + tempering</td>
<td>402</td>
<td>437</td>
<td>451</td>
<td>412</td>
</tr>
<tr>
<td>Hot deformation ε = 90 % + tempering</td>
<td>409</td>
<td>437</td>
<td>451</td>
<td>412</td>
</tr>
</tbody>
</table>

Table 1. Parameters of fine structure of bainite after hot deformation

\( D_{HKL} \) – size of blocks, \( \Delta a/a \) – microstresses, \( \rho_\alpha \) - density of dislocations

After tempering the hardness of steels was defined (table 2).

Steels 1,3,4,5 with bainite microstructure have hardness 400..455 HB after hot deformation or deformation and tempering. It is important that bainitic structure in hot deformed steels was formed without special heat treatment. That allows to affirm that essential level of hardness of railway wheel rims may be provided after hot deformation without heat strengthening quenching. But it is essentially also to define the level of the mechanical properties and resistance of steels to the martensitic transformation during heat of tread of railway wheel.

The complex of the new wheel steels characteristics was as follows (Table 3)
Properties of bainite steels are better than properties of standard wheel steel with perlitic structure.

During operation of railway wheel the tread is exposed to heat and mechanical loads, which promote the accumulation of heat and mechanical fatigue, wear of tread and flange, plastic shears in the thin surface layer, appearance of some defects which are caused by formation of martensite near tread (Fig. 3). These defects are formed in conditions of abrupt braking, when thin surface layer of tread is heated up to temperature of austenite area (upper 800°C) by friction from abrupt action of the brake block. Deformation of this thin layer in the plastic austenite condition takes place, but it can not endure a big operating load, then tread abruptly cooling in the time of disengagement of brakes and this leads to formation of the “white layer”. It is known “white layer” represents ultra dispersed martensite (gardenite), which has high brittleness, especially by the blows of wheel against the butts of rails (that is by dynamic load). Moreover, it promotes formation of some defects in the areas of heat action and this lead to increase of quantity of metal which is removed by the turning in the process of tread profile restoring.

For comparison the specimens of standard wheel steel and experimental steels 1, 3, 4, 5, 6 were exposed to heating in the austenite area by the Jomini end quenching.

The results of microhardness measuring are shown in table 4.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Place of measuring from the end of specimen, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard wheel steel</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>640</td>
</tr>
<tr>
<td>3</td>
<td>420</td>
</tr>
<tr>
<td>4</td>
<td>450</td>
</tr>
<tr>
<td>5</td>
<td>460</td>
</tr>
<tr>
<td>6</td>
<td>600</td>
</tr>
</tbody>
</table>

Standard wheel steel and steel 6 have inclining to the martensitic transformation. Steels 1, 3, 4, 5 showed stable values of microhardness with the level of bainite microstructure, and this was confirmed also by the metallographical research of these specimens. Of course, it is not possible to expel the possibility of formation of inclusions and mechanical fatigue in wheel steel. But advantages of the bainite wheels are evidently in this problem by the comparison with wheels from standard steel.


The results of investigation shown the possibility of railway wheels production with bainite structure, hardness of 400 HB and high complex of the mechanical and operating properties without heat strengthening treatment. These tasks solved owning to application of new wheel steels and up-to-date technology.

5. Literature.


wheel steels on wear and restoration modes of the wheelset profile.
Layered composites based on niobium with silicide-carbide or silicide-boride hardening

Korzhov Valery Polikarpovich, Kiiko Vyacheslav Mikhailovich, Prokhorov Dmitry Vladimirovich, Zheltvakova Irina Sergeevna
Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Region

Abstract: The work is devoted to the development of a solid-phase technology for obtaining high-temperature layered composites from Nb-alloys. The following are presented: one of the options for the formation of the initial multilayer package and its diffusion welding (1), the microstructure of the obtained composites (2) and the results of testing composites (3) for strength at room temperature and temperatures up to 1350°C, taking into account the structure anisotropy, crack resistance and tests for creep with two options for processing the obtained experimental data.

KEYWORDS: COMPOSITE, HEAT RESISTANCE, LAYERED STRUCTURE, NIOBIUM, CREEP, CARBIDE-SILICIDE, CARBIDE-BORIDE, STRENGTH, CRACK RESISTANCE, DIFFUSION WELDING, SOLID PHASE TECHNOLOGY

1. Introduction

Workings of constructional materials designed for use at high temperatures, based on niobium and molybdenum can result in materials with the highest operating temperature ceiling. The especially high modulus of elasticity for molybdenum and its intermetallic compounds suggests that materials based on it can achieve the highest strength [1–3]. High melting points, strength at high temperatures and creep resistance of niobium and molybdenum compounds, as well as the possibility of organizing increased resistance to oxidation, as, for example, in Mo–Si-B alloys [4], open up a real prospect for obtaining heat-resistant composites based on them.

In addition, the combination of molybdenum or niobium and their purely intermetallic compounds or carbide-silicides in the structure of the composite makes it possible to reduce the density of the composite in comparison with the density of these metals due to the relatively low density of intermetallic compounds and carbide-silicides of niobium and molybdenum [5].

The problem of fracture toughness of composites, which exists in connection with the presence of brittle compounds in their structure, is not insurmountable. One of the possibilities of its solution by decelerating cracks at a weak interface between brittle phases was first shown back in 1964 in [6]. This idea was later used in the development of various layered and fibrous composite materials [7, 8].

In the work, the authors used a “non-melting” method for producing flat products from Nb-alloys, free from the problems of their compatibility with the crucible and guaranteeing the direction of the structure to the product. For its formation, a diffusion method was used, which consists in the solid-phase interaction of two or more components. The directionality of the structure and the interaction of the components were achieved in multilayer stacks of metal foils during their diffusion welding under pressure.

2. Heat-resistant composites from Nb-alloys

2.1. Composites Nb/(Si–C)1 and Nb/(Si–C)2

We investigated layered composites of a multicomponent Nb-alloy with silicide-carbide hardening, obtained by diffusion welding of multilayer packages under pressure in vacuum. The structure of the composite makes it possible to reduce the density of the composite in comparison with the density of these metals due to the relatively low density of intermetallic compounds and carbide-silicides of niobium and molybdenum [5].

The elements of the assembly were U-shaped elements made of Nb foils coated with a multicomponent powder mixture (Fig. 1). The number of items in the package – 15 pcs. Nb foil thickness – 50 microns. One outer and one inner side of the U-elements were coated with a suspension layer of a multicomponent mixture of powders in polyvinyl glycol. Coating composition: 55.2Nb–22.0Ti–8.9Mo–5.6Si–5.42ZrH–1.7Cr–1.2 wt. %Al. The zirconium in the powder mixture was in the form of a hydride. Hydrogen was removed from the coating by heating, starting from 350–400°C. The package, made of U-elements, retained its integrity by alternating Nb-foils and coatings. The number of Nb-layers in a package is 30 pcs. The number of coatings is one less.

Diffusion welding of packages Nb/(Si–C)1 and Nb/(Si–C)2 was carried out at 1400°C, but in two modes that differed in welding time and pressure: 1–5 h at 8.4 MPa and 2–10 hours at 15.3 MPa. Carbon penetrated into the powder coating while welding the bags from the atmosphere in the welding chamber with a graphite heater.

In fig. 2 shows the microstructures of layered composites Nb/(Si–C)1 and 2. Their thickness after welding is 3.3 and 2.7 mm, respectively. Composite thickness with longer welding times was noticeably thinner. The structures are similar in that they consisted of layers inheriting the Nb-foil and layers of the products of sintering powder coatings and their diffusion interaction with the Nb-foil. In the structures of both composites, the layers are designated as (Nb, Ti), indicating that this is an alloy in which the main elements are niobium and titanium. For example, in the Nb/(Si–C)1 (Nb, Ti)-layers the composition was 66.5 Nb–24.3 Ti–9.2 at. %Me (Me – Mo, Cr, Al and Si) with “traces” of carbon.

In composite 2, a change in the concentrations of phase-forming elements, Nb and Ti, in the carbide-silicide phase was traced with distance from the boundary with the (Nb, Ti)-layer. The composition varied from almost equal concentrations of Ti and Nb, ~23.6 at. %, to a concentration ratio in favor of titanium 34.6 at. % Ti and 13.8 at. % Nb → 42.6 at. % Ti and 36.6 at. % Nb:

$$
(Ti_{0.67}Nb_{0.33}Me_{1.17})_{1.1} (Si_{0.66}Al_{0.05}C_{0.28}H_{0.89}) \rightarrow
(Ti_{0.67}Nb_{0.33}Me_{1.17})_{1.1} (Si_{0.66}Al_{0.05}C_{0.28}H_{0.89}) \rightarrow
(Ti_{0.67}Nb_{0.33}Me_{1.17})_{1.1} (Si_{0.66}Al_{0.05}C_{0.28}H_{0.89}) \rightarrow
$$
The unidentified phase in the composites was a dark gray phase localized within the Me(Si,C) or Me(Si,C,Al) phases. It is not marked in the figures, but according to local X-ray spectral analysis, it is based on Nb, Si, and C: 53.7 Nb, 30.6 Si, 15.0 at. % C. In terms of concentration, this phase can be assigned to the eutectic regions: (Nb + α(Nb,Me)(Si,C)) of the Nb–Si phase diagram or to (Nb + β(Nb,Me)(C, Si)) of Nb–C phase diagrams.

**Mechanical characteristics.** After DW, the packages had the form of plates, from which specimens were cut in the form of rectangular rods for strength testing by the 3-point bending method at room temperature and high, up to 1350°C, temperatures.

Crack resistance tests were performed on notched specimens. The critical stress intensity factor \( K^* \) was calculated under plane deformation conditions using the formula:

\[
K^* = \frac{P}{B(2S)^{1/2}} \frac{W^{1/2}}{W_0^{3/2}},
\]

where \( P \) is the maximum load, \( S \) is the base or distance between the supports, \( B \) and \( W \) are the width and height of the specimen, and are the depth of the notch. The load was applied from the side opposite to the notch.

Together with the \( K^* \) measurements, the effective surface destruction energy \( g \) of the sample was determined. In theory, strength testing is considered as the separation of a sample into two parts by a macroscopic crack and the formation of two fracture surfaces. Then \( g \) can be estimated by the ratio of the work of external forces to the doubled area of its cross-section:

\[
g = \frac{1}{2}\sqrt{Q} \frac{\delta}{2},
\]

where \( Q \) is the load on the sample, \( \delta \) is the deflection and \( F \) is the cross-sectional area of the sample. In reality, this is the area under the experimental load-deflection relationship.

Since the layered structure of the composite has anisotropy, it was useful to apply the load \( P \) perpendicularly (\( \perp \)) and parallel (\( \parallel \)) to the layers (\( ab \)) in the tests for strength and crack resistance for their assessment. In fig. Fig. 3 shows the dependences of the ultimate strength on the testing temperature of the composites Nb/(Si-C) 1 and 2. It was expected that with a load applied parallel to the layers, the strength would be higher. This was the case for the Nb/(Si–C)2 composite (see symbols ○ in Fig. 3, b). This is due to the higher moment of resistance of the carbide-silicide layers with a parallel orientation of the direction of application of the load and the plane of the layers. But for the Nb/(Si–C)1 composite with a shorter welding time and pressure at \( 20^\circ C \), this was not observed (see Fig. 3, a). Moreover, for \( P \parallel \) (ab) \( \sigma_0 \) was even less.

**Creep tests.** At this stage of the work, for testing samples for creep, the scheme of their 3-point bending was chosen, as one of the most acceptable in terms of requirements for the manufacture of samples (their shape and size). Taking into account the conditions and limitations of this scheme [9], as well as using unconventional methods of processing experimental data [10, 11], it is possible to obtain (as preliminary) results of creep tests for a comparative analysis of the characteristics of developed materials in a relatively short time. Such tests seem to be especially convenient in the conditions of the initial stage of research work.

The high-temperature tests were carried out in the same chamber and according to the scheme as the 3-point bending tests, as well as taking into account the results previously obtained when testing specimens of the same material for short-term strength. The specimen was “stepwise” loaded with specified loads and held at each load under steady-state creep conditions. During the tests, the temperature, load, time and deflection of the sample were recorded. The processing of the results was done proceeding from the power law of creep in tension [12], that is, the behavior of the material in tension was simulated from bending tests: \( \dot{\varepsilon} = \eta \dot{\varepsilon} (\sigma/\sigma_n) \), where \( \dot{\varepsilon} \) is the creep rate, \( \dot{\varepsilon} \) is the constant, and \( \sigma_n \) is one of which must be chosen arbitrarily. Let \( \eta = 10^{-4} \text{ h}^{-1} \). This means that stress \( \sigma_n \) causes 1% deformation in 100 hours. Following the scheme [(10, 12)] for solving the problem of rod bending under steady-state creep conditions, for our case we obtain an expression that relates the
value of the applied load \( P \) [MPa] and the deflection rate \( v \) [\( \mu \text{m/h} \)] at the center of the rod, i.e. at the place of load application:

\[
(1) \quad v = \frac{2P}{\pi L} \frac{L}{h} \left( \frac{2G}{\beta h} \right)^{n+1},
\]

where \( L \) is the base length, \( b \) and \( h \) are the width and height of the sample. Determining the rate of steady-state creep \( v \) at various loads from the experimental dependences using expression (1), the values of \( \sigma_0 \) and \( n \) were obtained for the tested samples.

In tests for creep (long-term strength), the sample was loaded with a given load according to the 3-point bending scheme and held there for a given time. The movement of punches was recorded depending on the time. First, there was a choice of clearances in the supports and equipment. When this process ended, the movement of the punch reflected only the deflection of the specimen (Fig. 6). The loads were 2, 5 and 6 kg. At 2 kg, the sample did not bend for more than 13 hours, which corresponded to the horizontal line of the time dependence of the bending.

The processing of the obtained creep data is as follows.

The exponent \( n \) in equation (1) for the deflection rate \( v \) was determined from the expression

\[
v = \frac{P}{\pi\sigma_0 h}, \quad \text{as} \quad n = \frac{\ln \left( \frac{P_2}{\sigma_0 h} \right)}{\ln \left( \frac{P_2}{P_1} \right)} \quad \text{or} \quad n = \frac{\ln \left( \frac{v_2}{v_1} \right)}{\ln \left( \frac{P_2}{P_1} \right)},
\]

where \( P_1 \) and \( P_2 \) are known loads 5 and 6 kg, respectively, in the 2nd and 3rd experiments of creep tests, and \( v_1 \) and \( v_2 \) are the deflection rates calculated similarly to the tangents of the steady-state creep lines in the 2nd and 3rd experiments, respectively. Indexes 5 and 6 at \( v \) and \( P \) repeat loads of 5 and 6 kg. Next, we obtain the values of \( \sigma_0 \) and \( n \) for the tested sample at 1100°C: \( \sigma_0 = 80.0 \text{ MPa} \) and \( n = 3.78 \). And, finally, we construct the dependence of the creep strain rate \( \dot{\varepsilon} \) on the stress \( \sigma \) (Fig. 7).

**Fig. 6.** Dependence of the deflection in bending on the test time at 1100°C and a load of 2, 5, and 6 kg for the Nb/(Si–C)2 composite

**Fig. 7.** The rate of creep deformation in tension \( \dot{\varepsilon} \) depending on the stress \( \sigma \) at \( v \) corresponding to 6 kg for the Nb/(Si–C)2 composite at 1100°C

Using the constructed dependence \( \dot{\varepsilon} = f(\sigma) \), we estimate the strength of the obtained composite loaded with a stress of 50 MPa. This stress corresponds to the creep strain rate \( \dot{\varepsilon} \), equal to 1.07·10^{-5} \text{ h}^{-1}. You can find out how much a rod of length \( l = 100 \text{ mm} \) will elongate, made of this material in 100 hours: \( \Delta l = \dot{\varepsilon} \cdot l \cdot \Delta t = 1.07 \times 10^{-5} \cdot 100 \text{ m} \cdot 100 \text{ h} \), or 0.11 mm. The elongation was 0.11 mm.

**Conclusions for the section.** Microstructure studies show in favor of the chosen method of obtaining heat-resistant composites from multicomponent alloys. Without resorting to melting technologies, layered composites of an alloy of niobium with Ti, Mo, Cr, Zr and Al, strengthened by the compounds of these metals with carbon and silicon, were obtained.

1. The results of stress tests at long exposures and high welding temperatures are aimed at obtaining completed multilayer or layered structures.

2. The values of fracture toughness \( K^* \) of composites are such that they occupy a position between ceramics and high-strength metal alloys, which is not satisfactory enough. It is possible to improve \( K^* \) (1) by increasing the proportion of viscous-plastic (Nb)-solid solution in the layered structure of the composite. But it seems more efficient (2) to preserve the viscous-plastic state of the layers inheriting metal alloys in the foil composite.

The point is that Nb foils and alloy foils become stronger as a result of the penetration of carbon, silicon and boron into them during diffusion welding of the packages. To prevent this from happening, it is possible to pre-arrange diffusion barriers against the penetration of C, Si, and B into the visco-plastic layers of the composite, which, possibly, can be thin layers of the same carbides, silicides, and borides.

### 2.2. Composite Nb/(Si–C)3.

The composite was prepared using a slightly different technique than composites Nb/(Si–C)1 and Nb/(Si–C)2. First, a 2-sided suspension coating of a powder mixture of niobium with Ti, Mo, ZrH2, Cr, and Al of a certain concentration was applied to the Nb-foils. Coated foils and sections of TRG (thermally expanded graphite) tapes were used to make up a multilayer package, which was heat treated under pressure at a temperature of 1500°C for 2–3 hours. After the package was disassembled (it was easily disassembled), a silicon coating was applied to its surface, and a package was made from such segments, from which, after diffusion welding under pressure, a layered composite in the form of a plate 3–4 mm thick was obtained.

During the second welding, the final sintering (1) of the powder mixture already with silicon and additional penetration of carbon into it, (2) additional alloy formation, (3) diffusion formation of metal carbide-silicides and, in fact, (4) the formation of a layered composite took place. The result of welding in the form of a microstructure of a cross-section at two magnifications and a cross-section of the composite in the fracture zone after a short-term bending test is shown in Fig. 8 and 9.

**Fig. 8.** Composite Nb/(Si–C)3. Macrostructure of a cross-section after diffusion welding at 1500°C and a pressure of 19 MPa for 3 h

**Fig. 9.** Microstructure of the Nb/(Si–C)3 composite after welding and its cross section at the fracture site during 3-point bending tests

The light layers are identified as Nb-solid solution in place of Nb-foils, between which there are reinforcing layers of metal carbide-silicides.

**Creep tests.** The composite was subjected to creep tests. The experiments consisted of holding the samples under load at a constant temperature. Temperature range – 1150, 1200, 1250 and 1300°C. The load values were significantly less than the load at which the sample was destroyed during short-term tests. In the experiments, the dependences of the sample deflection on time were obtained. To determine the creep characteristics, the dependence of the creep rate on stress and temperature was used: \( \dot{\varepsilon} = K \cdot \sigma_n \cdot e^{Q/RT} \) [equation (1)], where: \( \dot{\varepsilon} \) is the creep strain rate, \( K \) is a constant, \( \sigma \) is the stress, \( n \) is the rate sensitivity index strain to stress, \( Q \) is the activation energy.
activation energy, $\hat{k}$ is the Boltzmann constant, $T$ is the temperature. The starting points for calculating the parameters of Eq. (1) were the time dependences of the deflection value experimentally measured for each sample at the stage of steady-state creep at three applied stresses and two temperatures. From the data obtained, the deflection rate $\dot{\varepsilon}$ was determined.

The relative strain rate $\dot{\varepsilon}$ in the section of steady creep was calculated using the formula for the strain rate (in $s^{-1}$): $\dot{\varepsilon} = 4h/f^2$ (2), where $f$ is the deflection rate (mm/s), $h$ is the sample height (mm) and $l$ is the distance between the supports (mm). For further calculations, equation (2) was represented as:

$$\dot{\varepsilon} = \left(\frac{s_0}{\sigma_0}\right)^n \times (\alpha/s_0)^{\beta} \times e^{Q/kT}$$

where $s_0 = 1$ MPa, $\dot{\varepsilon}_0$ (s$^{-1}$) and $\sigma_0$ (MPa) are constants. At constant temperature, expression (3) was represented as: $\dot{\varepsilon} = N \times \left(\sigma/\sigma_0\right)^n$ (4), where $N = \dot{\varepsilon}_0 \times (s_0/\sigma_0)^{\beta} \times e^{Q/kT}$ [equation (5)].

The parameters $N$ and $n$ are determined from the graph $\dot{\varepsilon} = f(\sigma)$, presented in logarithmic coordinates, at each test temperature.

The constants $M = \dot{\varepsilon}_0 \times (s_0/\sigma_0)^{\beta}$ and $Q$ were determined from two equations (5) for two different temperatures (Fig. 10).

![Fig. 10. Dependences of the creep rate on stress for the Nb/(Si–C)3 composite at temperatures in the range 1150–1300°C. Horizontal line drawn at 100-hour strength](image)

**Fig. 11.** Dependences of the creep strain rate $\dot{\varepsilon}$ on stress for the composite Nb/(Si–C)3: 1 – 50 MPa, 1150°C; 2 – 52.55 MPa, 1150°C; 3 – 45.28 MPa, 1300°C

Evaluation of the creep strain rate of the composite at different temperatures shows that the 100-hour creep limit (horizontal line in the figure) of the Nb/(Si–C)3 composite decreases with an increase in the test temperature from 90 MPa at 1150°C to 25 MPa at 1300°C (Fig. 10).

The results obtained were compared with similar results for cast (Nb–Si)-alloys obtained by directional solidification. Such studies with the processing of experimental data using a similar technique were carried out in our laboratory. The comparison showed that the Nb/(Si–C)3 composite had a higher level of 100-hour strength than the (Nb–Si)-alloys with a directed structure at 1150°C: 90 and 60 MPa, respectively.

Creep tests, but with processing already according to the method known here, which we used for the Nb/(Si–C)2 composite [10–12]. The method simulates flexural testing according to the tensile behavior of a material. Using the constructed dependences for $\dot{\varepsilon} = f(\sigma)$, we now estimate the strength of a composite based on a multicomponent Nb-alloy loaded with a stress of 50 MPa (Fig. 11). This stress in these experiments at 1150°C corresponds to the creep strain rate $\dot{\varepsilon}$, equal to $0.98 \times 10^{-5}$ h$^{-1}$. Then a rod with a length of $l = 100 \text{ mm}$, made of such a material, will lengthen by $98 \text{ mm}$ in 100 hours: $\dot{\varepsilon} = (\Delta l)/\Delta T$, then $

\Delta l = \dot{\varepsilon} \Delta T = 0.98 \times 10^{-5} \text{ h}^{-1} \times 100 \times 100 \text{ mm} = 0.098 \text{ mm}$.

Note that, in contrast to Fig. 7, here the dependences $\dot{\varepsilon} = f(\sigma)$ are given in logarithmic scales along both axes.

### 2.3. Composite Nb/(Si–B)

The anisotropy of the layered structure in the composite caused anisotropy of the strength properties in bending tests if a load was applied perpendicularly and parallel to the plane of the layers. The dependence of strength on the test temperature for this composite is shown in Fig. 12. Anisotropy persists at temperatures of 1100–1300°C.

**Fig. 12. Dependence of $\sigma_{\text{rel}}(\bullet)$ and $\sigma_{\text{rel}}(\circ)$ composite Nb/(Si–B) with unpolished surfaces on the test temperature**

The lower strength at room temperature than at 1100°C in the composite was due to the roughness of the two surfaces of the test pieces after spark cutting. For the same composite with surfaces polished after spark cutting, the strengths in the perpendicular and parallel directions at room temperature were equal: $\sigma_{\text{B}} = (600 \pm 180)$ and $\sigma_{\text{B}} = (790 \pm 48)$ MPa. Anisotropy $\sigma_{\text{B}}/\sigma_{\text{B}} = 1.32$. In high-temperature tests, the quality of the sample surfaces did not affect the strength of the composite. The average strength level of the composite reinforced with silicon and boron compounds was ~450 MPa at 1100°C and ~350 MPa at 1300°C.

This work was financially supported by the Russian Foundation for Basic Research (project No. 20-03-00296).

### REFERENCES

Properties of composites with nanodiamonds of detonation synthesis

Doctor of Technical Sciences, Professor, Dean of the Special Engineering Faculty E. A. Petrov

Biysk Technological Institute of Altai State Technical University named after I.I. Polzunov

SC Federal Research and Production Center “Altai” Biysk city

E-mail: htemi@bti.secna.ru

Abstract: Modern metals, alloys and polymers, using in mechanical engineering, now have such high-temperature and strength properties that do not meet the advanced requirements. One of the methods to improve their physico-mechanical properties is the method of hardening by dispersed additives. Nanodiamond (ND) and diamond-carbon -containing material (NDC) of detonation synthesis, having nano-structure and high surface energy, impact structurally on any materials contacting with them. Detonation synthesis is a fundamentally new and productive type of basic technology for producing nanostructures and nanomaterials. ND of detonation synthesis is a unique material that combines the properties of diamonds and the advantages of nanostructures. Industrial development of the given method made it possible to actually reach large-volume production and consumption of ND in a number of industries. The effectiveness application of ND and NDC in industrial lubricants, polishing, composite galvano-chemical coatings, metal and polymer-based composites has been shown.

Keywords: NANODIAMOND, DIAMOND CARBON MATERIAL, POLYMER COMPOSITES, METAL-DIAMOND COATINGS, MICRO HARDNESS, WEAR AND TEAR, LUBRICANTS, POLISHING MATERIALS

1. Introduction

Artificial diamonds are considered to be strategic materials all over the world, as they play a vital role in the development of the industry. With the establishment of a new detonation method for the synthesis of diamonds, there appeared fundamentally new opportunities for the implementation of advanced technologies [1,2]. The synthesis is carried out by detonation of explosives in an explosion chamber, while nanocarbon (NDC) and nanodiamonds (ND) are formed in condensed detonation products with a high mass yield [3,4]. The diamonds are generated from explosives by chemical reactions under rather non-equilibrium conditions, whereupon their structure becomes defective and the particle size is small. The average size of the diamond microcrystallites is between 4 and 6 nm, and the specific surface area of the powders ranges between 300 and 400 m²/g [5].

Possessing nanoscale and high surface energy, diamonds have a structural and dispersion-strengthening effect being in contact with any materials. By morphology, microstructure, element composition, and reactivity, NDC and ND are close to each other. Therefore, as products of detonation synthesis, NDC powders themselves can be attractive both scientifically and practically.

NDC and ND is currently applied as anti-friction additives to motor, industrial oils and greases; in pastes and suspensions for super finishing material polishing; in wear-resistant electrochemical and chemical metal-diamond coatings; as dispersion-strengthening additives in composite materials based on polymers, metals, alloys and rubbers; as effective sorbents, catalyst carriers, biomarkers, transporter of medicinal substances and etc. [6].

In this work, the properties of composites with nanodiamonds of detonation synthesis are presented.

2. Industrial lubricants

Figure 1 shows the comparative results of research into the tribotechnical characteristics of oil at various loads (P) in the friction zone. Compared to pure oil, a NDC additive reduces the friction coefficient (f) and, consequently, the oil temperature (T) in the friction and pad wear (I) zone. In addition, the limit load increases by three times. Concentrated carbon properties such as the nano size and round shape of particles, adsorption, and sedimentary stability in oil suspensions fully manifest themselves here. Solid particles with an oil film on their surface to avoid dry friction are always present in the friction zone. Therefore, this effect reached in all lubricants: motor and technological oils; plastic and hard lubricant.

Fig. 1 Tribotechnical characteristics of industrial oil. Dotted lines for pure oil, solid lines for oil with an addition of 0.1% NDC.

3. Composite galvano-chemical coatings

Nanodiamond properties such as resistance to acidic media and sedimentary stability made it possible to improve the properties of composite coatings produced by chemical and electrochemical deposition of metal films. As ND are introduced into the process for various metals, the same picture is observable: the grain size decreases (fig. 2,3), the micro hard ness increases, and the wear resistance of coatings is improved (table 1).
Wear reduction cannot be explained only by ND inclusion, since the ND content in a coating, for example, electrochemical nickel, does not exceed 1.5% and in a chromic coating it does not exceed 0.05%. Thanks to their surplus surface energy, ND have a structuring effect on deposited metal films, reducing the grain size and disordering the chromium structure to the limit at maximum micro hardness values. The use of this effect in industrial technology has confirmed the efficiency of metal-diamond coatings at 200 factories Russian. This technology is used company by Armoloy, USA. The implementation of the process does not require the remodeling of electroplating equipment, since the electrolyte is modified by adding an ND aquatic suspension to the initial plating tank.

### Table 1. ND electrolyte additive effect on various metal sediment properties

<table>
<thead>
<tr>
<th>Sediment type</th>
<th>ND in electrolyte, g/l</th>
<th>Micro hardness, GPa</th>
<th>Wear resistance increase, times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium electrochemical</td>
<td>13.0±15.0</td>
<td>9.8±11.1</td>
<td>13.2±14.6</td>
</tr>
<tr>
<td>Nickel electrochemical</td>
<td>9.5±10.5</td>
<td>2.8±3.0</td>
<td>4.6±5.8</td>
</tr>
<tr>
<td>Copper electrochemical</td>
<td>5.0±10.0</td>
<td>2.0±2.1</td>
<td>3.2±3.3</td>
</tr>
<tr>
<td>Cobalt-phosphorous electro chemical</td>
<td>0.5±2.0</td>
<td>5.0±5.25</td>
<td>6.8±7.0</td>
</tr>
<tr>
<td>Copper chemical</td>
<td>2.0±6.0</td>
<td>1.9±2.1</td>
<td>6.4±6.6</td>
</tr>
<tr>
<td>Nickel chemical</td>
<td>4.5±5.5</td>
<td>4.2±4.4</td>
<td>6.1±6.3</td>
</tr>
</tbody>
</table>

4. Composite material for super-finish polishing

Polishing is a traditional sphere of diamond application. The best polishing abrasives have particle sizes no less than 0.1 μm. Thanks to its homogeneous granulomers size composition, ND as the finest abrasive has turned out to be indispensable for super finish polishing. Nanodiamond suspensions and pastes allow surface finishes of several angstroms (table 2, fig. 4), which is an order of magnitude higher than the best international results in this sphere.

### Table 2. Results of the polishing. Suspension ND (4%) in ethyleneglycoles.

<table>
<thead>
<tr>
<th>Material</th>
<th>Roughness (Ra), nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard alloy</td>
<td>1±5</td>
</tr>
<tr>
<td>Steel; Sapphire</td>
<td>5±6</td>
</tr>
<tr>
<td>Quartz; Silicon</td>
<td>0.5±1.5</td>
</tr>
<tr>
<td>Molten silicon oxide</td>
<td>0.5±1.0</td>
</tr>
<tr>
<td>NaCl; KBr crystal</td>
<td>2±3</td>
</tr>
</tbody>
</table>
Fig. 4. Roughness of silicon plate before polishing (a) and after (b). Multi-level NDC particle aggregation involves a specific polishing mechanism. The impact of the polishing system (ND-carrier) on the treated surface on the one hand is mitigated, and on the other is intensified by the generation of new diamond surfaces. NDC is effective where the main result of the polishing process is a surface frequency class, not performance.

5. Composites

Nanodiamonds with developed surfaces and high surface energy have dispersion strengthening and structuring effects on any material that contacts them. Dispersion strengthening can explain the proper ties of metals and polymers with NDC additives. Thus, the micro hardness of aluminum samples improves as the NDC content increases (table 3), approaching that of low-grade steels but still preserving the advantages of a light metal. The wear resistance of aluminum compacts increases by 1.3 times from 2% NDC, and from 10% to 1.8 times. Similar results were obtained when NDC was introduced into magneto-ugly amorphous alloys used in magnetic heads of digital magnetic recording systems.

The wear resistance of fluoroplastic (Teflon) approaches 1.2 times, and (very importantly), elasticity; other indicators remain unchanged.

Table 5. Wear resistance of Fluoroplastic with different additives

<table>
<thead>
<tr>
<th>Additive (5%)</th>
<th>Surface area (additive), m²/g</th>
<th>Surface wear area, mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDC</td>
<td>344</td>
<td>7.2</td>
</tr>
<tr>
<td>NDC</td>
<td>468</td>
<td>5.9</td>
</tr>
<tr>
<td>ND</td>
<td>282</td>
<td>10.6</td>
</tr>
<tr>
<td>SiO₂</td>
<td>400</td>
<td>19.0</td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>28</td>
<td>13.7</td>
</tr>
<tr>
<td>Co[Al₂O₃]</td>
<td>10</td>
<td>17.5</td>
</tr>
<tr>
<td>SiC</td>
<td>15</td>
<td>19.7</td>
</tr>
<tr>
<td>Graphite</td>
<td>10</td>
<td>28.2</td>
</tr>
<tr>
<td>MoS₂</td>
<td>0.2</td>
<td>28</td>
</tr>
</tbody>
</table>

Bench and performance tests show that industrial rubber parts last 1.3–2 times of their guideline life; tires last 1.3 times of their standard run.

6. Conclusion

NDC of detonation synthesis is a unique material that combines the properties of diamonds and the advantages of nanostructures. Possessing nanoscale and high surface energy, diamonds have a structural and dispersion-strengthening effect being in contact with any materials. The effectiveness application of ND and NDC in industrial lubricants, polishing, composite galvano-chemical coatings, metal and polymer-based composites has been shown. Currently, the detonation method allows to receive ND with grain size 60-90 nm [7]. Their use will increase the range of composites with new properties.

Acknowledgments

The study was carried out with the financial support of the Russian Federal Property Fund in the framework of a scientific project No. 18-29-19070 MK.

References


Model for high-pressure water atomization of metal melt using a vortex type jet

Ternovoy Yu. 1, Bagliuk G. 2, Panova V. 1
Institute of Engineering of the National University, Zaporizhzhia, Ukraine 1
Institute for problems of materials science, National Academy of Science of Ukraine, Kyiv, Ukraine 2
gbag@ukr.net

Abstract: In this paper the physical model for high pressure water atomization of metal melts using hydraulic nozzle of a vortex type was proposed. The developed model assumes, that due to high speed water flow with significant centrifugal component of its velocity vector the rarefaction is formed, which causes intensive air suction leading to the formation of rotating gas (vapor-air) layer of toroid-like shape, providing a gap between the water flow and the metal stream. Thus water stream is separated from the heated surface of metal stream and the formation of particles during crystallization of melt droplets occurs due to surface tension mainly in this vapor-air layer. The cooling of melt droplets in the gas-water leads to the formation of spherical powder particles. The proposed model correlates well with the known experimental data on the production of spherical powders using a vortex-type annular hydraulic nozzle.

Keywords: model, metal powder, water atomization, nozzle, melt, jet, swirling, crystallization, gas ejection, particles.

1. Introduction

One of the most common methods for producing of metal powders in large-scale production is water atomization of the melt [1]. The process of water atomization of liquid metal with using of a ring nozzle according to the standard scheme has been widely studied experimentally and theoretically [1-3]. When using this technology in a wide range of technological parameters of the process, the powder particles acquire an irregular shape, which partially limits their scope, in particular due to the relatively low yield.

As a result of a change in a number of basic parameters of the atomization process, namely, the angle of attack of the water flow causing it to “twist”, the authors [4] and later [5] proposed and experimentally substantiated a method for producing powders whose quality is fundamentally different from that characteristic for traditional water atomization schemes.

This method was the basis of technologies that received the name, respectively, “atomization of melts with high-pressure water in air-water whirlwing” or «ultra high pressure swirl water atomization».

In [6] we showed that the atomization of melts with high-pressure water in whirlwing conditions is a promising scheme for the production of metal powders with increased bulk density and fluidity up to the production of spherical powders. At the same time, if the theoretical foundations of processes are sufficiently deeply developed for traditional schemes for melts water and gas atomization, and atomization using centrifugal forces, then information on the particle formation mechanism for the scheme for atomization of melts with water “in whirlwing conditions” is practically absent in available literature sources.

Thereby, the aim of the present work was to analyze the known experimental data and develop a schematic model of the mechanism of formation of powder particles using a melt atomization scheme that ensures the formation of a rotation of the water flow in the nozzle area.

2. Research results and discussion

In [2] the model of the process of atomization the melt with high pressure water [2] was presented, which was tested for the manufacturing of high speed steels, ferroalloys, complex alloys, aluminum alloys powders. The model includes the following steps (fig. 1): transformation of the initial metal stream upon contact with the water stream into a conical film converging to the axis of the stream; development of longitudinal and transverse waves on the film surface; instability and decay of the end of the film into droplets. Drops of metal are intensively cooled in the spray zone in a water-vapor medium and crystallize quickly without reaching geometric equilibrium in the form of coral-shaped particles (fig. 2).

The formation of coral-like particles is caused by the action of dynamic water flow, as well as by the boiling of water droplets formed when water enters the melt, which confirms the structure of the surface layer of the crystalized plume section in the atomization unit (fig. 3).
Fig. 3. Macro (a) and microstructure (b) of the subsurface layer of crystallized section of melt jet flame for water atomization of P6M5 high speed steel

As it had been shown by the results of theoretical and experimental studies of the traditional process of water atomization, with an increase in water consumption, its flow rate and the temperature of the melt overheating, which contributes to a decrease in its viscosity, the likelihood of obtaining finer powders at a given thickness of the metal jet increases. However, it is not possible to affect the particle shape of the main powder fraction during atomization according to this mode.

Unlike the traditional water atomization process, the feature of “tornado” atomization technology in the is the atomization of liquid metal jet of a vortex-type annular hydraulic nozzle (fig. 4,a), which supplies a high-pressure water jet along its axis while rotating it around metal stream. This character of the jet flow is ensured by the set of the nozzle’s special design, which provides for a change in the direction of the axes of the nozlepieces in such way that the horizontal component of the water jet velocity vector in each nozzle is directed at an angle $\omega > 0$ relative to the radial direction (fig. 4,b).

The rotational movement of the water stream causes the formation of the centrifugal component of the velocity vector of its movement, which leads to the formation of rotating water stream in the form of a hyperboloid (fig. 4,c), into the cavity of which a metal stream is fed.

Moreover, while using traditional methods for producing powder by high-pressure water atomization of the melt, the powder particles have a predominantly coral-like shape (fig. 5,a), the use of a ring nozzle with rotating jet results in powder particles of a spherical or spheroidal shape (fig. 5,b).

The results of experimental studies of real processes of melts atomization using of hydraulic nozzle of a vortex type with application of high-speed filming made it possible to propose a physical model of atomization in the following mode.

When a water jet contacts a surface of melt jet heated by more than 550-600 °C, the so-called film boiling occurs, when water is separated from the heated surface by a continuous film - vapor shell. Moreover, in the area of the neck of the hyperboloid (fig. 5,c) and below, due to the presence of significant centrifugal component of the water flow velocity vector, the rarefaction is formed, which causes intensive air suction leading to the formation of rotating gas (vapor-air) layer, providing a gap between the water flow and the metal stream of order of thickness of about $10^{-3}$ m (fig. 6).

Fig. 4. Schematic cross-section of water jet for water atomization in air-water whirlwing (a) and schematic diagram of air-water stream (b, c) [7]

Fig. 5. SEM micrographs of Cu-10 % Sn alloy powders produced by high-pressure water atomization using traditional technology (a) and ring nozzle with rotating jet (b) [7]
Fig. 6. Flow separation scheme for atomization using a vortex type nozzle: $V_{\text{H2O}}$ - velocity of the water conical stream; $V_f$ - velocity of the ejected gas (air); $\delta_m$ - the gap between the water and the jet of melt; $V_\theta$ - circular rotation velocity of the air-water stream.

Under the influence of gas-dynamic vacuum generated in the region of the vapor-air layer, the initial cylindrical stream of liquid metal is deformed: a hollow liquid-metal cone is formed from it, thinned in its lower part to the film-like thickness. At the same time, oscillatory processes develop in a thinning melt film due to the instability of its motion as a result of small-order disturbances. Roughnesses and roughness of the nozzle surface, irregular hole geometry, pulsations in the liquid, etc. can serve as a source of the latter. Initial perturbations favor the formation of waves, which, in turn, increase, first contribute to the formation of a liquid toroidal thickening along the periphery of the film, and then to pinch the jet and separate it into separate strands - melt micro-jets flowing from the periphery of the film. The latter, in turn, under the influence of disturbing forces break up into droplets.

The spherical shape of the obtained powder particles in this case is explained by the fact that the formation of particles during crystallization of the melt drops occurs mainly due to surface tension in the vapor-air layer, when the rotating stream of water from the nozzle does not touch the metal stream but only the final solidification and cooling of the powder particles occurs in water.

Such a cooling regime significantly changes the thermophysical characteristics of the process compared to conventional methods of water atomization, since the vapor-air layer, due to the reduced heat transfer coefficient, removes heat much worse than water, which leads to a significant decrease in the crystallization rate.

In addition, due to the rotational component of the flow rate and the absence of direct contact of the melt jet with water, the particles collide less with each other and experience less deforming effect on their shape.

The speed of the gas column is determined by the flow rate of water $V_{\text{H2O}}$ (fig. 6) and significantly decreases with distance from the surface of their contact. Therefore, the thickness of the gas layer $\delta_p$ is of great importance, which is ensured by a combination of the geometric parameters of the nozzle for the diameter of the metal jet. To ensure effective atomization, it is necessary to achieve some optimal (minimum) value of $\delta_p$, at which the gas flow rate will correspond to the velocities characteristic of gas atomization. The angle of attack of the water flow, as well as the angle of its swirling, are in this case those parameters that determine the location and depth of the created vacuum, and therefore the magnitude of the ejection and the flow rate of the sucked gas.

The indirect confirmation of the adequacy of the proposed model is the appearance of the crystallized section of the torch of the melt jet, which remains after the completion of the atomization process using a vortex-type nozzle (fig. 7, a), which differs significantly from the similar portion of the torch obtained using a direct-flow nozzle (fig. 7, b).

Fig. 7. Crystallized section of melt jet flame for atomization using a vortex-type nozzle (a) and with using of a direct-flow nozzle (b).

The results presented on fig. 7 also correlate well with the model of water atomization in a vortex flow proposed in [7], which is conditionally displayed in fig. 8.

Fig. 8. Models of high-pressure water atomization using a direct-flow nozzle (a) and a vortex-type nozzle [7].

Thus, the proposed model allows us to conclude that atomization under the conditions of vortex motion of an energy carrier jet is essentially gas-like atomization with gas moving at a speed and in the direction determined by the flow of water, which also determines the temperature gradient of the gas layer.

However, the analysis of the microstructure of powder particles obtained using this technology indicates substantially cellular nature of the structure (fig. 8), which indicates high crystallization rates, significantly exceeding the crystallization rates during traditional (water free) gas atomization. The reason for the noted effect is the
presence in the gaseous layer of a significant amount of microscopic drops of water, which lead to quenching of the metal drops during their crystallization, which was shown earlier in [8].

**Fig. 8. The microstructure of ferromanganese powder produced by water atomization using a vortex type nozzle**

3. **Conclusions**

1. Using of hydraulic nozzle of a vortex type for high-pressure water atomization of the melt provides spherical shape of powder particles.

2. The physical model of atomization using hydraulic nozzle of a vortex type was proposed. In accordance with this model, water stream is separated from the heated surface of metal stream with a continuous film - vapor shell and the formation of particles during crystallization of melt droplets occurs due to surface tension mainly in this vapor-air layer.

**References**

Effects of various fire retardants on mechanical and fire properties of plywood

Nadir Ayrilmis
Department of Wood Mechanics and Technology, Forestry Faculty, Istanbul University, Bahcekoy, Sariyer, 34473, Istanbul, Turkey
nadiray@istanbul.edu.tr

Abstract: Effects of various fire retardant (FR) chemicals on mechanical and fire properties of plywood panels were investigated. Boron compounds such as, borax and boric acid; and phosphate compounds such as, monoammonium phosphate and diammonium phosphate were used as fire retardant chemicals in the plywood panels. An exterior liquid phenol formaldehyde resin with 47% solids content was used as adhesive. The 2.2 mm thick Tetraberlinia wood veneers were treated with the liquid solution of FR chemicals. The plywood having 5-layers were produced from the treated wood veneers. The mechanical properties of the plywood produced with treated veneers was found to be lower than that of the control group. Among the treated plywood panels, the plywood treated with borax had the shortest flame length after burner was turned off, followed by diammonium panels treated with boric acid (49.2 s), borax (44.5 s), and monoammonium phosphate (41.2 s), respectively. As compared to the control, the fire resistance of the plywood panels showed individually different effects related to improvement of fire resistance of the panels. For example, the OSB panels treated with diammonium phosphate were the latest ignited group (52.8 s) which were followed by the panels treated with boric acid (49.2 s), borax (44.5 s), and monoammonium phosphate (41.2 s), respectively. As compared to the control group (7.5 cm), the plywood treated with borax (3.6 cm) had the shortest flame length after burner was turned off, followed by diammonium phosphate (4.2 cm), boric acid (5.1 cm), and monoammonium phosphate (5.8 cm).

KEYWORDS: WOOD-BASED PANELS, FIRE-RETARDANTS, BORON COMPOUNDS, TECHNOLOGICAL PROPERTIES, PLYWOOD

1. Introduction

Plywood is a wood-based panel which is widely used in construction industry. Since plywood is commonly used in buildings, its fire resistance is very important to decrease fire risk and prevent to human death. It is well known that one can significantly improve the fire performance of wood-based composites by chemical treatment and thereby widen the options for their utilization. Three methods are commonly employed to provide wood-based products with improved fire-resistance and reaction-to-fire: chemical impregnation, incorporation of flame retardants into the adhesive, and flame-retardant coatings [1]. For chemical impregnation, the most widely used flame-retardant chemicals for treating wood-based products are inorganic salts that contain elemental phosphorus or boron. Boron compounds such as borax and boric acid are considered to be effective flame retardants that exert less impact on mechanical properties compared with some other flame retardant chemicals [2,3]. Phosphates such as mono- and diammonium phosphates, and ammonium polyphosphate are another group of fire retardants [4]. The phosphates are one of the oldest known fire-retardant systems. They are usually included in proprietary systems used for wood. For example, monoammonium phosphates (MAP) have been used in extinguishers for a long time in many places such as cars and homes, plants. Boron and phosphate compounds are widely used as FR chemicals in wood composite industry. In this study, the effect of loading level of boron and phosphate compounds on the mechanical and fire properties of plywood was investigated.

2. Materials and methods

2.1. Materials

2.1.1. Wood material

Commercial rotary veneers (2.2 mm thickness) of Tetraberlinia bifoliolata roundwood as raw material in the production of plywood production were supplied from a commercial plywood company, Kuris Plywood Company, in Istanbul, Turkey. The veneers without defect were sized to 490 mm x 490 mm by saw. The moisture content of the veneers was 7-8% based on the oven-dry weight of wood.

2.1.2. Resin

Phenol-formaldehyde (Polifen47) resin was supplied from Polisan The Chemical Company in Dilovasi, Turkey. The mixture of filler and extender was added into the PF resin, based on the oven-dry weight of PF resin. The dry mixture was prepared from 80 wt% calcium carbonate and 20 wt% the extender (10 wt% corn powder and 10 wt% corn starch powder).

Table 1: Technical specifications of phenol-formaldehyde (Polifen 47) resin

<table>
<thead>
<tr>
<th>Technical specifications of PF resin</th>
<th>Method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (20 °C, g/cm³)</td>
<td>TS 1724 ISO 675:1997/T1</td>
<td>1.195-1.205</td>
</tr>
<tr>
<td>Solids content (% weight)</td>
<td>TS EN 480-8</td>
<td>47±1</td>
</tr>
<tr>
<td>Viscosity (20 °C, cps)</td>
<td>TS 6126 ISO 2555:1998/T1</td>
<td>250-500</td>
</tr>
<tr>
<td>pH (20 °C)</td>
<td>TS EN ISO 10523</td>
<td>10.5-13 max. 1.0</td>
</tr>
<tr>
<td>Free formaldehyde (% weight)</td>
<td>TS EN 1243</td>
<td></td>
</tr>
</tbody>
</table>

2.1.3. Fire-retardant chemicals

Four powder chemicals were used in the treatments: borax, boric acid, monoammonium phosphates, and diammonium phosphate. The technical grades of the chemicals were supplied from local market in Istanbul, Turkey.

2.2. Treatment of wood veneers

Veneer samples were kept in a conditioning chamber until they reach 7% moisture content. In the next step, the specimens were soaked for 3 h in plexiglass boxes while laid horizontally 4 cm apart from each other in 3% or 6% aqueous solutions of borax (Na₂B₄O₇ 10H₂O) or boric acid (H₃BO₃), or in 3% or 11% aqueous solutions of monoammonium phosphate (NH₄H₂PO₄) or, diammonium phosphate ((NH₄)₂HPO₄). The temperature of the various solutions was 60 °C during the treatment process. Each treated veneer sample was then reconditioned to 7% moisture content before plywood panels were manufactured. Before and after treatment process samples were weighted to calculate chemical retention. A total of 20 five-ply plywood panels, 4 plywood for each treatment were manufactured from the veneer with the dimension of 490 mm x 490 mm x 2.20 mm.

2.3. The production of plywood panels

After preparing commercial wood veneers with dimensions of 490 mm x 490 mm x 2.2 mm, 5-layer, the plywood panels were produced under laboratory conditions. Each type of modified UF adhesive was uniformly spread on a single bonding surface of
veneers using a plastic brush at the rate of 200 g/m². After the glue application, individual sheets of the wood veneer were assembled with the same grain directions for all veneers. The plywood mats were hot pressed under 1.2 N/mm² of pressure at a temperature of 140 °C for 12 min in a laboratory type hot press. The densities of plywood panels ranged from 0.69 to 0.71 g/cm³. Plywoods were conditioned at 20 °C and 65% relative humidity until the constant weight before the physical and mechanical tests. The experimental design is given in Table 2.

### Table 2: Experimental design

<table>
<thead>
<tr>
<th>Plywood code</th>
<th>Concentration Fire retardant solution (wt%)</th>
<th>Retention of fire retardant</th>
<th>The number of panels produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Borax</td>
<td>6%</td>
<td>14.54</td>
<td>4</td>
</tr>
<tr>
<td>Boric acid</td>
<td>6%</td>
<td>19.37</td>
<td>4</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>3%</td>
<td>21.00</td>
<td>4</td>
</tr>
<tr>
<td>Monoammonium phosphate</td>
<td>3%</td>
<td>25.57</td>
<td>4</td>
</tr>
</tbody>
</table>

2.4. Test methods

The density, and the mechanical properties such as, bending strength, modulus of elasticity, internal bond, and bond quality of the specimens were carried out according to EN (European Norm) standards (Table 3). Fire properties such as flame height, and char area of the specimens were evaluated according to DIN (Deutsches Institut für Normung) standard (Fig. 1).

### Table 3: Test methods, the number of specimens and their size

<table>
<thead>
<tr>
<th>Test method</th>
<th>Standard no</th>
<th>Size (mm)</th>
<th>The number of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>TS EN 323</td>
<td>50 x 50</td>
<td>30</td>
</tr>
<tr>
<td>Thickness swelling</td>
<td>TS EN 317</td>
<td>50 x 50</td>
<td>30</td>
</tr>
<tr>
<td>Bending strength (//)</td>
<td>TS EN 310</td>
<td>250 x 50</td>
<td>18</td>
</tr>
<tr>
<td>Bending modulus (//)</td>
<td>TS EN 310</td>
<td>250 x 50</td>
<td>18</td>
</tr>
<tr>
<td>Bending strength (┴)</td>
<td>TS EN 310</td>
<td>250 x 50</td>
<td>18</td>
</tr>
<tr>
<td>Bending modulus (┴)</td>
<td>TS EN 310</td>
<td>250 x 50</td>
<td>18</td>
</tr>
<tr>
<td>Tensile-shear strength</td>
<td>TS EN 314</td>
<td>100 x 20</td>
<td>30</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>DIN 4102-1</td>
<td>90 x 190</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1. Mechanical properties

The bending strength values of the plywood specimens parallel and perpendicular to the panel surface are presented in Figure 2. The panels treated with borax had highest bending strength, followed by di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP), and, boric acid, respectively. A similar trend was determined for bending modulus (Fig. 4). All the treated panel groups showed lower performance related to mechanical properties when compared to control panels group (Fig 5). The bending strength values of the plywood specimens were compared with to EN 636 (2012) standard. The FR chemical retention values of the each plywood type was different from each other. The FR retention values of plywood specimens produced using the BX, BA, MAP or DAP treated wood veneers were found to be 14.54, 19.37, 21.00, 25.57 kg/m³, respectively. Borax treated specimens showed better mechanical performance than the boric acid treated specimens. Similarly, di-ammonium phosphate treated specimens showed better performance than the mono-ammonium phosphate treated specimens. The bending strength and bending modulus of the plywood specimens parallel to the fiber direction of the surface veneer were considerably higher than the bending strength perpendicular to the fiber direction of surface veneer.

![Fig. 1: Fire test according to DIN 4102-1 standard.](image1)

![Fig. 2: The plywood sample.](image2)
The tensile shear strength of the plywood specimens shows the bond performance between the wood veneers in the plywood (Fig. 4). The bond performance between the veneers of the plywood specimens showed a similar trend to the bending properties. Although all the plywood produced using modified veneers showed lower tensile shear strength than that of the control group, they complied with the EN 314-2 (2003) standard value (minimum 1 N/mm²). The boric acid and mono-ammonium phosphate showed considerably decreased the bond performance of the plywoods as compared to borax and di-ammonium phosphate treated plywood specimens.

3.2. Fire resistance

The ignition time and flame length of the plywood specimens are given in Figure 5. The FR chemicals improved the fire resistance of the plywoods. Their effects on the fire resistance of plywood was related to the type of FR chemical. The chemicals showed individually different effects related to improvement of fire resistance of the panels. For example, the OSB panels treated with diammonium phosphate were the latest ignited group (52.8 s) which were followed by the panels treated with boric acid (49.2 s), borax (44.5 s), and monoammonium phosphate (41.2 s), respectively. As compared to the control group (7.5 cm), the plywoods treated with borax (3.6 cm) had the shortest flame length after burner was turned off, followed by diammonium phosphate (4.2 cm), boric acid (5.1 cm), and monoammonium phosphate (5.8 cm).
Fig. 5: Ignition time and flame length of the plywood specimens (A: Ignition time, B: flame length)

The main reason for the later ignition time of the plywood containing diammonium phosphate can be explained by the fact that it more delays the release and amount of flammable gases from plywood as compared to the mono-ammonium phosphate. Furthermore, melting temperature of diammonium phosphate (155 °C) is lower than monoammonium phosphate which is more stable thermally lower than the melting temperature (190 °C) on the sample surface by starting an early reaction. Thus, diammonium phosphate causes carbonization early and the decrease the release of flammable gases from the plywood as compared to the monoammonium phosphate [8].

4. Conclusions

The FR chemicals showed an improvement in the fire resistance of the plywood specimens. However, the mechanical properties were slightly decreased after the treatment. As compared to the boric acid and monoammonium phosphate, borax and diammonium phosphate could be used to improve the fire resistance of the OSB panels because of their relatively little effects on the mechanical properties of the panels. The boric acid and monoammonium phosphate decreased the mechanical properties of the plywood specimens more than borax and diammonium phosphate. The hot water immersion method was used to impregnate the veneers by FR chemicals in this study. If the veneers are treated with FR chemicals using vacuum/pressure method, the fire resistance of the plywood specimens can be more improved.

5. Acknowledgement

This work was supported by the Research Fund of Istanbul University-Cerrahpasa. Project number: 35099

6. References


Fabrication, structure and use of nanocellulose as reinforcement in polymer composites

Nadir Ayrimis
Department of Wood Mechanics and Technology, Forestry Faculty, Istanbul University, Bahcekoy, Sariyer, 34473, Istanbul, Turkey
nadiray@istanbul.edu.tr

Abstract: Nanocellulose is defined as term refers to the cellulosic materials with defined nano-scale structural dimensions. Nanocellulose can be mainly categorized into three main types; nanocrystalline cellulose (NCC), nanofibrillated cellulose (NFC), and bacterial nanocellulose (BNC). The special attention is the size of nanocellulose fiber which generally contains less than 100 nm in diameter and several micrometers in length. The NCCs have very attractive fundamental properties such as high strength and stiffness, low density, biodegradability, transparency, and extremely low thermal expansion property. They have extremely strong mechanical properties, e.g., a Young’s modulus of 130-140 GPa. As a result of the recent developments in the nanotechnology in the last decade, nanocellulose has garnered much attention for its use in biocomposites, biofilms, medicine, coatings, thermoplastic and thermosetting resins. The production cost of nanocellulose is gradually decreasing due to increasing utilization by many industries all over the world. In this study, structure of use of nanocellulose and its use in polymer composites was reviewed.

KEYWORDS: NANOCELLULOSE, POLYMER COMPOSITES, REINFORCING FILLER, NATURAL FIBERS

1. Introduction

The preparation of polymer nanocomposites using nanocelluloses has been found to be of growing interest due to the unique characteristics of those nanomaterials, such as numerous surface –OH groups and their associated ease of surface modification, high strength, (potentially) low cost, and renewability. However, those nanomaterials also suffer from certain disadvantages, including high moisture adsorption and poor compatibility with the hydrophobic polymer matrix [1].

Nanocelluloses are natural materials with at least one dimension in the nano-scale. Cellulose nanofibers (CNFs) (Fig. 1). The CNFs can be produced from any kind of plant cell walls by simple mechanical methods or a combination of both chemical and mechanical methods. The word “nanocellulose” generally refers to cellulosic materials with one dimension in the nanometer range. They exist in nature as nano-structured materials, so called cellulose nanofibers (CNFs) [2]. The significance of forest biomaterials has been sharply increasing due to their abundance and substitutability and as a potential alternative to petroleum resource. Thus, high-quality utilization of forest biomaterial and their developments have intensively been requested for the next generation to ensure our future environmentally-friendly biomaterials.

Research field of forest biomaterials has been dealing with many aspects of the utilization, significance, understanding and promotion of forest resources and industries [1]. Recently, researchers in the world have focused on these inherent strength and performance of CNFs and on the applications for a new class material (Fig 2). With advances in the ability to prepare and characterize CNFs, CNFs has been using for a wide variety of applications including polymers, textiles, cosmetics, food products, and nanocomposite materials as well as medical applications. Among those applications, light-weight and high-performance CNF-reinforced nanocomposites have attracted great attention. Light-weight, high-performance CNF-reinforced nanocomposites are expected to become the next generation of green materials, since they have the potential to replace conventional petroleum-based materials in a wide range of applications. CNFs provide benefits such as improved strength and stiffness with little sacrifice of toughness, reduced gas/water vapor permeability, a low coefficient of thermal expansion, and a large heat-deflection temperature [5]. The reinforcing effects of CNF on the properties of nanocomposite have been intensively studied [6,7].

![Figure 1. Types of nanocellulose [3].](image1)

Bio-nanocomposites are a new concept of combined and applied materials, which are produced using reinforcement particles with at least one dimension at the nanoscale. Cellulose microfibril is the major constituent of plant cell walls and has a width about 10-30nm in diameter with crystalline domain and amorphous region [4]. In wood cell walls, the cellulose microfibril was surround by hemicellulose and lignin

![Figure 2. Dimensions of nanocellulose](image2)

Preparation and properties of cellulose nanofibers

Generally, there are two representative CNFs, nanocrystalline cellulose (NCC) and microfibrillated cellulose (MFC). NCC is generally prepared by acid hydrolysis under strict conditions and has high crystallinity and low aspect ratio. The product, microfibrillated cellulose (MFC), exhibits gel-like characteristics. NCC suspensions have liquid-crystalline properties. In contrast to MFC and NCC, which are prepared from already biosynthesized cellulose sources, a third nanocellulose variant, bacterial nanocellulose (BNC), is prepared from low-molecular-weight resources, such as sugars, by using acetic acid bacteria of the...
genus *lacconacetobacter* [1]. The usage areas and SEM images of CNCs, CNFs, and BC are presented in Figure 3 [9].

![Diagram](image)

**Figure 3.** Some usage areas (A) and representative SEM images (B) of the three types of nanocellulose: CNCs, CNFs and BC [9].

**Cellulose nanocrystal preparation by acid hydrolysis (chemical treatments)**

The amorphous regions around the cellulose microfibrils could be destroyed by acid hydrolysis under controlled conditions, keeping the crystallites intact [5]. The acid hydrolysis is selective in cellulose fibrils, resulting in colloid suspensions of cellulose nanocrystals. The presence of sulfate groups resulting from the acid hydrolysis treatment when using sulfuric acid to prepare cellulose whiskers (CNW) Nanocrystalline cellulose (NCC) induces the stability of the ensuing aqueous suspension. Using HCl for hydrolysis increases the thermal stability of cellulose nanostructures, but chloride ions are easily removed by repeated washings with water. Whiskers of cellulose are primarily obtained by acid hydrolysis, with strong acids such as sulphuric and hydrochloric, which leads to nanocrystals of cellulose fibrils with diameters in the range between 5 - to 10-nm range and lengths on the order of 100 to 200 nm, depending on the source. In contrast, nanofibrils, which tend to have roughly 5-nm diameters, as spaghetti-like because they are longer (a micrometer or more), flexible, and easily entangled [10]. Nanocellulose-based materials have high strength and low weight. The highest grades have attributes that offer great reinforcing strength and/or optical clarity, while lower grades can offer increased strength and improved properties at lower costs [11].

**Bacterial nanocellulose**

As opposed to the existing methods for achieving nanocellulose by way of mechanical or chemo-mechanical processes, Bacterial cellulose (BC) is made by bacteria through biosynthesis of cellulose and fabricates bunches of microfibril. These bunches of microfibril have remarkable crystallinity (up to 84–89%), and an appropriate elastic modulus. Although bacterial cellulose is produced in nature, it can be produced from cultures in laboratories as a large-scale process. By controlling culturing conditions, the resulting cellulose can be tailored to have specific desirable properties. (BC) is more preferred over plant cellulose for edible applications; which is available in relatively pure form and no chemical process are required for the isolation of BC. In this regard, the bacterial nanocellulose produced by genus *Gluconacetobacter* (*Gluconacetobacter xylinus*) is recognized for its preferable properties. Superior mechanical and thermal properties, high crystallinity and water holding capacity are the reasons of specialty of bacterial nanocellulose [12]. The cellulose crystal is one of the strongest and stiffest organic molecules, with a modulus of 145 GPa and a strength estimated at 7500 MPa. The extension to break of a NCC is estimated to be only 2%. NCCs have high surface areas (~250 m2/g), are hydrophilic, and are quite amenable to surface derivatization [6].

Nanocellulose is regarded as a good alternative to improve the qualitative properties of biopolymers due to positive characteristics such as biodegradability, renewable, abundance and inexpensive cost, low density, strength and high durability as well as the possibility to derive from agricultural wastes and food industries. Global nanocellulose market was valued US$ 160.98 Mn in 2017 and is estimated to reach US$ 687.97 Mn by 2026 at a CAGR of 17.51% [20]. Based on their dimensions, functions, and preparation methods, which in turn depend mainly on the cellulosic source and on the processing conditions, nanocelluloses may be classified in three main subcategories (Table 1) [9].

**Table 1. The family of nanocellulose materials [9].**

<table>
<thead>
<tr>
<th>Type of nanocellulose</th>
<th>Selected reference and synonyms</th>
<th>Typical sources</th>
<th>Formation and average size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microfibrillated cellulose (MFC)</td>
<td>Microfibrillated cellulose, nanofibrils and microfibrils, nanofibrillated cellulose</td>
<td>Wood, sugar beet, potato tuber, hemp, flax</td>
<td>Delamination of wood pulp by mechanical pressure before and/or after chemical or enzymatic treatment diameter: 5–60</td>
</tr>
</tbody>
</table>
The NCCs have very attractive fundamental properties such as high strength and stiffness, low density, biodegradability, and extremely low thermal expansion property. They have extremely strong mechanical properties, e.g., a Young’s modulus of 130-140 GPa [1] (Table 2).

Table 2. The comparison of tensile properties of cost of nanocrystalline cellulose (NCC) and other synthetic fibres [14].

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>Tensile strength (MPa)</th>
<th>Tensile modulus (GPa)</th>
<th>Cost ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi Strength steel</td>
<td>7.9</td>
<td>600</td>
<td>210</td>
<td>1</td>
</tr>
<tr>
<td>Aluminum 6061-TL</td>
<td>2.7</td>
<td>275</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>E-glass</td>
<td>2.5</td>
<td>3500</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>Carbon fiber</td>
<td>1.8</td>
<td>4000</td>
<td>230</td>
<td>20</td>
</tr>
<tr>
<td>Nanocrystalline cellulose</td>
<td>1.5</td>
<td>7500</td>
<td>135</td>
<td>4-10</td>
</tr>
</tbody>
</table>

Industrial applications of cellulose nanofibers

Recently, researchers in the world have focused on these inherent strength and performance of CNFs and on the applications for a new class material. With advances in the ability to prepare and characterize CNFs, CNFs has been using for a wide variety of applications including textiles, cosmetics, food products, and nanocomposite materials as well as medical applications. Among those applications, light-weight and high-performance CNF-reinforced nanocomposites have attracted great attention. As a nanoscale filler, CNFs provide benefits such as improved strength and stiffness with little sacrifice of toughness, reduced gas/water vapor permeability, a low coefficient of thermal expansion, and a large heat-deflection temperature [1]. Sehaqui et al. [16] developed rapid preparation procedure for large, flat, smooth, and optically transparent cellulose nanopapers using a semiautomatic sheet former. The gel “cake” is peeled from the membrane and stacked first between two woven metal cloths and then two paper carrier boards [17]. The application of the nanopaper-making strategy to cellulose/inorganic hybrids demonstrates the potential for “green” processing of new types of nanostructured functional materials [1]. Chun et al. [18] developed eco-friendly cellulose nanofiber paper-derived separator membranes (CNP separators) for use in lithium-ion batteries (Fig. 6). The CNP separator has been substantially improved the ionic conductivity, electrolyte wettability, and thermal shrinkage. With its transparency, strength and optic properties, nanocellulose is being researched by Pioneer Electronics as a replacement for glass for flexible screens [9].

Advantages of nanocellulose
- Abundantly available
- Low weight
- Biodegradable
- Non-toxic and optical transparency
- Cheaper
- Renewable
- Unique mechanical properties
- Good thermal stability
- High specific surface area
- Modest abrasivity during processing
- Highly absorbent when used as a basis for aerogels or foams.
- Very high tensile strength – 8-10 times that of steel
- Stiffer than Kevlar®
- Electrically conductive

Drawbacks of nanocellulose
- Substantial hydrophilicity
- Poor compatibility

Additives for foods, cosmetics th advances in the ability to prepare and characterize CNFs, it has been using for a wide variety of applications including textiles, cosmetics, food products, and nanocomposite materials as well as medical applications. Among those applications, light-weight and high-performance CNF-reinforced nanocomposites have attracted great attention. As a nanoscale filler, CNFs provide benefits such as improved strength and stiffness with little sacrifice of toughness, reduced gas/water vapor permeability, a low coefficient of thermal expansion, and a large heat-deflection temperature [1]. Sehaqui et al. [16] developed rapid preparation procedure for large, flat, smooth, and optically transparent cellulose nanopapers using a semiautomatic sheet former. The gel “cake” is peeled from the membrane and stacked first between two woven metal cloths and then two paper carrier boards [17]. The application of the nanopaper-making strategy to cellulose/inorganic hybrids demonstrates the potential for “green” processing of new types of nanostructured functional materials [1]. Chun et al. [18] developed eco-friendly cellulose nanofiber paper-derived separator membranes (CNP separators) for use in lithium-ion batteries (Fig. 6). The CNP separator has been substantially improved the ionic conductivity, electrolyte wettability, and thermal shrinkage. With its transparency, strength and optic properties, nanocellulose is being researched by Pioneer Electronics as a replacement for glass for flexible screens [9].

Plant-derived nanocellulose is an eco-friendly new material.
Nanocellulose offers an alternative to even stronger applications, while dramatically increasing strength. When properly aligned, nanocellulose can be perfect building material for the future body armor studies [20].

Resin is one of the important factors affecting mechanical and physical properties of wood-based composites. Urea-formaldehyde (UF) resin is commonly used in the manufacture of plywood, laminated veneer lumber, particleboard, and fiberboard etc. The advantages of UF resins are low cost, water solubility, easy use (under a wide variety of curing conditions), relatively low cure temperature, microorganisms resistance, low abrasion hardness, excellent thermal properties, and clear or light color (especially of the cured resin) [21]. Due to these advantages, wood-based composite industry utilizes UF as a common resin, worldwide. However, the mechanical performance of resin bonds between the UF and wood is limited, in particular humid conditions. Since the elastic modulus of cured UF bond lines is high, the deformation of the resin layer under mechanical loading is usually small. As a result, stress concentrations along the bond line of a wood resin joint are generated that reduce the overall strength of the joint [22]. UF-resins are a widely used class of low-priced wood resins, which are well known for their pronounced brittleness and their tendency to develop microcracks which limits their mechanical performance. The combination of low price and poor mechanical performance makes UF an ideal candidate for studying the effect of added filler [22].

Ayrilmis et al. [21] reported that the tensile shear strength of the specimens slightly increased with the incorporation of (MFC 0-1 wt%) while it considerably increased as the amount of MFC increased from 1 to 3 wt%. As compared to the control specimens, the tensile shear strength of the specimens increased by 5.7% as 3 wt% MFC (5% suspension in water) was incorporated into the UF-adhesive. However, the further increment (5 wt%) in the MFC content decreased the tensile shear of the specimens (-14.3% of control specimen). The specific surface area of the MFC was 86 m$^2$/g. It was estimated that the high specific surface area of 5 wt% MFC was one of the main reasons decreasing the bond performance of the UF adhesive. The improvement in the bonding performance of the UF-resin indicates that the addition of a certain amount of MFC in the UF-resin improves the mechanical performance of wood resin bonds, thus opening up new fields of application for UF, which is currently used only in the non-structural field.

Ayrilmis et al. [23] aimed to understand the effect of relationship between the molar ratio of UF adhesive and MFC on mechanical properties of laminated veneer lumber (LVL) and adhesive characteristics of UF adhesive. LVLs were produced using different molar ratio UF adhesives having different amounts of microfibrillated celluloses (MFCs). Adhesive characteristics, gel time, viscosity, and acidity of the E0 and E1 class UF adhesives with the MFCs were determined. The bending properties and tensile shear strength of the LVLs were investigated. At the same content of the MFCs, the bonding performance of the E0 class UF adhesive improved more than that of the E1 class UF adhesive. The higher bond strength for the UF adhesive containing the MFCs could be explained by the possible reaction between the methylol groups of the UF adhesive and the hydroxyl groups of the cellulose. Substantial increases in the gel time sand viscosities of the UF adhesives were observed as the amount of MFCs increased in the adhesive. The gel time of the UF adhesives increased with increasing amount of the MFCs.

Due to the large quantity of materials used in buildings, and their constant exposure to indoor air, there is a growing concern regarding the effects of these indoor pollutants on the health and comfort of the building occupants. Building materials can release wide range of pollutants. One of the hazardous pollutants of the indoor air are volatile organic compounds (VOCs) emitted from wood-based panels, which can cause indoor air related health problems. Ayrilmis et al. [24] investigated the formaldehyde emission and TVOC emitted from the laminated veneer lumber (LVL) produced with the different grade UF resins (super E0, E0, and E1 grades) modified with different amounts of the MFC using a thermal extractor. The formaldehyde emission from the LVLs produced with the SE0 grade UF resin considerably decreased with increasing MFC content at 25 °C while this was not observed for the E0 and E1 grade resins. The results revealed that the MFC did not work for decreasing of formaldehyde emission of the LVLs produced with the E0 and E1 resins at 35 °C and 45 °C. However, the VOCs emitted from the LVLs considerably decreased with the incorporation of the MFC at environmental temperatures of 25 °C and 35 °C, except for 45 °C. The MFC was not effective to reduce the VOCs from the LVLs at higher temperatures. The xylene was the highest detected compound in all samples, followed by ethylbenzene and toluene. Styrene, however, was not detected at all in any of the LVLs. The use of MFC in the UF resin can be environmentally friendly solution for reducing the VOCs from the wood-based panel used for indoor furniture.

CONCLUSIONS

Nanocellulose have been widely used in polymer composites for a long time due to its unique properties. It is commercially produced in many countries due to its excellent properties. Polymer composite industry is the most pronounced
sector which use the nanocellulose as reinforcing filler because it is based on abundant resources, economic, renewable, and commercially processable. Nanocellulose is a material of the future with potential for replacing synthetic materials which cause environmental pollution. Many countries have focused on the nanocellulose researches to produce strategic materials in near future. The research and development on the BNC, CNF, and CNC has rapidly increased in recent years. In particular, it is estimated that the potential use of CNC will increase in the production of high performance materials in near future.

REFERENCES


Synthesis of energy-efficient control methods of the electromechanical disintegrator operating modes

Vasyl Shynkarenko, Viktoriia Kotliarova
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
E-mail: svf1102@gmail.com, sharik_2004@ukr.net

Abstract: The present trend in the development of highly efficient technological equipment for the production of nanomaterials is being analysed. It is associated with the synthesis of energy-efficient control methods for the operating modes of electromechanical disintegrator of multifactorial action. As a result of genetic modelling, the deterministic relationship between the genetic information of generative electromechanical chromosomes, structure of the resulting magnetic flux in the active zone of electromechanical disintegrator and its functional operating modes has been established. According to the results of structural synthesis, methods for technical implementation of energy-efficient modes of material processing, which ensure the increase of productivity of the electromechanical disintegrator, have been optimized and developed. The credibility of theoretical results was confirmed by experimental studies.

Keywords: GENETIC MODELING, STRUCTURAL SYNTHESIS, CONTROL METHODS, OPERATING MODES, ELECTROMECHANICAL DISINTEGRATOR, ACTIVE ZONE, DISCRETE FERROMAGNETIC PARTICLES, NANOMATERIALS, ENERGY-EFFICIENCY, PRODUCTIVITY.

1. Introduction

The creation of highly efficient technological equipment for the production of powder materials and homogeneous mixtures of the nanoscale range is one of the priority areas of modern science and technology. The importance of such research is determined by the widespread use of nanopowder materials and technologies in such important fields as electronics, pharmaceuticals, chemical industry, materials science, and others. This indicates the relevance and novelty of research in this area.

It is known that the energy efficiency of ultra-fine grinding processes and the quality of finished products is determined by the type of process equipment. The vast majority of existing equipment is based on the use of the mechanical principle of action (hammer grinders, spherical mills, and disintegrators). The peculiarity of such equipment is their high energy consumption and low energy efficiency. Therefore, the problem of creating new types of energy-efficient equipment for the implementation of nanotechnology remains open. According to experts, one of the promising areas for improving energy efficiency, intensification of processes in ultra-fine grinding technologies is the creation and use of electromechanical mills [1] and electromechanical disintegrators (EMDs) of multifactor action [2].

EMDs belong to a new class of highly efficient technological equipment, in which technological processes of materials processing are carried out by converting electromagnetic energy of inverse magnetic fields into energy of mechanical motion of discrete ferromagnetic particles (DFPs), which is carried out directly in the active zone of the disintegrator. EMDs find practical application in the implementation of a wide range of technologies: fine and ultrafine grinding of materials; production of nanopowders; homogeneous mixing and preparation of composite mixtures; production of multicomponent fuel mixtures; dispersion of liquid-phase and heterogeneous systems; acceleration of chemical processes, wastewater treatment, intensification of microbiological processes, wastewater treatment, etc. [3, 4]. According to the results of multifactorial action on the processing substance in the technologies of ultrafine grinding (especially in the nanometre range), the physical properties of materials can change significantly and acquire qualitatively new, sometimes unique properties.

According to the results of the analysis of industrial operation and the results of experimental studies on the prototypes of EMDs, a number of specific phenomena and effects that accompany the operating modes of EMDs have been detected [5]. Since the trajectory of the working bodies is determined by 6 degrees of freedom, during the operation of EMDs there appears a problem of controlling the uniformity of distribution and intensity of DFPs, which is directly related to the efficiency of processing, ingredient processing, energy-efficient processing modes and quality of the output product. The lack of flexible control of processing modes does not allow to carry out technological processing of materials at the optimal level. The complex functional relationship between geometric and electromagnetic parameters, the complexity of the collective motion of the DFPs and the turbulence of the treated medium in the active volume are virtually unanalyisable and significantly complicate the mathematical modelling of physical processes in EMDs. The presence of this set of significant differences requires the development of new systems approaches to the analysis of physical processes and the synthesis of EMD structures with specified operational properties.

The analysis of data of industrial operation and results of experimental researches of EMDs allow to allocate the following directions of increase of their efficiency [6, 7]:
- optimization of EMD operation modes;
- compensation of negative influence of final electromagnetic effects;
- optimization of spatial geometry and electromagnetic parameters of DFPs;
- optimization of geometric relations;
- synthesis of competitive technical solutions of EMDs;
- optimization of input parameters of supply voltage.

In the following paper, based on the generalization of the results of industrial operation, experimental data and analysis of physical processes and phenomena accompanying the operating modes of EMDs, the purpose is to synthesize structural energy-efficient ways to control the operation modes of EMDs and propose ways to implement them.

2. Features of electromagnetic processes

The specific nature of the structure and features of electromagnetic processes that ensure the operation of double winding EMDs [8, 9], cause significant differences in their operating modes from disintegrators and mills of mechanical and electromagnetic types. These differences are caused by:
- the presence of a two-way system of inductors with counter-orientation of travelling or rotating magnetic fields on active surfaces, phase shifted by an angle $\gamma = \pi/3$;
- a relatively large value of the non-magnetic (inter-inductor) gap $\Sigma$, which houses the working chamber (WCH) with DFPs and process environment;
- the limiting ratio of the value of the non-magnetic gap to the length of the pole division $(\Sigma/2r \approx 0.6 - 0.7)$.
- discrete structure of ferromagnetic working bodies, the characteristic geometry of which is much smaller than the length of the pole division ($l/d < r$);
- complex spatial motion (6 degrees of freedom) of the DFPs, the idealized motion of which consists of the rotational motion of the elementary DFP relative to its centre of mass ($n_p = 3000$ rpm, provided $f = 50$ Hz) and the rotational motion of the particle on a circular trajectory ($n_t = 3000$ rpm), within the corresponding pole division $\tau$;
- multifactorial complex action of a number of physical factors on the processed technological environment (Fig. 1), which includes intensive mechanical grinding and mixing, the action of high-gradient alternating magnetic field and high-potential electrostatic charge field, the influence of surface acoustic waves, local thermal overheating as well as the influence of accompanying processes of electrolysis and cavitation (subject to the presence of liquid ingredients);
- a wide variety of genetically acceptable Species of the functional class of EMDs, the quantitative composition of which significantly exceeds the species diversity of electric machines [10].

The working process of machining is characterized by high-frequency collisions of DFPs with each other, with particles of the substance and the walls of the working chamber, which causes a sharp change in the trajectory of their movement, the emergence of alternating accelerations and accompanied by processes of dispersion, mechanical activation, intensive mixing and others (Fig. 1).

![Fig. 1: Main physical factors and processes that determine the technology of ingredient processing in the active volume of electromechanical disintegrator.](image)

The presence of the mentioned set of factors (Fig. 1) determines the complex effect on the processed environment, which intensifies the technological process, provides a change of physical properties of the processed substances and significantly expands the range of applied technologies.

3. The genetic model of the structure formation of the resulting magnetic field

The integral function of synthesis $F_3$ must take into account the following set of partial requirements:

1) The presence of a dual-inductor system with equivalent geometry and mass of active parts ($2M_{A1}$);
2) Electromagnetic method of excitation of inductors active surfaces ($\phi_{E1}$);
3) Dual-inductor version of the magnetic system with independent power supply of $m$-phase distributed windings ($2N_1$);
4) Electromagnetic inversion of the inductors $V_1 = (-V_2)$ travelling magnetic fields;
5) The presence of nonmagnetic WCH with the discrete ferromagnetic working bodies ($n N_2$);
6) A number of pole divisions of the windings in the $OX$ coordinate ($N_t \geq 2$).

The search space for $R^e$ synthesis is limited by the electromagnetic chromosomes of 2.2y subgroup of the first major period in the periodic structure of genetic classification [11]. Chromosome-isotopes [12] and their hybrid compositions are not taken into account. Given these partial requirements and constraints, the vector of the integral search function in the multidimensional feature space $R^e$ takes the form:

$$F_3 = [2M_{A1}; \phi_{E1}; 2N_1; V_1 = (-V_2); n N_2; N_t \geq 2].$$

The structure of an ideal homologous series [13] of subgroup 2.2y contains six base-level electromagnetic chromosomes

$$H_{02y} = (C_{CT}; C_{KN}; C_{PL}; C_{TP}; C_{SF}; C_{TC}).$$

The synthesis of the genetic model can be performed on the basis of the parental chromosome $C_{PT}$ with the genetic code of the PL 2.2y, which determines the boundaries of the structure of the dominant Species of double-winding EMDs [6, 7]. The given search function (1) corresponds to a multilevel genetic model (Fig. 2). The synthesis of the model is carried out using genetic synthesis operators (replication, intra-Species hybridisation, spatial and electromagnetic inversion and mutation). The sequence of application of genetic operators is determined in accordance with the logic of genetic modelling “from simple to complex”, by gradually complicating the parent chromosome [14].

![Fig. 2: Genetic model of synthesis of the resulting magnetic field structures in the EMD active zone: (PL 2.2y)$_1$ – parent chromosome; (CL 2.2x)$_2$ – secondary chromosome; WCH – working chamber; $S_{17}$–$S_{31}$ –information chromosomes; $S_{32}$–$S_{37}$ –generative chromosomes; $P_{10}$–$P_{15}$ –populations of technical solutions that satisfy the functions of synthesis; 1–4 – levels of genetic organization of structures.](image)

The synthesized model reproduces the multilevel process of complication of the parental chromosome in accordance with the logic of genetic synthesis for a given function $F_3$ and taking into account the given constraints. The structure of the model (Fig. 2) contains four levels of genetic complexity:
The modelling results show that there is a deterministic relationship between the structure of generative electromagnetic chromosomes ($S_{124}$-$S_{247}$), the structure of the resulting magnetic field and the modes of operation of the EMDs (Table 1), which gives the opportunity of pre-selection and technical implementation of control methods for material processing through appropriate adaptation of the structure of the magnetic system and changes in the relative orientation and velocity of DFPs.

Analysis of the results of decoding the microgenetic program (Table 1) shows that each generative chromosome corresponds to a specific structure of the resulting magnetic field and mode of operation:

- mode No. 1 with inverse travelling fields $V_1 = (-V_2)$ and the coordinated orientation of the DFPs vortex zones fixed by the $OY$ coordinate ($S_{214}$ chromosome):  
  \[ S_{214} = [2\{(PL.2.2\cdot y)\}_1 \cdot R_{OZ}I_{OZ}(R_{3})_1 \times n(CL.2.2\cdot x)_2; M; R_1] \times (WCH); \]  
- mode No. 2 with the coordinated orientation of the travelling fields $V_2 = V_2(S_{215})$ chromosome:  
  \[ S_{215} = [2\{(PL.2.2\cdot y)\}_1 \cdot R_{OZ}I_{OZ}(R_{3})_1 \times n(CL.2.2\cdot x)_2; M; R_1] \times (WCH); \]

### Table 1: The results of decoding the genetic program of structure formation of the resulting magnetic field in the nonmagnetic gap of EMDs.

<table>
<thead>
<tr>
<th>Chromosome number</th>
<th>Structural formula of a chromosome</th>
<th>Chromosome status</th>
<th>Structure of the resulting field</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1. Parental chromosome</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PL 2.2y</td>
<td>(PL 2.2y)$_1$</td>
<td>Parental (primary)</td>
<td>–</td>
</tr>
<tr>
<td>CL 2.2y</td>
<td>(CL 2.2x)$_2$</td>
<td>Secondary</td>
<td>–</td>
</tr>
<tr>
<td><strong>Level 2. Genome structure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{10}$</td>
<td>2(PL.2.2y)$_1\cdot R$</td>
<td>Replicated ($K_R = 2$), information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{31}$</td>
<td>2(PL.2.2y)$<em>1\cdot R</em>{OZ}$</td>
<td>Oriented isomer ($OZ$, information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{21}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}$</td>
<td>Spatially inverse, information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{214}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Electromagnetically inverse ($OZ$), information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{15}$</td>
<td>n(CL.2.2x)$_2; M; R$</td>
<td>Mutated, secondary, information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{25}$</td>
<td>n(CL.2.2x)$_2; M; R$</td>
<td>Replicated secondary, information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{215}$</td>
<td>n(CL.2.2x)$_2; M; R$</td>
<td>Spatially inverse ($V_{224}$), information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{214}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Hybrid (paired), information</td>
<td>–</td>
</tr>
<tr>
<td>$S_{214}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Combined, information</td>
<td>With a coordinated orientation of fixed vortex zones</td>
</tr>
<tr>
<td><strong>Level 3. Structural detailing of $S_{214}$ chromosome</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{214}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Replicated ($K_R \geq 2$), information</td>
<td>With a coordinated orientation of fixed vortex zones</td>
</tr>
<tr>
<td>$S_{214}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Isomer 1, generative</td>
<td>With a coordinated orientation of fixed vortex zones ($\bigcirc\bigcirc$)</td>
</tr>
<tr>
<td>$S_{215}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Isomer 2, generative</td>
<td>With a coordinated orientation of travelling fields ($\rightleftharpoons$)</td>
</tr>
<tr>
<td>$S_{216}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Isomer 3, generative</td>
<td>With an alternate orientation of fixed vortex zones ($\bigcirc\bigcirc$)</td>
</tr>
<tr>
<td>$S_{217}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Isomer 4, generative</td>
<td>With a combination of orientation and vortex zones ($\rightleftharpoons$)</td>
</tr>
<tr>
<td>$S_{216}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Mutated, generative</td>
<td>With a coordinated orientation of moving vortex zones ($\bigcirc\bigcirc\rightarrow$)</td>
</tr>
<tr>
<td>$S_{217}$</td>
<td>2$(PL.2.2y)<em>1; R</em>{OZ}; I_{OZ}; M; R_1$</td>
<td>Mutated, generative</td>
<td>With an alternate orientation of moving vortex zones ($\bigcirc\bigcirc\rightarrow$)</td>
</tr>
</tbody>
</table>
- mode No. 3 with the inverse travelling fields \( V_j = (-V_j) \) and alternate orientation of the fixed \( OX \) coordinate of the DFPs vortex zones \( (S_{3T}) \):

\[
S_{3T} = \{2[(PL.2.2y_1)^{1}\cdot R_0\cdot I_0\cdot (R_1^2\cdot I_1^2)\times (mCL.2.2x)\cdot M_1] \times \} \times (WCH); \tag{5}
\]

- mode No. 4 with alternating sequence of zones with travelling and inverse fields by \( OX \) coordinate \( (S_{4T}) \):

\[
S_{4T} = \{2[(PL.2.2y_1)^{1}\cdot R_0\cdot I_0\cdot (R_1^2\cdot I_1^2)\times (mCL.2.2x)\cdot M_1] \times \} \times (WCH); \tag{6}
\]

- mode No. 5 with the inverse travelling fields \( V_j \neq (-V_j) \) and the coordinated orientation of the travelling fields by the \( OX \) coordinate of the DFPs vortex zones \( (S_{5T}) \):

\[
S_{5T} = \{2[(PL.2.2y_1)^{1}\cdot R_0\cdot I_0\cdot (R_1^2\cdot I_1^2)\times (mCL.2.2x)\cdot M_1] \times \} \times (WCH); \tag{7}
\]

- mode No. 6 with the inverse travelling fields \( V_j \neq (-V_j) \) and the alternate orientation of the travelling fields by the \( OX \) coordinate of the DFPs vortex zones \( (S_{6T}) \):

\[
S_{6T} = \{2[(PL.2.2y_1)^{1}\cdot R_0\cdot I_0\cdot (R_1^2\cdot I_1^2)\times (mCL.2.2x)\cdot M_1] \times \} \times (WCH). \tag{8}
\]

According to the results of structural synthesis, methods of technical realization of energy-efficient modes of materials processing have been optimized and developed. This increases the productivity of electromechanical disintegrators, the efficiency of which is confirmed by experimental studies on flat double-winding EMD samples in technologies of coal-water slurry fuel preparation [15] and the activation of Portland cement [16].

5. Conclusions

1. For the first time a genetic model of structure formation of EMD active parts with three-level structural detailing has been developed, which allows synthesis and analysis of genetically acceptable magnetic field structures in the active zone of the disintegrator at the stages of search design.

2. For the first time a deterministic connection between the genetic information of generating electromagnetic chromosomes and the corresponding structure of the resulting magnetic field in the EMD active zone zone has been established, which significantly simplifies the task of synthesis and analysis of magnetic field structures.

3. According to the results of genetic modelling and synthesis, processing modes, which provide a change in the mutual orientation of the vortex zones and a uniform distribution of working bodies and control of the intensity of their movement in the working volume of EMDs, have been optimized.

4. According to the results of research, methods of technical implementation of material processing modes, which provide the implementation of energy-efficient processing modes and increase the productivity of EMDs of multifactorial action, have been developed.

5. The reliability of the results of theoretical studies is confirmed by experimental studies, the results of which show that the use of the proposed methods of controlling the modes of operation of EMDs in technologies for production of coal-water slurry mixture and activation of cement increases their efficiency.

6. References

5. I. L. Slavinskii, V. S. Popkov, V. F. Shinkarenko, “Apparatus for working materials in magnetic field”, Copyright certificate of the USSR No. 1449156, Bul. No. 1, 07.01.89
Hydrophilized unsaturated polyester resin based on a two-component system of sulfur and cement

Assoc. Prof. Cherkezova R. PhD., Ch.Assist. Prof. Hristova T. PhD, Assist. Prof. Zafirova K.
Medical University „Prof. Dr. Paraskev Stoyanov“ Varna, Bulgaria;
E-mail: rumchara@abv.bg, Tatiana. Hristova@mu-varna.bg, Kristina.Zafirova@mu-varna.bg

Abstract: This work develops a multicomponent system comprising unsaturated polyester resin (UPER) hydrophilizing a two-component system of sulfate-resistant cement (SC) and sulfur, diluent water and a redox system. The hydrophilized unsaturated polyester resin (HUPER) so obtained can be used as a basis for polymer-silicate composites with good strength properties, precise embossed printing on the surface of various molds, and good visual characteristics. Polymer-silicate compositions with low and high content of SC were selected, and the constant amount of SC in the two groups obtained corresponded to a gradual change in sulfur content. Time kinetic dependencies of the cross-linking process of unsaturated polyester at a given amount of redox system were monitored. Reproducibility of results for different polymer compositions was achieved thereby enabling a possibility to predict them.

KEYWORDS: HYDROPHILIZATION, RESIN/MINERAL DISPERSE SYSTEM, CEMENT, SULFUR.

1. Introduction
This work is a continuation of the development of various methods for hydrophilization of UPER, which is a component of a multicomponent polymer system. In this specific case, we use SC and sulfur (S) as hydrophilizers in different proportions. A literature review shows that there are studies on UPER including the individual influence of SC[1-3]; just a few studies of the effects of sulfur are found [4,5]. A matter of interest is the influence of the two components, which may be confined to the quantitative proportion thereof. Cross-linking by a redox system of cobalt naphthenate (CN) and cyclohexanone peroxide (CHP) of UPER is not inhibited by the presence of the two hydrophilizing components, and what is more, it is also possible when the system is diluted with water [5-7].
The samples obtained based on different compositions are technologically reproducible which is proven by a large number of experiments with averaged results. The results of studies on the hardening kinetics and strength properties allow us to forecast the characteristics of resulted materials.

2. Materials and methods

2.1. Materials
We used:
Resin of type Vinalkyd 550 PE-R (Orgachim Resins – Ruse) containing 35% styrene and 65% unsaturated polyesters, which is a condensation product of propylene glycol and maleic anhydride. A 50% solution of cyclohexanone peroxide in dibutylphthalate was used as a curing initiator, and a 10% solution of cobalt naphthenate in styrene was the accelerator.
Sulfate-resistant blast furnace cement CEM III A-S 42.5 N SR – Devnya Cement, town of Devnya (SC).
Sulfur powder (S), A.R. (purum p.a. ≥99%) – Sigma – Aldrich.

2.2. Methods
Methods of obtaining compositions based on unsaturated polyester resin hydrophilized with cement have been developed, in which the percentage of water is always 50% in relation to cement, sulfur is in different amounts in relation to cement, and a CN/CHP redox system in constant proportion in relation to resin. Test pieces were examined for impact strength according to Izod by Izod impact testing machine GB 1843-2008. Test pieces were examined for compression strength by means of HZ-1005 Computer-type Tensile Testing Machine. Flexural stress and flexural modulus are calculated according to EN ISO 178:2019.

3. Results and discussion
The mass of all components included in the development of HUPER was summed up and reduced to 100%. A minimum amount of SC (12.8%) was used in the particular multicomponent polymer system whose data are provided in Table 1. Table 1 presents data on different compositions according to the technology for the amount of added water, which should be 50% in relation to the quantity of SC.

Table 1. Data on the obtaining of compositions based on UPER hydrophilized with different amounts of sulfur at constant quantity of SC (12.8% ± 0.02%), and 50% of water in relation to the quantity of SC.

<table>
<thead>
<tr>
<th>Composition No.</th>
<th>S quantity [%]</th>
<th>Time [τ, min]</th>
<th>Temperature T max, [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>29</td>
<td>95.5</td>
</tr>
<tr>
<td>2</td>
<td>0.03</td>
<td>32</td>
<td>124</td>
</tr>
<tr>
<td>3</td>
<td>0.08</td>
<td>52</td>
<td>110</td>
</tr>
<tr>
<td>4</td>
<td>0.08</td>
<td>49</td>
<td>85.5</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
<td>71</td>
<td>64.5</td>
</tr>
<tr>
<td>6</td>
<td>0.13</td>
<td>11</td>
<td>41</td>
</tr>
</tbody>
</table>

The development of that system resulted in experimental material of a large number of samples, five of which were selected, including a reference standard at 0% S. The composition of those samples include various gradually changing amounts of sulfur and allows the kinetics of the polymerization process to be traced (Fig.1).
There are 6 kinetic curves corresponding to the samples selected. Each kinetic dependency was obtained by reading the temperature change associated with to the release of a specific amount of heat at regular intervals (1 minute) reaching experimentally to a given temperature peak. The temperature so reached corresponds to gelation, which is consistent to a certain degree with HUPER cross-linking. It is observed that the peak temperature depends on the amount of sulfur. Curves 2 and 3 in which the amount of sulfur is 0.03% and 0.05%, respectively, indicate a sharp increase in the peak temperature versus the standard process at 0% S (curve 1). However, the greatest increase in the amount of sulfur from 0.05% to 0.08% results in a sharp increase in the gelation time when the temperature peak drops, which is most pronounced for sample 6 (curve 6): the temperature is 2.5 times lower.
Two groups of kinetic dependencies are therefore formed:
The first group (from 0.03% to 0.05% S) is characterized by gradual
increase in the gelation time, as the temperature is still above the
standard; The second group (from 0.08% to 0.13% S), which is
characterized by significant increase of time with gradual decrease
in the peak temperature.
It follows that the characteristics of samples examined could be
forecasted in reference with their future use for technological
purposes.
The data in Table 2 were obtained from similar development of
multicomponent hydrophilized polymer system (100%), as in this
case the amount of SC used is 36.2%. The requirements for the
amount of water are technological (50% in relation to SC).
In this situation, 5 samples were also taken and compared against
the reference (zero sample), where the amount of sulfur is different
at the same quantity of SC.

Table 2. Data on the obtaining of compositions based on UPER
hydrophilized with variable amounts of sulfur at constant quantity
of SC (36.2% ± 0.02%) and 50% of water in relation to the quantity
of SC.

<table>
<thead>
<tr>
<th>Composition No.</th>
<th>S quantity %</th>
<th>Time [τ, min]</th>
<th>Temperature T max, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>27</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>47</td>
<td>67.5</td>
</tr>
<tr>
<td>3</td>
<td>0.03</td>
<td>58</td>
<td>56</td>
</tr>
<tr>
<td>4</td>
<td>0.04</td>
<td>50</td>
<td>45.5</td>
</tr>
<tr>
<td>5</td>
<td>0.06</td>
<td>21</td>
<td>37</td>
</tr>
<tr>
<td>6</td>
<td>0.07</td>
<td>10</td>
<td>37.5</td>
</tr>
</tbody>
</table>

The idea of so selected hydrophilizing components (SC and S)
forming a two-component hydrophilized system (Table 1 and
Table 2) is first to monitor the influence of sulfur at constant
amount of SC, and second, to record the influence of SC at equal
masses of sulfur.

Fig. 2 presents kinetic curves T, °C /τ, min for samples at the
indicated quantity of SC and gradual increase in the amount of
sulfur, as the kinetic dependency of the zero sample is used for
comparison. In this case, it is obvious that the peak temperature and
the time to reach it are also influenced by the change in the amount
of sulfur, however the nature of curves differs from that in Fig. 1,
which is due to the larger quantity of SC. At smaller amounts of
sulfur (curves 2 and 3), temperatures are also higher than the
temperature of the reference sample but are twice lower than the
corresponding curves at lower quantity of SC. Curves 4 and 5 in
Fig. 2 (compared to the zero sample) have lower peak temperatures,
as the gelation time in this case is considerably higher (hours and
days) compared to the kinetic dependencies presented in Fig. 1.

It follows that the quantity of SC is of utmost importance. For
example, it is obvious for curves 2 in Fig. 1 and Fig. 2, in which the
amount of sulfur is the same and the quantity of SC is three times
different, that the peak temperature is twice higher at smaller
quantity of SC, and is reached in a significantly shorter period (32
min. relative to 47 min.).
Namely these results enable the variation of quantitative
compositions in order to be used in the technological development
of a material with pre-set curing time. This is the meaning of the
forecast characteristics of materials and the possibility for their
reproducibility in accordance with formualnts.
Strength tests were carried out on so selected samples from 1 to 6.
Results of impact strength, flexural strength and elasticity modulus
are presented below.
The data in Fig. 3 suggests that, at 12.8% SC, the values of that
strength indicator are higher at larger amouns of sulfur (0.05% and
0.08%) and lower at 0.1% and 0.13%. It follows from the same
figure that a larger quantity of SC does not influence the values,
excluding the sample with the highest content of sulfur.

Fig. 3. Impact strength data in polymer compositions at constant
composition of SC (12.8% and 36.2%) and
gradual change in the amount of sulfur (according to Table 1 and
Table 2)

The flexural strength data (Fig. 4) suggests that this indicator lowers
its value as compared to that of the reference sample. The
interesting thing here is the amount of sulfur 0.13% which has a different influence – the value is the lowest at the lowest amount of sulfur, and the highest at the high amount of sulfur.

The elasticity modulus (Fig. 5) presents a peculiar peak at 0.05% amount of sulfur, the same peak is shifted to the highest quantity of SC (36.2%) and the highest amount of sulfur (0.07%).

4. Conclusion
The development of a multicomponent polymer system and the selection of different compositions based on it enable us to make various surveys resulting in the following more significant conclusions:

1) Kinetic dependencies at two different quantities of SC with gradually changing amount of sulfur were traced, and it was established that the gelation time was more influenced at lower quantity of SC (12.8%), i.e. kinetic curves have more pronounced extreme nature.

2) Subject to compliance with the formulation data when preparing the compositions of different samples, a comparative characteristics of the peak temperature and the curing time could be made and reproducibility of results and projected characteristics of materials could be achieved.

3) The impact strength data suggested that the values of that indicator were largely insensitive to changes in the amount of sulfur at 36.2% SC.

At 12.8% SC, there is a dependency on the amount of sulfur, which will be the subject of future studies.

4) The flexure strength data suggested that the values of that indicator were the highest at 12.8% SC and 0.05% S. Such peak in the value of the indicator occurred at 36.2% SC and 0.07% S.

The shift in the peak at different quantities of SC and sulfur will also be a subject of other scientific research.

5. References
1. Introduction

It is known that under conditions of large / severe plastic deformations in alloys occurs significant refinement and change in diffusion activity associated with an increase in the number of vacancies in the material and thermodynamic conditions affecting the kinetics of the decomposition of a supersaturated solid solution of alloying elements in the matrix. In works describing these processes, the role of thermal the effect of deformation, which is especially pronounced at high speeds and degrees of deformation, in as a result of which the temperature of the workpiece can rise by hundreds of degrees, exceeding the recrystallization thresholds. In this regard, work in the direction of determining the dependences of phase transformations and structural changes from thermomechanical conditions of the deformation process of low-alloyed dispersion-hardening copper alloys are relevant, and the creation of scientific foundations using these patterns determines the novelty of the proposed research.

2. Objective and research methodologies

The work used an industrial conductive alloy Cu-0.6Cr. The initial state was obtained in the process of high-temperature treatment at 1000 °C for 1 hour and subsequent quenching in water. Alloy samples 10 mm in diameter and 14 mm in height were upset on a Gleeble-3500 physical modeling complex at a strain rate of 3, 30, and 300 mm/s. The temperature of the experiment was 20, 400, and 800 °C, while the strikers and, respectively, the samples were heated, after which the exposure was carried out for 10 s and the heating was turned off during deformation. Temperature control was carried out using a K-type thermocouple fixed on the sample surface by contact welding. The upsetting was carried out to the degree e = 1.1, which corresponds to 0.5 cycle of deformation by the ECAP method. Structural studies were carried out using transmission microscopy (JEM Jeol 2100) and EBSD (TESCAN MIRA 3 LMH). X-ray diffraction analysis was performed on a Rigaku Ultima IV in copper radiation. The microhardness was measured using a Micromet 5101 microhardness tester. The electrical conductivity was measured by the eddy current method using a VE-27NTs.

As can be seen from Fig. 1, the maximum heating always occurs at a speed of 300 mm/s. In this case, deformation heating at 400 and 800 °C is almost identical. A decrease in the sample temperature at a rate of 3 mm/s and temperatures of 400 and 800 °C is associated with the cooling of the samples.

An elongated structure is formed during upsetting at 20 °C (Fig. 2). At the same time, at a velocity of 3 mm/s, dislocation accumulations are observed mainly in the border regions. Dislocation walls are also observed along the boundaries in the structure. A more developed dislocation structure is observed at speeds of 30 and 300 mm/s. Dislocation networks, boundaries with a high density of dislocations, and dislocation walls in the grain body are visible. On dislocations, precipitates of the second phases are observed, however, there are practically no dislocations and dislocation walls in the grain. At a deformation temperature of 800 °C, the processes of dynamic recrystallization and polygonization will actively occur in bronze. At a speed of 3 mm/s, predominantly thin boundaries of thermal origin close to perfect are observed (Fig. 2). In the body of grains, precipitates of the second phases are observed, however, there are practically no dislocations and dislocation accumulations in the body of grains (Fig. 15.10 a, b). At a strain rate of 30 mm/s, both extinction contours in the boundary regions and dislocation clusters in the form of walls and grids are observed. At a strain rate of 300 mm/s, apart from dislocation networks and walls, fragmented twins of thermal origin are observed. The boundaries are nonequilibrium. The average sizes of the structural components are shown in the graph (Fig. 3a). Using the EVSD analysis, the proportion of high-angle boundaries was estimated (Fig. 3b).
An elongated structure is formed during upsetting at 20 °C (Fig. 2). At the same time, at a velocity of 3 mm/s, dislocation accumulations are observed mainly in the border regions. Dislocation walls are also observed along the boundaries in the structure. A more developed dislocation structure is observed at speeds of 30 and 300 mm/s. Dislocation networks, boundaries with a high density of dislocations, and dislocation walls in the grain body are visible. On dislocations, precipitates of the second phase are observed.

During upsetting at 400 °C, an elongated structure is also formed (Fig. 2). At a speed of 3 mm/s, a process of deformation-stimulated decomposition of a supersaturated solid solution (SSS) occurs, as evidenced by small particles less than 5 nm in size attached to dislocation networks and boundaries of structural elements. A similar picture is observed at a strain rate of 30 mm/s. At 300 mm/s, extinction contours are observed along the boundaries of structural elements, indicating the accumulation of high energy at the grain boundaries.

At a deformation temperature of 800 °C, the processes of dynamic recrystallization and polygonization will actively occur in bronze. At a speed of 3 mm/s, predominantly thin boundaries of thermal origin close to perfect are observed (Fig. 2). In the body of grains, precipitates of the second phases are observed, however, there are practically no dislocations and dislocation accumulations in the body of grains (Fig. 15.10 a, b). At a strain rate of 30 mm/s, both extinction contours in the boundary regions and dislocation clusters in the form of walls and grids are observed. At a strain rate of 300 mm / s, apart from dislocation networks and walls, fragmented twins of thermal origin are observed. The boundaries are nonequilibrium. The average sizes of the structural components are shown in the graph (Fig. 3a). Using the EVSD analysis, the proportion of high-angle boundaries was estimated (Fig. 3b).

3. Conclusion

Based on the results of structural studies (TEM, XRD), it was found that with an increase in the initial temperature, a structure with a larger grain and subgrain size is formed. At the same time, at a temperature of 800 °C, a predominantly grain structure is formed with a low dislocation density of $0.4-0.7 \times 10^{14} \text{m}^{-2}$, which is associated with the processes of dynamic recrystallization and polygonization.

At temperatures of 20 and 400 °C, a grain-subgrain structure is formed. The highest dislocation densities are formed at a deformation temperature of 20 °C – $5.4-7.1 \times 10^{14} \text{m}^{-2}$. Also, with an increase in the deformation temperature, the decomposition of the solid solution occurs more efficiently, as evidenced by the X-ray diffraction data on the lattice parameter and data on the electrical conductivity. Thus, at a deformation temperature of 20 °C at different deformation rates for the Cu-0.6Cr alloy, the lattice parameter is $3.6180 \pm 0.0005$ Å, and the electrical conductivity does not exceed 61 ± 2% IACS, while at a deformation temperature of 800 °C With the lattice parameter $3.6170 \pm 0.0005$ Å, and the electrical conductivity reaches 70-71% IACS at the studied strain rates.
Fig. 3. Change in the average size of the structural components -TEM (a) and the proportion of high-angle boundaries (EBSD)

As evidenced by the microhardness data (Table 1), the maximum microhardness is achieved at a deformation processing temperature of 20°C and reaches a value of 1300-1350 MPa. The data on electrical conductivity indicate that the degree of decomposition of a solid solution depends on the rate of deformation. The most complete decomposition of a supersaturated solid solution occurs at a speed of 300 mm/s at all deformation temperatures of −20, 400, 800°C.

Table 2. Microhardness, MPa.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>3 mm/s</th>
<th>30 mm/s</th>
<th>300 mm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 °C</td>
<td>1300±50</td>
<td>1350±50</td>
<td>1330±50</td>
</tr>
<tr>
<td>400 °C</td>
<td>850±40</td>
<td>870±40</td>
<td>890±40</td>
</tr>
<tr>
<td>800 °C</td>
<td>740±40</td>
<td>770±40</td>
<td>710±40</td>
</tr>
</tbody>
</table>

Table 3. Electroconductivity, %IACS.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>3 mm/s</th>
<th>30 mm/s</th>
<th>300 mm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 °C</td>
<td>61±2</td>
<td>64±2</td>
<td>70±2</td>
</tr>
<tr>
<td>400 °C</td>
<td>60±2</td>
<td>64±2</td>
<td>71±2</td>
</tr>
<tr>
<td>800 °C</td>
<td>60±2</td>
<td>63±2</td>
<td>71±2</td>
</tr>
</tbody>
</table>
Evolution of creative thought with elements of artificial intelligence on example of synthesis of clamping mechanisms

Kuznetsov Yuri
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine, 03056, Pobeda av. 37

Abstract. History of gradual increase of elements of artificial intelligence is resulted in the process of creative thought at creation of on principle new structures and charts of clamping cartridges on the example of cangovykh. Thinking process on the lasts of peat-time of application of artificial intelligence presented as a binary koda and waves of frequency impulses, reminding cerebration.

KEY WORDS: CREATIVE THOUGHT, ARTIFICIAL INTELLIGENCE, COLLETS, EVOLUTION, CLAMPING MECHANISM.

Problem statement. The main feature of modernity is the challenges induced to humanity by the fourth industrial revolution, Industry 4.0 [8] with a focus on artificial intelligence and the integration of science, education, manufacturing and the social sphere to achieve goals such as: 1-productivity increase; 2-quality improvement; 3-reduction of energy and raw material costs while preserving the environment; 4-reduction and facilitation of manual labour; 5-facilitation and reduction of routine mental work; 6-expansion of functional and technological capabilities of equipment during modernization. Not everyone clearly understand the challenges of time, holding the progress back. However, devastatingly criticized previously, cybernetics and genetics have paved the way for the new knowledge and its interdisciplinary application in the creation of new techniques and new technologies. New scientific ideas and inventions, as a rule, are in the short term attempted to be implemented into the national economy and social sphere to increase the well-being and quality of life. The solution of this acute problem in the absence of complete information forces to intensify the process of creative thinking through the use of artificial intelligence systems [1,7,12,13,18,23]. The process of creative thinking is associated with many obstacles, since the problem of thinking has no unambiguous interpretation and covers a wide range of actions for the left and right hemispheres of the human brain from alternative-logical to intuitive-practical thinking.

Regarding clamping mechanisms (CM) with compact collets (CC), creative thinking was aimed at finding technical solutions (fig.1) in the creation of the first single-spindle and multi-spindle auto lathes at the end of the XIX century [20,22,24].

Analysis of latest research and publications. The range of issues related to artificial intelligence is infinitely wide and cannot be covered in one work. Therefore, in this paper, the subject matter is the limited scope of creative activity, being associated with clamping chucks and, in particular, collets, which are widely used in auto lathes for clamping rods, pipes and workpieces [17,20,22,24]. In addition, collets and collet chucks are used not only in various machines and technological equipment, but in everyday life, medicine, etc.

The author’s rich experience and interdisciplinary approach together with using the evolution theory [2,5,21], advances in genetics [6], cybernetics [3,4], creatology [14] and creativity methodology [1], where, along with associative and algorithmic methods, system-morphological approach [1,9,25] occupies a large part of the search for solutions, allowed getting closer to the real understanding of the brain and the action of its right hemisphere in a short term, starting from ideas that, at first glance, seem bizarre. are in the short term attempted to be implemented into the national economy and social sphere to increase the well-being and quality of life. The solution of this acute problem in the absence of complete information forces to intensify the process of creative thinking through the use of artificial intelligence systems [1,7,12,13,15,18,23]. The process of creative thinking is associated with many obstacles, since the problem of thinking has no unambiguous interpretation and covers a wide range of actions for the left and right hemispheres of the human brain from alternative-logical to intuitive-practical thinking. Regarding clamping mechanisms (CM) with compact collets (CC), creative thinking was aimed at finding technical solutions (fig.1) in the creation of the first single-spindle and multi-spindle auto lathes at the end of the XIX century [20,22,24].

Fig. 1. Three types of collet chucks of a single clip in auto lathes of the first generation with pressing action (a), with a fixed collet (b), with tightening action (c): 1 - clamp collet; 2 - spindle; 3 - pressure sleeve; 4 - stop nuts
**Task description.** The purpose of this work is to trace the stages of evolutionary development and substantiate the principles of creative thinking on the example of the search for clamping chunks (ClC), as a process of creative analysis and synthesis followed by the search for new technical solutions in artificial intelligence systems.

**Basic data statement.** Starting from the seventh decade of the XX century (fig.2), when a specialized method of finding new technical solutions, called the differential-morphological method of synthesis, was proposed, we are going to trace the stages of creative thinking evolution with increasing elements of artificial intelligence.

The essence of the differential-morphological method [17] is that to resolve contradictions at the stage of searching for structures (morphology) of the CM and, in particular, ClC, use heuristic techniques of complete, incomplete and combined dismemberment of the clamping element (CE) (fig.3), which gives various main and additional effects, and at unidirectional dismemberment the synthesized structures correspond to new principles of clumping or provide new qualities.

**Fig.2. Evolution of creative thinking in synthesis and genetic prediction of collets and other clamping chucks**

The essence of the differential-morphological method [17] is that to resolve contradictions at the stage of searching for structures (morphology) of the CM and, in particular, ClC, use heuristic techniques of complete, incomplete and combined dismemberment of the clamping element (CE) (fig.3), which gives various main and additional effects, and at unidirectional dismemberment the synthesized structures correspond to new principles of clumping or provide new qualities.

**Fig. 3. Single clamp collet chuck diagram with tightening action (a) and its wedge CE with options for complete (b) and incomplete (c) dismemberment in X, Y planes**
To identify different structures alphanumeric codes of dissections were used, illustrated by the example of complete (fig.4), which gives different effects.

<table>
<thead>
<tr>
<th>No.</th>
<th>Geometric symbol</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alphabetic</td>
</tr>
<tr>
<td>1</td>
<td><img src="image1.png" alt="Image" /></td>
<td>X0Y0</td>
</tr>
<tr>
<td>2</td>
<td><img src="image2.png" alt="Image" /></td>
<td>X0X</td>
</tr>
<tr>
<td>3</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Y0Y</td>
</tr>
<tr>
<td>4</td>
<td><img src="image4.png" alt="Image" /></td>
<td>X0Y</td>
</tr>
<tr>
<td>5</td>
<td><img src="image5.png" alt="Image" /></td>
<td>X0Y</td>
</tr>
<tr>
<td>6</td>
<td><img src="image6.png" alt="Image" /></td>
<td>Y0X</td>
</tr>
<tr>
<td>7</td>
<td><img src="image7.png" alt="Image" /></td>
<td>Y0X</td>
</tr>
<tr>
<td>8</td>
<td><img src="image8.png" alt="Image" /></td>
<td>X0Y0Y</td>
</tr>
<tr>
<td>9</td>
<td><img src="image9.png" alt="Image" /></td>
<td>X0Y0Y</td>
</tr>
<tr>
<td>10</td>
<td><img src="image10.png" alt="Image" /></td>
<td>X0X0Y</td>
</tr>
<tr>
<td>11</td>
<td><img src="image11.png" alt="Image" /></td>
<td>X0X0Y</td>
</tr>
<tr>
<td>12</td>
<td><img src="image12.png" alt="Image" /></td>
<td>X0X0Y0Y</td>
</tr>
</tbody>
</table>

*Fig. 4. Complete dissections codes for a wedge clamping element (CE) in XY plane of force action from the clamp drive*

The application of the genetic-morphological approach [8] was oriented towards the clamping of one axisymmetric rotating object with access to the radial and axial clamping principles, which limited the field of search for new solutions. However, the question of simultaneous multi-place clamping of rotating objects fell out of sight, which is widely used in machine tools for processing non-rotating workpieces. One of the first examples of the tangential clamping principle was the invention of the "Collet Chuck" (patent SU N292734), in which holes were made at the end of the collet lips, the axes of which lie in the planes passing through the collet axis and through the middle of the slots forming the petals.

The solution to the problem of simultaneous multi-place clamping of rotating objects with the application of a tangential force offset from the axis of rotation determined the relevance and purpose of these studies. In the direction of the development of previously performed works [5], it is proposed to add to the well-known genetic classification of a single clamp [6] (axial and radial principles with genetic codes $F_1(F_а, F_r, F_t); M_1(M_а, M_r, M_t)$) the tangential principle of single and multi-place clamping with the application of force at the output of the power flow, offset from the axis of rotation by a radius $R$. At the same time, it appears in addition to the well-known genetic classification [7, 8], which has 48 power flows, another 24 with genetic codes $F_2(F_а, F_r, F_t)$.

In these studies, the code $Fа1 - Fт2$ with a wedge transducer (displacement, force, energy) and orientation on the collet clamp (Fig. 5) was selected.

*Fig. 5 Diagram of the transfer of genetic information with a wedge transducer from the input (point 1) to the output (point 2) in a tooling with tangential clamp*

Earlier, based on the analysis of evolutionary development and the long-term use of collet chucks in machine tools in various countries of the world and the process of their mutation [1,4,7,10], the collet chuck with a pulling collet was selected as the most common (Fig. 6, table 1)
Mutations create variability

Selection acts against harmful mutations

Reproduction and mutation occurs again

Objects with beneficial mutations are more likely to survive

Reproduction (distribution)

Fig. 6 Natural selection of single-clamp collet chucks for single-clamping lathes due to mutations with symbols:

- Push act
- Motionless act
- Addictive act

As an example, for the case of the input axial force \( F_{a1} \) and the output tangential force \( F_{t2} \), Fig. 5 shows the synthesized instrumental collet mandrel (end mill) with the simultaneous clamping of four cutting inserts. In multilevel genetic modeling and description, the following was taken into account [8, 10]: each level of the structural hierarchy preserves hereditary (genetic) information of a previous level; the structure of an object of an arbitrary level is formed on the basis of structures of previous levels (the higher the level of the hierarchy, the higher the complexity of the object); each object of an arbitrary hierarchy level is represented by a genetic code or structural formula.

### Table 1. Examples of description (modeling) and application of tooling with the tangential principle of a collet clamp

<table>
<thead>
<tr>
<th>No.</th>
<th>Structural scheme</th>
<th>Structural genetic formula</th>
<th>Application area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( F_{a1} ) → WD → ( F_{t2} ) → CL</td>
<td>( F_{a1} )–WD–( F_{t2} )–CL</td>
<td>A clamped cylindrical part or a flying cutter with a long collet is not aligned</td>
</tr>
<tr>
<td>2</td>
<td>( F_{a1} ) → WD → ( F_{t2} ) → CL</td>
<td>( F_{a1} )–WD–( F_{t2} )–CL</td>
<td>Similar to pos.</td>
</tr>
<tr>
<td>3</td>
<td>( F_{a1} ) → WD → ( F_{t2} ) → CL</td>
<td>( F_{a1} )–WD–3( F_{t2} )–3CL</td>
<td>Simultaneous clamping of three cylindrical parts</td>
</tr>
<tr>
<td>4</td>
<td>( F_{a1} ) → WD → ( F_{t2} ) → CL</td>
<td>( F_{a1} )–WD–3( F_{t2} )–3FL</td>
<td>Simultaneous clamping of three flat tail assembly tool plates (milling cutters, countersinks, reamers)</td>
</tr>
</tbody>
</table>
The description (modeling) with the complexity of the structure and the buildup of genetic information is presented in the form of structural genetic formulas at the following levels:

- Genetic, \( F_{a1} \), chromosomal, \( F_{a1} - F_{t2} \), object, \( F_{a1} - K_{R1} F_{t2} \); population, \( F_{a1} - W_{D} - K_{R2} F_{t2} \); specific, \( F_{a1} - W_{D} - K_{R2} F_{t2} - K_{R2} \) (cylindrical shape of the clamping object); \( F_{a1} - W_{D} - K_{R2} F_{t2} - K_{R2} FL \) (flat shape of the clamping object).

The latest model, taking into account the universal genetic replication operator \( K_{R} = K_{R1} = K_{R2} \) [7, 10], is shown in Fig. 7 for various circuits of tooling equipment.

![Fig. 7. Schemes of tooling with a collet clamp and genetic formulas at a species level: a) \( F_{a1} - W_{D} - F_{t2} - FL \); b) \( F_{a1} - W_{D} - 2 F_{t2} - 2 FL \); c) \( F_{a1} - W_{D} - 3 F_{t2} - 3 FL \); d) \( F_{a1} - W_{D} - 4 F_{t2} - 4 FL \).](image)

One of the ways of creative thinking was an attempt of structural-circuit synthesis and prediction of new CM using a morphological approach and combinatorial algorithms [11], representing combinatorial calculations from a set of special methods and techniques, such as binary presence system or absence of elements in the CM system, being improved or simplified (1 – yes, 0 – no). Starting with the first mechanized axisymmetric CM, which are widely used in lathes, drilling, milling, grinding and multi-purpose machines, there are the following system elements (fig. 8): power source (PS), energy converters (EC), clamping drive (CD), clamping chuck (CH), clamping object (CO). The latter can be single, rod, pipe or other workpiece for the manufactured detail, for example, in lathes, or a tool (drill, cutter, grinding wheel, etc.).

![Fig. 8. Elements of the CM system and connections between them](image)
In any CM system, there must be an input (power source-weight 1) and an output (clamp object-weight 1). All other elements in the series circuit without taking into account the control system (EC, CD, CH), in fact, according to combinatorics may or may not be present, when it comes to simplifying and reducing the circuit.

According to the evolutionary and genetic synthesis theory [2,21] a possibility of 100% prediction and directional synthesis of new CMs using generating systems with a given objective function [19] occurs, which requires complex mathematical transformations with the construction of models for micro- and macroevolutions and writing cumbersome structural genetic formulas [21]. Therefore, the paper proposes a simplified system-morphological approach with the construction of a digital matrix and the gradual removal of system elements in binary coding. Thus, in the evolutionary development of the CM system, only 7 combinations with the following codes can be predicted from the past through the present to the future when searching for all the following variants: CM1-11111, CM2-10111, CM3-11011, CM4-11101, CM5-10011, CM6-11001, CM7-10001. Until now, systems CM1-CM3, and partly CM4 are mainly used in the production. Each code gives a push to search for different options for its implementation.

The expansion and further improvement of the genetic-morphological approach proposed in [9,19] is caused by the requirements of modern tool production and the need to expand the technological capabilities of machine tools based on the modular principle [10]. Therefore, the CM generating system is expanded due to the introduction of tangential clamping forces at the output, generating 24 more variants of the new principles (table 2). For rotating objects, the total number of clamping principles will be 48 + 24 = 72. The next step to artificial intelligence in the search for new technical solutions is the use of wave and digital representation in the form of frequency pulses and binary code by analogy with the work [12], which is presented in Fig.9 in comparison with Fig.4.

<table>
<thead>
<tr>
<th>№</th>
<th>Structure</th>
<th>Geometric symbol</th>
<th>i</th>
<th>Binary code</th>
<th>Frequency pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>0</td>
<td>0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
<td>1 0 0 1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>0</td>
<td>0 1 0 1 0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>1</td>
<td>1 1 0 0 0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>0</td>
<td>0 1 0 1 0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>1</td>
<td>1 0 0 1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>0</td>
<td>0 0 1 1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>1</td>
<td>1 1 0 1 0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>0</td>
<td>0 1 0 1 1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>1</td>
<td>1 1 0 0 1</td>
<td></td>
</tr>
</tbody>
</table>

Fig.9 Binary codes and wave through frequency pulses for complete dissections of the wedge CE in XY plane action of force from the clamp drive
The process of human-generator of ideas thinking can be represented as a combination of frequency pulse waves set with bursts of overcoming the psychological barrier and receiving feedback in memory and personal computer in the form of frequency pulses with the same parameters, within which resonant phenomena may occur, boosting the pulse (fig.10, 11).

**Fig. 10. Transformation of technical solutions using wave representation through frequency pulses and binary code in the XY plane**

**Fig. 11. Transformation of technical solutions using wave representation through frequency pulses and their amplification in the XY plane**

**Conclusion:** The analysis of evolution stages for creative thinking with elements of artificial intelligence and the offered ideas and approaches allow asserting about the reality of simplified systems of artificial intelligence use with a high level of creativity. Therefore, work in this direction must be continued.

**References**


24. Kelle Ph. Automaten, Spriger Verlag, 1951.

Complex study of the bioaerosol composition of the atmosphere over urban areas based on lidar monitoring during the quarantine COVID-19

Angelova B.², Assoc. Prof. Ilieva M.², Assoc. Prof. Ilieva R.², Grigorov I. PhD³, Kolarov G.¹, Paneva D. PhD³, Kolev Ch. PhD³, Prof. Z. Cherkezova-Zheleeva¹, Prof. Groudeva V.², Prof. Stoyanov D.¹, Prof. Nedkov I.¹

¹- Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria
²- Faculty of Biology, Sofia University “St. Kl. Ohridski”, Bulgaria
³- Institute of Catalysis, Bulgarian Academy of Sciences, Sofia, Bulgaria

E-mail for correspondence: nedkovivan@yahoo.co.uk

Abstract: A comprehensive study of the air condition in urban areas was conducted, based on lidar monitoring. The subject of monitoring are two districts of Sofia the capital of the R.Bulgaria. The time period of the study is May-June 2020 and coincides with the introduced quarantine period in connection with the COVID-19 pandemic. The study includes lidar monitoring of the selected urban areas taking into account the mass concentration of particulate matter (PM). The method is combined with in situ sampling taking into account also the size control in μm – PM2.5 and PM10. The data are compared with those from the indications for the period of the licensed laboratories of the Ministry of Environment and Water and the Civil Network. A physicochemical study of the phase composition, structure and dispersion of the collected PM was performed by the methods of powder X-ray diffraction and Mössbauer spectroscopy. Predominant pollen and spore contamination was reported using Cascade Impactor measurements. Most part, the PMs studied show a conglomerate of several particles.

Keywords: BIOAEROSOL, PARTICULATE MATTER (PM), LIDAR MONITORING, PM SAMPLING

1. Introduction

Atmospheric pollution is a huge problem for the people living in big cities and is relevant through such planetary problems as global warming and damage to the ozone layer. Air pollution and urban air quality are listed as two of the world’s worst toxic urban air quality problems in the 2013 and interest in it has been growing so far [1, 2, 3]. The present-day scientific interest over following the advances in measurement technologies [4, 5, 6, 7, 8, 9, 10], which have allowed for monitoring the processes in the atmosphere and understanding of the biogenetic composition and of the physicochemical properties of atmospheric particles. Particulate matter (PM) emitted by vehicles in urban traffic, seasonal heating and industrial activities, can greatly affect environment air quality and have direct implications on human health. This paper talks over the most recent results of air quality investigation at some residential districts of Sofia-the capital of R. Bulgaria within the application of Lidar monitoring of scanning the horizontal aerosol distributions and the vertical long-distance transport of air masses at operational distances exceeding 25 km. The studies were expanded with local sampling based on spatio-temporal data from lidar monitoring and indepth study of the bio-chemical and physical properties of PM. These studies are a natural continuation of our work covered in the book "Atmospheric Air Pollution Monitoring" [11].

2. Methods, instruments, and procedures

The lidar mapping was performed by a lidar system installed on the Lidar station of Institute of Electronics. The site at residential district Mladost is located at a distance about 3 km and Dragan Tsankov blvd. is at a distance of 5.5 km from the lidar. This lidar system is capable of scanning the horizontal and vertical aerosol distributions and transport of air masses with a spatial resolution of 30 m and a beam divergence of ~1 omrad at operational distances of about 25 km. The laser emitter (wavelength of 510.6 nm) is a pulsed CuBr vapor laser with a repetition rate of 10 KHz at a 15-ns pulse duration. The receiving system comprises a Carl Zeiss Jena Cassegrain telescope (aperture of 20 cm, a focal distance of 1 m), a 2-mm-wide focal diaphragm, an interference filter with 2-nm-wide passband, and an EMI 9789 photo-multiplier tube operating in a photon-counting mode. The receiving system is fully computerized for collecting and processing the lidar data using a PCO 1001 1024-channel digital interface system for signal strobing and accumulation.

The PM sampling were realized using Andersen Cascade Impactor [12]. For enumeration of microbiota into the atmospheric air, an active sampling with FSC-A6 ICFM impactor was engaged. Glass Petri dish (φ 90x15 mm) with 27 ml sterile nutrient media was positioned beneath each stage. Nutrient agar with cycloheximide was used for bacteria and YGC agar for fungal enumeration. The Petri dishes were incubated for 48h at room temperature (25°C). The positive hole method and expressed as CFU/m³ was used for total colony counts (Andersen, A.A., 1958). The control and selection of particles by size and mass concentration in this experiment was expanded through systematic use during lidar experiments and in the daily experimental practice of the Microcontroller SDS 011 – PM2.5 n PM10. Additionally, the material collected on the filters and the stage after three hours of aspiration during the lidar monitoring was studied by SEM and EDAX. Mössbauer analysis was made using a Wissenschaftliche Elektronik GmbH apparatus, working at a constant acceleration mode; 57Co/Cr source, α-Fe standard. The parameters of hyperfine interactions of the Mössbauer spectral components were determined by computer fitting.

3. Results and discussion

The city of Sofia has a well-developed control network of local licensed stations for daily pollution control in selected points of the town. The subject of this study is to compare the network information with the lidar measuring during the months May and June 2020, which are part of the quarantine period of the COVID-19 pandemic. The measurement of pollution for the period shows a relatively low concentration of PM, which is due to understandable reasons of limited traffic and relatively warm weather for the season (average monthly temperature in the range of 16-20°C), which significantly reduces the use of heating appliances, respectively the use of solid fuels. The limited traffic opens a good opportunity to study the contribution of organic particles and especially those related to the flowering of plants, which is typical for the second half of May and the beginning of June. In the second half of June, significant relief was introduced in quarantine measures and industrial life returned to its traditional activities. Although the pollution did not exceed the critical values [13], we conducted in-depth studies of the PM and microbial contents (Mladost and Lozenets), where more than 160 thousand citizens live.

3.1. Lidar monitoring

Analyzing the PM in aerosol loadings formed in the vicinity of the grounded level of the atmospheric urban areas and experimentally measured of the mass concentration of the aerosol by the lidar technique were able to draw the important conclusion. Two major lidar parameters were calibrated, namely, the extinction
and the backscatter coefficient $\beta(r)$, in terms of the aerosol mass concentration following the well-known method [10,13] and making use of the mass concentration $M_a$ data obtained by the sampling device. For the lidar ratio $LiR = \alpha(r)/\beta(r)$ we adopted the typical value of $LiR = 50$ [10,13]. The parameters $\beta(r)$ and $\alpha(r)$ were calculated using the lidar equation under the assumption of a horizontally-homogeneous atmosphere:

$$P'(r) = P_0 \frac{c_2}{2} C \frac{\beta(r)}{r^2} \exp \left[ -2 \int_0^r \alpha(\tau) d\tau \right]$$

where $P'(r)$ is the power of the detected laser radiation backscattered from the atmosphere from a distance $r = \frac{ct}{2}$ after a period of time $t$ following the moment of laser pulse emission, and $\tau$ is the pulse duration. Under the homogeneity assumption, the extinction coefficient $\alpha(r)$ is calculated as

$$\alpha(r) = -\frac{1}{2} \frac{dS(r)}{dr}, \text{ where } S(r) = \ln \left[ r^2 P(r) \right]$$

Calibration dependencies of the mass concentration in $[mg/m^3]$ of, respectively, $\alpha(r)$ and $\beta(r)$ was developed. In both cases, the linear fit $Y = a + bX$ shows acceptable values of the standard deviation (less than 4 %) and the correlation coefficient (over 0.92). The plots can be used directly for calibrating the lidar maps, shown above, in mass concentration.

The lidar observation schedule complied with the generally accepted manner of treating the aerosols mass concentration by air-quality monitoring systems. The sampling device pumps atmospheric air through the filter (typically a volume of 60–100 m³) for an interval of about a few hours. Thus, the laser beam was stationary and directed to pass above the aspirator at a height of $h_{asp} < dR$. $dR = 30 m$ being the lidar’s radial resolution. The height of placing the aspirator was also chosen to comply with this condition, $h_{asp} < dR$. The lidar signals represent the number of backscattered photons $L_{lid}(k, R, \tau_m)$, where $k = 1$, $K_{max}$, $K_{max} = R_{max}/dR$, and $\tau_m = 5 \text{ min}$ is the time of photons accumulation. The total time of measurement lasted from one to several hours, depending on the particular weather situation. The computer system processes the input data by solving the lidar equation (1), with its output being profiles of the backscatter coefficient $\beta(k, R)$ or the extinction coefficient $\alpha(k, R)$, as calibrated in terms of aerosols mass concentration (see Fig. 3 above). The set of lidar profiles obtained for the entire period of measurement is used to construct 3D lidar maps, with the $x$ axis presenting the accumulation time with a step of $\tau_m = 5 \text{ min}$ and the $y$ axis, the distance from the lidar with a step $dR$. The $z$ axis corresponds to the color-coded coefficients of backscatter or extinction.

The lidar monitoring of the selected areas was carried out with a starting point – Lidar station of the Institute of Electronics, as the laser beam is horizontal at a height of about 40 m and its direction is marked on the city map (see Fig.1). The lidar measurements were also performed with inclined lidar drilling with a variable angle to the horizon, as the height at the end of the route reaches a height of 2 km. Fig.1b shows a lidar map in the form of a corner sector of daily observation (19.05.2020), which well illustrates the capabilities of the lidar and is a typical lidar image for the studied period. Fig.1a for comparison shows the lidar map of a typical image for April 2019.

Figures 1a and 1b well illustrate the difference between the pollution found by the lidar during the quarantine period and the conventional state of the atmospheric pollution in the same caisson but with heavy traffic. Apparently in the COVID-19 quarantine period the surface atmospheric layer has a very low concentration of PM. The data from the lidar monitoring shown in Fig.1 make it possible to obtain fast and accurate information in time-space coordinates. It is evident that for the studied period the pollution in the ground layer of the urban atmosphere is insignificant, but the lidar makes it possible to report pollution in the higher layers of the atmosphere.

The dependence of the aerosol extinction coefficient in the surface atmosphere on the distance to the Lidar station was also investigated. This coefficient is one of the most accurately measured optical parameters of the atmosphere and is used to calibrate lidar signals at mass concentration [11]. The data shows that the surface aerosol atmosphere is almost homogeneous at distances up to over 8 km from the location of the lidar and varies in small ranges from 0.01 to about 0.03 micrograms per cubic meter. At these extinction values, the atmosphere can be considered clean during the quarantine period, which is mainly due to the greatly reduced car traffic, as well as the reduced industrial activity of the citizens due to the state of emergency. It can be expected that by May and the beginning of June 2020 the air quality has improved.

3.2. Particle size distribution studies

In order to better assess the accuracy of lidar monitoring, in parallel with daily pollution measurements were made using electronic sensors type Microcontroller SDS 011, which detects pollution with PM2.5 and PM10. The controllers were located at a height of 10 m from the ground. Our measurements were compared with data from licensed stations and those of the civil network.

Below in Fig.2 shows histograms that illustrate well the approach to these measurements. Data from 05 and 06 May 2020 were selected, in which relatively high pollution was reported. This is a time when the merger of two weekends ends and during which there was an increase in car traffic of vacationers returning to the capital. Our measurements are compared with the data from the nearest measuring points of the licensed network of the Ministry of Environment and Water and of the civil network of the Cleanliness Movement. The results were obtained using an electronic tester type Microcontroller SDS 011 for PM2.5 and PM10. The survey was conducted daily in May and June 2020. Fig.2 illustrate the approach in measuring pollution.
For this purpose, a method for calibration was developed. In practice, the measurements of pollution with controllers were presented by: 

\[ \text{PFM2.5} = \sum \text{PM2.5} \quad t_k \times 1 \quad N; \quad \text{PM10} = \sum \text{PM10} \quad t_k \times 1 \quad N; \quad \text{PM2.5} = \sum \text{PM2.5} \quad t_k \times 1 \quad N; \quad \text{PM10} = \sum \text{PM10} \quad t_k \times 1 \quad N; \quad (6) \]

where \( \text{PM2.5} \), \( \text{PM10} \) in (4) are the sensor’s measured total mass concentrations and \( \text{PM2.5} \), \( \text{PM10} \) in (5) are the corresponding total mass concentrations, measured by the Municipality reference Station. As seen in (4) and (5) the calculated total mass concentrations are averaged quantities over the entire measurement time \( T_m \) at the assumption for the uniform and stationary aerosol field.

One can now calculate the calibration coefficients to the sensor time series in (3) using the ratios \( R_{\text{PM}} \) for both particle types PM2.5 & PM10 respectively, using (4), (5) and given by:

\[ R_{\text{PM2.5}} = \frac{\text{PM2.5}}{\text{PM2.5}} \quad R_{\text{PM10}} = \frac{\text{PM10}}{\text{PM10}} \quad (6a) \]

At least, using the expressions in (6) the calibrated quantities \( X_{\text{cal}}(t_k) \) in the sensor measured PM mass concentrations \( X(t_k) \) can be presented by

\[ X_{\text{cal}}(t_k) = R_{\text{PM}} \times X(t_k); \quad t_k = t_0+n \Delta t, \quad k=1 \quad N. \]

The effects of the calibration algorithm above developed on the time history of the measured time series \( X(t_k) \) and \( X_{\text{cal}}(t_k) \) by the both types of sensors: of IE-BAS and the Civil network are presented on Fig.3a to 3c below. Here the plot in Fig.3a presents ratio of both mass concentrations of PM2.5/PM10, measured by the Reference station used also for the calibration of other two groups of sensors. As seen, the ratio PM2.5/PM10, averaged over the entire period from March 7 to March 25 is of order of 0.48-05, which is typical for the clear atmosphere conditions. Moreover, the time variations of the same ratio PM2.5/PM10, displayed as time series are given in Fig.3b. As seen, some non-strong air pollution are detected during the first half of the measurement period, when the same ratio is of order of 0.5, remaining relatively constant on the 0.5 level up to the end of the measurement period.

The effects of the calibration algorithm are further demonstrated on the next Fig. 3c to 3e. Here the ratio PM2.5/PM10 is calculated from the non-calibrated data, acquired by the sensors in the civil network. As seen in Fig.3c,e, here the PM2.5/PM10 varies within the limits of 0.4 to 0.6 for the first period as in Fig. 3c2. Then, during the last quarantine period the same ratio is rapidly increased up to the values of 1.6. As seen in Fig.3b such of high increase of the ratio PM2.5/PM10 was not observed in the previous Fig.3b. The next Fig.3c demonstrates the time history of the same ratio PM2.5/PM10 calculated from the same data as in previous figure, but after their calibration, according to the above Calibration algorithm. As seen, the variations of the same ratio within the first period remains within the same limits as in the first two figures. Moreover, the step increase of the ratio PM2.5/PM10 on the final quarantine period is missing here. This result is very important as it demonstrate the effectiveness of the Moreover, the same behavior of the ratio PM2.5/PM10 is displayed on the last Fig.3e, where the calibrated data from the IE sensors are shown. We will note that the mean ratios, calculated from calibrated data remains very close as shown in all of figures. As a conclusion, it could be stated, the calibration algorithm here developed could be useful in many cases.

Following the expression in (3) the reference data can be presented as well by

\[ Y(t_k); \quad t_k = t_0+\Delta t, \quad k=1 \quad N. \]

They are collected simultaneously by the officially calibrated Station (IOS) of the Sofia Municipality, disposed nearby to about 70m. The reference sensor data are given as well separately for the both particle types PM2.5 & PM10 respectively.

In the further analysis we will accept the aerosol field, carrying the aerosol PM2.5 & PM10 particles in the region of measurements as approximately uniform and stationary during the measurement time \( T_m \). Then, we could calculate separately from (3, 4) the total mass concentrations for the both types PM2.5 and PM10, given by:

\[ \text{PM2.5} = \sum \text{PM2.5} \quad t_k \times 1 \quad N; \quad \text{PM10} = \sum \text{PM10} \quad t_k \times 1 \quad N. \]

In our measurements, the influence of the parameters – temperature, humidity, wind speed and atmospheric pressure – was taken into account in parallel. The data are shown in Table 1.

**Table 1: Meteorological data during the measurement**

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>Relative humidity (%)</th>
<th>Wind (m/s)</th>
<th>Atmospheric pressure (hPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00</td>
<td>7</td>
<td>80</td>
<td>3.1</td>
</tr>
<tr>
<td>12.00</td>
<td>9</td>
<td>82</td>
<td>3.1</td>
</tr>
<tr>
<td>14.00</td>
<td>9</td>
<td>82</td>
<td>3.6</td>
</tr>
<tr>
<td>16.00</td>
<td>8</td>
<td>87</td>
<td>5.7</td>
</tr>
<tr>
<td>18.00</td>
<td>7</td>
<td>80</td>
<td>2.0</td>
</tr>
<tr>
<td>20.00</td>
<td>9</td>
<td>71</td>
<td>5.1</td>
</tr>
</tbody>
</table>

From the above data it can be seen that in practice we have two maximums of pollution – in the morning until 10.00 h and after 18.00 h. These peaks are repeated systematically on a monthly basis. In practice, the measurements of pollution with controllers coincide well with the lidar data for relatively high air purity (low mass concentration of PM) and similarity of pollution in large urban areas. This finding gave us reason to unify the measurements with those of the licensed stations near which our results were compared. For this purpose, a method for calibration was developed.

### 3.3. Calibration of sensor data

Below we will describe the algorithm applied for calibration of sensor data. The measured data are presented as time series, denoted by:

\[ X(t_k); \quad t_k = t_0+n \Delta t, \quad k=1 \quad N. \]

where \( \Delta \) is the sampling interval, \( t_k \) are the successive sampling instances, \( N \) is the total time of single measurements and \( T_m = N \Delta \) is the full measurement time. Moreover, the variables \( X(t_k) \) present the sensor measured separately PM2.5 & PM10 mass concentrations in (\( \mu g/m^3 \)).
3.5. Quantitative characteristics of the microbial component in the selected locations

Quantitative analysis was performed to determine the total number of cultured microorganisms as follows: aerobic heterotrophic bacteria (NA medium) and fungi (YGC medium). Samples were collected twice for each month (1 and 4 weeks) by means of a six-stage cascade impactor and performed in triplicate for each sample.

The results of the analysis show a significantly higher number of bacteria compared to that of fungi in both time intervals of the study. When comparing the data from this analysis over time: May, 2020 and June, 2020, a significant increase in the number of the two studied groups is reported. As already mentioned, the first interval tested in May is characterized by extremely low anthropogenic pressure due to the quarantine sanitary-epidemiological restrictions for the period (Fig. 5).

Cascade impactor aspiration methods are currently considered to be one of the most suitable for quantifying the microbial component, as they provide information on the size distribution of bioaerosol particles. The distribution of bioaerosols, respectively their precipitation and stability depend to a large extent on the size of the bioaerosol particles. The data from the comparative analysis of bacteria and fungi depending on the size of the bioaerosol particles in the above location are given in Table 2.

Table 2: Quantitative characteristics of bacteria and fungi depending on the size of bioaerosol particles in Lozenets location

<table>
<thead>
<tr>
<th>Location Lozenets</th>
<th>Size of bioaerosol particles (µm)</th>
<th>Bacteria (CFU/m³)</th>
<th>Fungi (CFU/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>May</td>
<td>June</td>
</tr>
<tr>
<td>I - 0.65 – 1.1</td>
<td>3.1±0.2</td>
<td>8.5±0.3</td>
<td>0</td>
</tr>
<tr>
<td>II - 1.1 – 2.2</td>
<td>13.2±0.1</td>
<td>39.5±0.2</td>
<td>8.1±0.1</td>
</tr>
<tr>
<td>III - 2.1 – 3.3</td>
<td>75.8±0.5</td>
<td>125.2±0.1</td>
<td>45.2±0.1</td>
</tr>
<tr>
<td>IV - 3.3 – 4.7</td>
<td>99.6±0.4</td>
<td>160.4±0.1</td>
<td>95.2±0.1</td>
</tr>
<tr>
<td>V - 4.7 – 7.0</td>
<td>90.3±0.1</td>
<td>171.8±0.2</td>
<td>37.5±0.1</td>
</tr>
<tr>
<td>VI - &gt;7.0</td>
<td>110.5±0.3</td>
<td>207.2±0.3</td>
<td>90.2±0.2</td>
</tr>
</tbody>
</table>

The results obtained show domination of bacterial bioaerosol particles with sizes over 7.0 µm, followed by those with sizes 4.7 - 7.0 µm; 3.3 - 4.7 µm and 2.1 - 3.3 µm. The cascade impactor does not allow the ingress of a particle larger or smaller than the corresponding level of the pores. This proves that the association of microbial cells with PM, leading to the formation of an aggregate of a certain size. The analysis of the size distribution of the fungal bioaerosol particles reveals the highest share of particles with sizes 2.1 - 3.3 µm and 3.3 - 4.7 µm.

3.4. Crystallochemical features of PM

The recorded X-ray diffractograms show that the examined PMs are X-ray amorphous. No crystalline phases were detected. One of the diffractograms is presented on Fig.4 and well illustrate the structural features of the PM.

Mössbauer’s analyzes of the studied PMs show the presence of iron ions in the second valence of oxidation, mostly in the atmosphere of district Lozenets, while equal amounts of divalent and trivalent iron were registered in the samples from district Mladost. The absence of sextet (magnetic) components and the presence of a predominant amount or entirely divalent iron is characteristic of PM with natural origin – mineral or biologic. Which can explain the amorphous structure illustrated in Fig.4.
4. Conclusions

In general, the following main conclusions are outlined: 1. Quarantine period has led to a sharp reduction in PM pollution. Traffic and the use of solid fuel for heating are strongly reduced and this is underlined by the data on lidar monitoring for the same period in 2019 and the increase in pollution while easing the quarantine measures (after 13.06.20). 2. The greatly reduced presence of PM due to traffic and heating has opened up a good opportunity to take into account the presence of microbial contamination in the ground layers of the atmosphere. 3. Their presence is either as well-formed microbially contaminated PMs in the form of bioaerosols associated with inorganic PMs. 4. The amount of microbiota (bacteria and fungi) increases significantly after the relief of the quarantine period, which shows a direct relationship between the inorganic and microbial content of PM.

5. Acknowledgments

This work was financed in part by contract DN18/26 with the National Science Fund, Bulgaria, and included in the European Program of the COST Action CA16202.

6. References

3. Environmental monitoring of bioaerosols at regulated facilities, Environment Agency, July 2018
On metrological support for enterprises

К вопросу о метрологическом обеспечении предприятий

Dr.sc.ing. Ivanova T., M.sc.ing. Rjabčikova I.,
E-mail: puchkova@inbox.lv

Abstract: The paper presents analysis of certification and metrological support of various equipment; examples of uncertainty calculation for test equipment; presents a plan to create a laboratory which will provide certification and metrological support services for industries.

Keywords: CERTIFICATION, METROLOGICAL SUPPORT, UNCERTAINTY CALCULATION FOR TEST EQUIPMENT

1. Введение

На каждом предприятии, занимающемся производством, услугами по ремонту, испытаниям и т.д., особую роль играет метрология. Срок поверки и калибровки приборов «внезапно» истекает, образуется простой производства.

С появлением новых идей и различных доработок в сфере машиностроения на предприятиях-заказчиках появляются новые технические задачи. Для решения таких задач как правило инженера изготовители разрабатывают усовершенствованное нестандартное оборудование и совместно с этим у предприятий возникают трудности с его метрологическим обеспечением и аттестацией.

Дело осложняется, если предприятие использует средства измерения специального назначения. Калибровать нестандартное средство измерения внешним службам сложно и дорого. Предприятию остаётся действовать собственными силами. Для этого нужно иметь отдельное разрешение от аккредитации, ужесточаются требования комиссий. Например, обучение и допуск сотрудников, наличие дополнительных методик для проведения метрологического обслуживания на собственном предприятии, и т.д. Из-за этого снижается производительность. Предприятие теряет деньги.

2. Изучение и анализ проведения аттестации оборудования

На рисунке 1 изображена примерная схема разработки, изготовления и аттестации различного оборудования в сфере машиностроения.

![Рисунок 1: Примерная схема разработки, изготовления и аттестации различного оборудования](image1)

Заказчик в техническом задании указывает все необходимые параметры и требования к оборудованию. Предприятие-изготовитель в соответствии с техническим заданием разрабатывает проектную документацию и согласовывает ее с заказчиком.

Проектная документация может содержать информацию о работе механизмов, гидравлических системах, автоматизации, должна иметь разработанную электрическую схему, а также всю необходимую информацию о встроенной измерительной системе.

Когда проектная документация готова, переходят к изготовлению оборудования. Закупают и изготавливают комплектующие, проводят монтажные работы и т.д. Для стационарного оборудования окончательный монтаж обычно выполняется по месту эксплуатации. На этом этапе следует следить за тем, чтобы закупаемые изделия имели сертификаты качества и не имели явных дефектов, а работники имели соответствующую квалификацию и допуски.

Контроль качества изготовленного оборудования является ответственностью изготовителя. Следует убедиться в работоспособности оборудования еще до аттестации.

Аттестация испытательного оборудования производится внешней метрологической службой или иной организацией, имеющей на это разрешение вышестоящих органов аккредитации. Аттестация может происходить как по месту изготовления, так и по месту эксплуатации оборудования, в зависимости от обстоятельств. Это комплексная проверка, которая состоит из следующих основных действий:

- Изучение и анализ технического задания.
- Проверка конструкторской документации – ее достаточность, соответствие техническому заданию, стандартам и т.д. Изучение электрической схемы. Обратить внимание на сопротивление изоляции электрических цепей в оборудовании и на порядок включения.
- Воздействие работы оборудования на окружающую среду. Обратить внимание на уровень вибрации, шума, магнитных и электромагнитных полей, количество выделяемого тепла и др.
- Безопасность оборудования для оператора и других людей.
- Метрологическое обеспечение. Следует убедиться в работоспособности и достаточной точности средств измерения, правильности оценки их неопределенности. Особое внимание необходимо обратить на наличие и количество измерительных каналов, а также на конструктивное расположение средств измерений. Убедиться, что измерительный канал имеет правильное подключение.

В зависимости от типа оборудования (см. Рисунок 2) процедура аттестации может отличаться.

![Рисунок 2: Аттестация оборудования](image2)
ТД. В этом случае, встроенный датчик температуры в выводом на лицевую панель (дисплей) кабины самолета ИЛ76 жидкости в насосе и пожар на двигателе. Предполагается, что при температуре более 120 градусов возможно самовозгорание необходимо контролировать температуру жидкости, так как ИЛ76 ТД‖ в разделе «Особенности эксплуатации и точности измерения, предприятия стандартные средства инженерных решений, повышения технологичности, контроля

- Цифровой датчик
- Терморезисторы
- Термопары

сигнал. В качестве температурных датчиков могут быть: управление является изменение температуры в электрический ток.

измерительной системы, которая встроена в оборудование. Необходимо убедиться, что измерения выполняются правильно в соответствии с техническим заданием и соблюдают закон о единстве измерений. К измерительной системе могут относиться стандартные средства измерения, нестандартные средства измерения, а также с их помощью могут выполняться прямые и косвенные измерения.

Стандартные средства измерения

К ним относятся механические весы, электронные весы, гири, компараторы массы, механические динамометры, манометры, штатгенциркули, линейки, хронометры, люксметры, термометры, гигрометры, барометры и т.п.

С появлением современных средств измерений в различных сферах индустрии особое значение придают электроизмерениям. Например, в сфере измерения массы, механические весы заменяют на электронные лабораторные весы и компараторы массы со встроенными термодатчиками и микроконтроллерами. Механические динамометры все чаще заменяют на тензодинамометры, обеспечивающие более высокую точность показаний. Чтобы преконтролировать температуру в помещении, жидкости, твердого объекта или расплавленного металла, предприятия вместо ртутных и спиртовых термометров используют электронные термометры со встроенными температурными датчиками. Основной действием температурных датчиков в автоматизированном управлении является изменение температуры в электрический сигнал. В качестве температурных датчиков могут быть:

- Термопары - представляет собой две проволоки из разных металлов, спаянных между собой. При разности температур между горячим и холодным концом в цепи возникает электрический ток.
- Термометры - работают на зависимости сопротивления материалов от внешней температуры.
- Цифровой датчик - представляет собой трехвыводную микросхему, позволяет с высокой точностью до 0,5 градуса получать температуру с множества параллельно работающих датчиков.

Нестандартные средства измерения

С целью упрощения различных конструкторских и инженерных решений, повышения технологичности, контроля и точности измерения, предприятия стандартные средства измерения заменяют на измерительные каналы.

Рассмотрим пример использования измерительного канала на предприятии:

Пример 1

В соответствии с технической документацией “Особенности конструкции и летной эксплуатации. Самолет ИЛ76 ТД” в разделе «Особенности эксплуатации гидросистемы» в случае утечки гидродвигателей в гидробаке необходимо контролировать температуру жидкости, так как при температуре более 120 градусов возможно самовозгорание жидкости в насосе и пожар на двигател. Предполагается, что в гидробаке установлены электронные датчики температуры с выводом на лицевую панель (дисплей) кабины самолета ИЛ76 ТД. В этом случае, встроенный датчик температуры в гидробаке, включая кабель со встроенным аналого-цифровым преобразователем с выводами на дисплей представляет собой измерительный канал. Вероятнее всего, такой канал должен быть отградуирован и затем откалиброван метрологической службой на заводе-изготовителе, так как показания температуры были как можно точнее, тем более в случае аварийной посадки. Следует также учесть, что при непрерывной эксплуатации воздушного судна ИЛ76 ТД измерительный канал может подвергаться различному повреждению, например, рассохшиеся клемники, коррозия и другие химические и механические воздействия. Кроме того, при замене кабеля в измерительном канале все метрологические характеристики будут недействительными. Канал необходимо калибровать заново.

Выполнение косвенных измерений

Для того, чтобы определить значение искомой физической величины, проводят измерения одной или нескольких других величин с использованием различных средств измерений. Затем значение искомой величины вычисляется по заранее известной формуле или таблице.

Расчет стандартной неопределенности результатов косвенных измерений производится по формуле:

\[ u^2(y) = \sum_{i=1}^{n} \left( \frac{\partial y}{\partial x_i} u(x_i)^2 \right) \]

где \( y = f(x_1, x_2, ..., x_n) \) – функция зависимости между определяемой величиной \( y \) и величинами \( x_i \), подвергаемыми прямым измерениям.

Пример 2

В техническом задании указано, что экспериментальным путем необходимо определить разрушающую нагрузку и предел прочности испытываемого материала. По требованию технического задания все средства измерения должны быть поверены либо откалиброваны, при этом точность измерений должна быть не хуже 5%.

Чтобы определить предел прочности испытываемого материала, необходимо измерить его геометрические параметры: толщину \( a \) и ширину \( b \), а также необходимо определить измеренную нагрузку при разрушении материала. Для этого необходимо знать неопределенность измерительного канала силы в разрывной машине.

Известно, предел прочности испытываемого материала определяется по формуле:

\[ b_i = \frac{P_i}{a_i b_i} \]

Для расчета определения предела прочности испытываемого материала с использованием метода косвенных измерений составляется бюджет оценки неопределенности в соответствии с руководством EA-4/02 “Expression of the Uncertainty of Measurement in Calibration”. Для данного случая используются следующие средства измерения:

- средство измерения длины (линейка, штатгенциркуль, датчик перемещения и др.) для определения параметров толщины \( a_i, (м) \) с неопределенностью \( \pm U(a_i), (м) \) – из калибровочного сертификата и ширины \( b_i, (м) \) с неопределенностью \( \pm U(b_i), (м) \) – из калибровочного сертификата.
- откалированный канал измерения силы, определяющий разрушающую нагрузку материала \( P_i, (Н) \) с неопределенностью \( \pm U(P_i), (Н) \) – из калибровочного сертификата.

Таблица 1. Бюджет неопределенности косвенного измерения с использованием метода косвенных измерений:
где \( k=2 \) – коэффициент охвата при нормальном распределении вероятности 95%.

Результат: \( x \pm U(x) \), (нг/м²).

### Пример 3

Установлены технические требования к противогазам. Необходимо определить время защитного действия фильтров противогаза от момента подачи продуктов сгорания (смесь тест-вещества) до момента появления заданного значения массовой концентрации тест-вещества после фильтра.

Рисунок 3: Испытательное оборудование для определения времени защитного действия противогаза

1 - сброс; 2 - подача воздуха; 3 - смесь тест-вещества; 4 - регулятор расхода воздуха; 5 - увлажнитель (блок создания влажного воздуха); 6 - терmostat; 7 - емкость с тест-веществом; 8 - образец фильтра; 9 - регулятор расхода тест-вещества; 10 - испытательная камера; 11 - средство измерения температуры; 12 - средство измерения влажности; 13 - средство измерения концентрации тест-вещества; 14 - средство измерения концентрации тест-вещества за фильтром.

Время защитного действия рассчитывается по формуле:

\[
x = \frac{R}{r}
\]

где \( t \) - время защитного действия, определенное при испытании, (мин);
\( R \) - измеренное значение входной массовой концентрации тест-вещества, (мкг/дм³);
\( r \) - заданное значение входной массовой концентрации тест-вещества, (мкг/дм³).

Таблица 2. Бюджет неопределенности косвенного измерения с целью определения времени защитного действия фильтров противогаза

(3) \( U(b) = k \cdot u(b) \)

(5) \( U(x) = k \cdot u(x) \)

где \( k=2 \) – коэффициент охвата при нормальном распределении вероятности 95%.

Результат: \( x \pm U(x) \), (мин).

### Заключение

Проведенный анализ процедуры аттестации оборудования показывает, что предприятие-изготовитель подготавливает всю необходимую документацию на проверку в метрологическую службу, но при этом метрологическая служба должна точно также разбираться в устройстве работы оборудования, которое аттестует. Исходя из этого, чтобы избежать двойной работы и снизить затраты, можно будет делегировать полномочия разработки методик измерения, выбор средств измерений и другие функции по метрологическому обеспечению метрологическим службам. На наш взгляд, это не будет приводить к конфликту интересов.

Появилась идея о создании лаборатории, оказывающей услуги по аттестации различного оборудования, машин и механизмов, различных установок, электрооборудования и электроустановок до 1000 В, включая услуги по метрологическому обеспечению, в т. ч. со специальными средствами измерений. Это позволит предприятиям снизить трудоемкость работ в сфере метрологии, снизить издержки и делегировать ответственность внешним специалистам. Лаборатория планирует предлагать следующие услуги:

- помощь по обеспечению всей необходимой документации для аттестации оборудования – это инструкции, руководство по эксплуатации, методики проведения измерений;
- консультации по заблаговременному выбору средств измерений для выполнения всех требований заказчика в части точности измерения, градуировки и калибровке каналов измерения, а также оценка неопределенности для прямых и косвенных измерений;
• attestация оборудования в соответствии с требованиями заказчика и законодательства.
Основные преимущества лаборатории:
• специалисты с опытом работы в сферах метрологии, управления качеством, авиационной индустрии, электроники, электротехники, энергетики, математического моделирования и статистики;
• опыт работы в проведении межлабораторных сравнений и валидации методик, участия в EURAMET;
• опыт работы с аккредитующими органами: UKAS, LATAK, AP MAK, Росавиация;
• опыт работы с клиентами из разных стран (Европа, Россия, США, Израиль, Китай, Индия);
• место расположения — г. Рига, Латвия — географически удобно для перевозки средств измерений и оборудования, возможность морских, воздушных, железнодорожных и автомобильных перевозок, пунктуальность курьерских и логистических служб.
Предполагается аккредитация лаборатории в Латвийском Национальном бюро аккредитации в соответствии со стандартом ISO 17020 по сфере “Аттестация различного оборудования, машин и механизмов, установок, электрооборудования и электроустановок до 1000 В, включая услуги по метрологическому обеспечению, в т. ч. с нестандартными средствами измерения”.

5. Литература
Remote real-time control of autoclave sterilization process

Stoyanka Madzharova\textsuperscript{1,*}, Rosen Gerasimov\textsuperscript{2}, Adriana Prodanova\textsuperscript{3}, Hristo Dinkov\textsuperscript{1}

University of Food Technologies - Plovdiv, Bulgaria\textsuperscript{1}
PU “Paisii Hilendarski”- Plovdiv, Bulgaria\textsuperscript{2}
Technical University Plovdiv, Bulgaria\textsuperscript{3}
nitani@abv.bg

Abstract: The article proposes a variant for real-time sterilization process control from anywhere in the world, based on the widespread communication protocol RS-232 or RS-485.

Keywords: STERILIZATION, REAL-TIME CONTROL, DTE, DCE, COMMUNICATION PROTOCOLS

1. Introduction

Sterilization remains one of the most widely used methods for preserving food. The correct conduct of sterilization regimes is an important stage in the technological process, which guarantees the production of food with high quality and a high level of microbiological stability.

Sterilization is a dynamic process (time-temperature dependent) and the creation of ideal or optimal conditions for its course is complicated. The process is a complex interaction between many interrelated factors that are difficult to reconcile with each other.

The challenge for the canning industry is to reduce costs - the presence of microflora in cans under the established sterilization regime is one of the reasons for marriage and leads to increased costs. In a certain sterilization regime in a certain autoclave there is a dependence between the development of thermal processes in it and in canned food. It finds expression in the so-called sterilization formula. For devices with periodic action, in which each sterilization cycle begins with a program, the conditional record is:

\[
\frac{A + B + C}{t^0}
\]

where: 
\begin{itemize}
  \item \textit{A} - duration of temperature rise in the autoclave from the initial to the set temperature, min;
  \item \textit{B} - Duration of temperature retention at the set level, min
  \item \textit{C} - Duration of lowering the temperature to the set temperature, min
  \item \textit{t}^0 - sterilization temperature, the maximum temperature of the heating medium, °C.
\end{itemize}

On the basis of mathematical models, sterilization methods have been created, based on the correct choice of temperature and time for the most difficult heating point in the can, depending on the type of microorganism that will be inactivated.

2. Materials for Production of Prototype Parts

Often the objects for research, control and management are characterized by a large number of various physical parameters that need to be transformed and measured. The incoming measurement information from the transducers is collected, processed and presented to the operator in an appropriate form. Some of the information needs to be responded to immediately, and the rest is recorded and further processed. Then it is necessary to build information and measurement systems. / The term “distributed metering systems” or “data collection systems” is also used /.

In the most general case, the information-measuring system is a complex measuring instrument, composed of measuring transducers, measures, devices and switches, connecting lines, digital and analog computing devices, designed for automated receipt of data from the studied object, for processing measuring information, and for converting the data into output signals of the system [1].

The management of the sterilization process must ensure the production of a safe and quality product, without deformations on the packaging. The control can be manual by operator, semi-automatic and fully automatic. In fully automatic control much of the currently used autoclaves in the canning industry, are adapted to communicate with the computer uses Aiki this communication protocols RS-232 or RS-485.

Fig. 1 Кривите на температурни промени във времето

The temperature change curve is directly related to the temperature curve of the medium of the heat carrier (autoclave).
In telecommunications, RS-232 is a standard originally introduced in 1960 [2] for the transmission of serial data communications. It formally defines signals connecting the DTE (data terminal equipment) as a computer terminal and the DCE (data circuit termination equipment or data communication equipment) as a modem. The standard specifies the electrical characteristics and timing of the signals, the meaning of the signals, as well as the physical size and pins of the connectors. The current version of the standard is the TIA-232-F interface between data terminal equipment and data end-use equipment using serial binary data exchange, issued in 1997. The RS-232 standard is commonly used in computer serial ports and it is still widely used in industrial communication devices.

A RS-232-compliant serial port was once a standard feature on most types of computers. Personal computers have used them to connect not only to modems, but also to printers, computer mice, storage, uninterruptible power supplies, and other peripherals.

RS-232, compared to later interfaces such as RS-422, RS-485 and Ethernet, has a lower transmission speed, short maximum cable length, large voltage swing, large standard connectors, no multipoint capability and limited multidrop ability. In modern personal computers, USB has displaced the RS-232 from most of its peripheral interface roles. Few computers today are equipped with RS-232 ports, so one must use either an external USB to RS-232 converter or an internal expansion card with one or more serial ports to connect to RS-232 peripherals. Nevertheless, due to their simplicity and ubiquity, RS-232 interfaces are still used - especially in industrial machines, network equipment and scientific instruments, where low-speed point-to-point and low-speed cable connections are perfectly adequate.

The short cable length is one of the serious limitations of the protocol. By default, the maximum cable length is 50 feet (15.24 meters) or the cable length is equal to a capacity of 2500 pF.

This limitation is often a serious problem in working with industrial machines using RS-232 or RS-485 protocols for communication. In FIG. 3 shows a variant for real-time communication.

With **position 3** - pressure sensor and the corresponding interface cable.

With **Position 4** - industrial converter RS232 / RS485 to TCP / IP, with models only with LAN port, and there are also models with the possibility of Wi-Fi connectivity (according to the 802.11 b / g / n standard). Even when using the combined model converter recommend is connect to the LAN port of the converter recommended cable - FTP category 5. This type of cable has an overall shield of foil wrapped around not shielded twisted pairs and drain wire. When the drain wire is properly connected, unwanted noise is diverted to ground, offering additional protection against electromagnetic interference (EMI) or radio frequency interference (RFI).

With **Items 6, 7 and 8** are depicted different types of devices (PC, laptop, tablet or smart phone), which could not access real-time information available to group virtual machines (**Item 5**) .

**Item 5** can be a physical computer (server) or group (virtual) machines, part of a private or public cloud, for example: Amazon Elastic Compute Cloud (EC2), Windows Azure and others. The use of virtual machines will reduce LSI mended chance of data loss and and reduces the cost of owning and maintaining the necessary information infrastructure. The use of virtualization in the present case it will allow and to significantly reduce the cost of license fees for the necessary software.

The proposed technical solution can be applied successfully not only in KONS erurnata industry as it is in the specific example, but in many other manufacturing processes. For example: CNC machines, medical equipment and others. Many industries use various (expensive) equipment that is designed to use RS-223 as a communication and control protocol.

Overcoming the above-mentioned limitations of RS-232 in combination with our proposed use of virtual machines with remote access (**Position 5**) will allow the use of highly specialized and expensive software for control of the respective machines of the SaaS or IaaS model.

Cloud computing is computing services provided to a user via a remote computer to which the user connects via the Internet or a dedicated communication line.

The term combines concepts such as software as a service (**software as a service, SaaS**), infrastructure as a service (**infrastructure as a service, IaaS**), platform as a service (**platform as a service, PaaS**) and other modern technologies in the form of online business web browser applications meet computing needs while storing software and user data on their servers.

In other words, the term refers both to software applications provided in the form of web services and to access to the hardware and system resources of the data center that offer these services. In fact, the combination of access to the center's hardware and software is what is commonly called a cloud. The cloud is considered a metaphor for the Internet, as it is often depicted in computer network diagrams and as an abstraction of the complex infrastructure behind it. [3]

**Infrastructure as a Service (IaaS)** is a cloud based system of hardware and software, in which the provider and provides users with access to computing resources such as servers, storage of their data and networking. Customers (**item 1**) use their own platforms and applications within the service provider’s infrastructure [4].

Main advantages of IaaS:

Instead of buying vast hardware directly, the user pays for IaaS as needed.

The infrastructure is scalable depending on the processing and storage needs.

Saves companies the cost of purchasing and maintaining their own hardware.

Because the data is in the cloud, there can be no point of failure.

![Fig.3 Real-time communication scheme](image-url)
Software as a Service (SaaS) is a cloud-based service that offers users access to a provider’s cloud software. Users do not install applications on their local devices. Instead, applications reside on a remote cloud network that is accessed by the network or API. Through the application, users can store and analyze data and collaborate on projects. [4]

Main advantages of SaaS:

Providers of SaaS services provide goods - applicants the necessary hardware, infrastructure, software and software (applications) via a subscription model.

Users must not manage, install or upgrade software; SaaS vendors manage this.

Data is protected in the cloud; equipment damage does not result in data loss.

Resource usage can be reduced depending on the needs of the service.

The applications are accessible from almost any device connected to the Internet, from almost anywhere in the world (Positions 6, 7 and 8) of Fig.3.

Both of the above models (IaaS, SaaS) of use are well applicable and “fit” to solve the problem addressed in our report. Users with more specific needs, as well as their own IT professionals, would be better to choose IaaS. It will give them more freedom to use, but also requires higher own IT expertise. Users who do not have very specific needs when using the software or do not have their own IT experts should choose the SaaS usage model.

In recent years, there are many examples of the use of the SaaS model, most of the major IT companies such as Google, Cisco, Microsoft, Dropbox and many others. Microsoft Office 365 is one example of a SaaS product that most of us know and have used.

The SaaS usage model is a kind of peak in the development of virtualization in recent years and gives a significant competitive advantage to companies that put it to use in the management of their production and business processes.

**Why companies perceive SaaS?**

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher return on investment (ROI)</td>
<td>40%</td>
</tr>
<tr>
<td>Improved application performance and reliability</td>
<td>19%</td>
</tr>
<tr>
<td>Less staff is needed</td>
<td>12%</td>
</tr>
<tr>
<td>Regular updating</td>
<td>8%</td>
</tr>
<tr>
<td>Others</td>
<td>21%</td>
</tr>
</tbody>
</table>

**Fig.4 Advantages of the SaaS model**

In a particular case, each owner of an autoclave or group of autoclaves (item 1) will not need to own and configure a server and the necessary specialized software. It will use a virtual machine, part of (item 5) with the necessary monitoring and control software installed on it. This significantly reduces the implementation time and the complexity of the process of modernization of the production process of sterilization.

The interesting question is what type of users would need the information so aggregated so far?

Possible users are:

1. Technologists monitoring and responsible for the relevant sterilization processes. These specialists could be, as well as employees of the company, the owner of the autoclave, and external experts hired to control the process.

2. Customers (with high quality requirements) of the respective canning production, who could observe (themselves or their specialists), the process of sterilization of the ordered (and we assume paid) production.

3. Students and lecturers from higher education institutions (UFT, etc.) with specialties related to training for the canning industry.

These three groups of users will be able to monitor and control the actual sterilization production processes from anywhere in the world. Something that was not possible with the existing restrictions imposed by the widespread use in industrial machines of the communication protocols RS 232 / RS 485. Any of the potential users could use access any of the devices under Positions 6, 7 and 8.

**3. Conclusions**

1. Versatility of the proposed model for overcoming the limitations of the communication protocols RS 232 / RS 485 widely used in equipment and machines

2. Enabling remote Internet access to industrial equipment and machinery using RS 232 / RS 485, protocols operating at short distances

3. Applying of the SaaS (Software As A Service) model for the use of software for a large group of software products managing industrial processes. A fact that leads to increasing the competitiveness of existing industries.

**4. References**


3. https://bg.wikipedia.org/wiki/%D0%98%D0%B7%D1%87%D0%B8%D1%81%D0%BB%D0%BD%D0%B8%D1%8F


uer_kato_usluga_vuprosi_i_otgovori/