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# DESIGN PROCESS FOR THE SUSPENSION SYSTEM OF THE TERRAIN VEHICLE WITH FOUR WHEEL DRIVE

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***Abstract**: This paper discusses the research methodologies utilized for developing a suspension system for a four wheel-drive terrain vehicles. The main research methods can be identified as literature studies; design processes by applying CAD systems, numerical analyses methods, mathematical modeling and simulation, optimization of the mechanical systems, as well as the comparison, analysis, and evaluation of the obtained results. The proposed suspension system for the terrain vehicle was successfully derived at from a classic double wishbone control arm. Optimization of the suspension parameters for passive ones is performed by Multi Objective Genetic Algorithms, whilst for active damping force by employing Hooke-Jeeves non-linear programming method. On the basis of comprehensive analysis it is shown the active systems are more adequate. The proposed suspension design provides relatively small lateral wheel motion, zero camber angles, and effectively absorbs the vibrations caused by road excitation.*

**Keywords:** DESIGN, SUSPENSION SYSTEM, OPTIMIZATION, MODELING, CAD

## *1. Introduction*

The primary function of the vehicle's suspension system is to keep quality contact between the tires and the road surface, as well as to isolate the vehicle's body from vibration coming from road disturbances. The suspension system physically connects the vehicle's chassis with its wheels, and consists of wheels with tires, springs, shock absorbers, and a few rods and linkages, as well as the steering system, Lajqi [1], Lajqi et al. [2, 3].

Scientific papers, patents, many original and innovative concepts regarding suspension have been studied and analyzed by different authors.

Mokhlespour et al. [4] in their research, present an optimization procedure for a double wishbone suspension system with variable camber angle adjusting of hydraulic mechanism.

Allred [5] explores how a compliant mechanism can be used within vehicles' suspension system. Such a mechanism has advantages regarding the questions of space requirements, lower number of joints, rigid links, and simpler design for manufacturing and assembly.

Heo et al. [6] have developed a method for computing kingpin geometry which is an important design feature of vehicle suspension geometry. The idea of a geometric kingpin axis has been used to design a relatively simple suspension mechanism such as a double wishbone type, and various techniques have been developed for designing the kingpin axes of multi-link suspensions.

Maher [7] has identified control strategies for vehicle suspension system by measuring operational data. Finding methods for identifying the values of suspension parameters has considerable interest, in practice. For facilitating experimental suspension system data, a quarter car suspension test rig has to be constructed.

Bouzara and Richard [8] have analyzed the effects of vibrations on the driving comfort and driving safety observed by a variation of different suspension coefficients, road disturbances, and seating positions. In their study they developed a mathematical model for simulating the dynamic behavior of a 3-D vehicle.

Gobbi and Mastinu [9] have used a simple linear model to derive at a number of analytical formulas that describe the dynamic behavior of the passive suspension system. They have introduced an optimization method, based on Multi-Objective Programming and Monotonicity analysis featuring the best compromises between those conflicting objective functions that indicate improved driving comfort, driving safety, and suspension travel.

Baumal et al. [10] demonstrated numerical optimization methods for partially automating the design process. A global optimization technique such as Genetic Algorithms is used to determine vehicle suspension parameters. Genetic Algorithms are also used to compare obtained results from cited literature based on a gradient projection method.

Alkhatib et al. [11] has used the Genetic Algorithms method for optimizing the problem of a linear vibration isolator. This method was extended to optimize a linear quarter vehicle model.

Yu and Yu [12] describe a procedure for obtaining an optimal vehicle suspension design on a quarter vehicle dynamic model. Two objective functions were used for minimizing the acceleration of the sprung mass and suspension travel, subject to a number of constraints. In solving this problem, the Genetic Algorithms have been used and consistently found to be near optimal solutions within specified parameter ranges for several independent runs.

The proposed suspension system for the terrain vehicle was successfully derived at from a classic double wishbone control arm. The control arms are long but both equal. Larger wheel motion is ensured without reducing driving performance. To improve the comfort and safety an optimal active damping force is determined by the active and semi-active systems. Optimization of the suspension parameters for passive ones is performed by Multi Objective Genetic Algorithms, whilst for active damping force by employing Hooke-Jeeves non-linear programming method. On the basis of comprehensive analysis it is shown the active systems are more adequate. The proposed suspension design provides relatively small lateral wheel motion, zero camber angles, and effectively absorbs the vibrations caused by road excitation.

## *2. Design processes by applying CAD systems*

Design processing forms a major part of research and development activities. This process covers the activities of preparing drawings, detailed technical specifications, as well as necessary information for manufacturing products in order to satisfy customer requirements.

Generally speaking, the task of each engineer is to apply his/her scientific and engineering knowledge to find one or more suitable solutions for specific design problems. In addition to the basic design, it is necessary to optimize it according to requirements and constraints; such are materials, technological possibilities, reasonably cost, legal restrictions, and environmental and human source-related considerations.

The design task becomes clearer after recognition of the problem and defining the criteria and requirements that engineers have to adopt and apply in order to design for production.

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According to Pahl et al. [13], Mastinu et al. [14] the four stages of the design process can be defined as is shown in Figure 1.

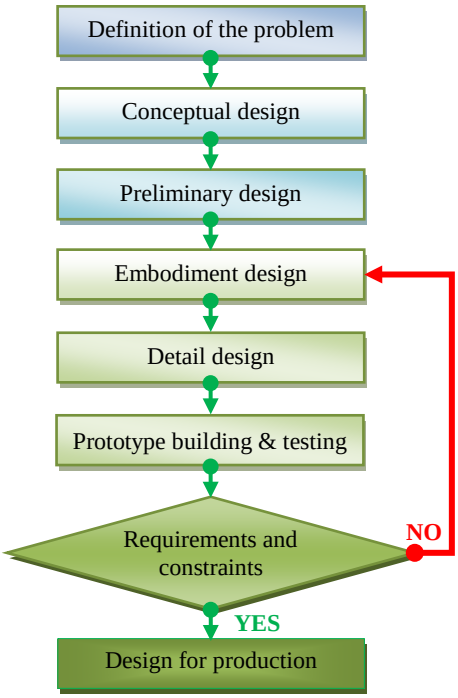


***Figure 1***. *Flowchart diagram showing the stages of the design process*

***Conceptual design*** is the part of the design process that determines the method of solving and treating a problem. At this stage it is necessary to identify the essential problems, establish the functions, and find working principles for the problem. The basic solution could be reached by examining the working principles of the problem and combining them with real possibilities, in order to find a solution.

***Preliminary design*** is the second stage of the design process, also known as feasibility design, and is considered as part of the conceptual design. The preliminary design is obtained by refining the conceptual design according to the design specifications regarding the best choice for the preliminary design.

***Embodiment design*** starts from preliminary layouts, selecting the most desirable preliminary layouts, the working concepts of a technical product, and again refining and evaluating using technical and economic criteria. Much work is then done to refine the concept. The geometry, shapes, weights, and interactions are determined during this stage.

***Detail design*** is the final stage of the design process that combines the embodiment of technical products with final instructions for manufacturing. This stage of design includes detailed explanations about the drawings, dimensions, tolerances, sizes, forms, surface properties of all the individual components, specifications of the materials, operating procedures, manufacturing costs, etc.

The classification of the design process as four stages is not a unique one and is in fact a general classification when considering complex mechanical systems. Nowadays, CAD systems are employed for implementing the design phases mentioned previously. The more up-to-date the greater those applications concerning CAD systems utilize computer software's such as AutoCAD, CATIA, Pro/ENGINEER, SolidWorks, etc.

The working principles of CAD systems are based on interactive computer graphics. The users of CAD systems are designers who use data for executing commands via various input devices of the computer, and develop images on the output device (monitor screen, printer) for faster and easier designing. The designer with his conceptual design performs a part of the design process, whilst the computer carries out the task most suited to its capability, such as fast calculations, searching, sorting, routine operations, displaying on a monitor, analyses of structural design, printing drawings, Balič [15].

The CAD system has many advantages compared with traditional manual design. It improves the efficiency and quality of work, saves money during design, as well as the manufacturing process. The other advantages of the CAD system could be hard to measure but some of them are: increasing the productivity of design, easy corrections of drawings, repetitive parts of a drawing, virtual reality simulation of the structural design, reducing storage space, etc. In addition to advantages, CAD systems also have some drawbacks, such as a high initial cost, requires adequate training and education of staff for efficient usage, reduction of human resources, etc.

## *3. Numerical analyses methods*

Nowadays, as also in past, numerical analysis through Finite Element Methods (FEM) is significantly used in different engineering fields, such as aerospace, automotive, heavy equipment and machinery, civil engineering, etc. Analysis by mechanical systems often presents difficult engineering tasks because of the high complexities of their geometry on the one hand, and the different applied loads (dynamic load, stiffness, etc.), on the other.

The behavior of these systems can be analyzed by setting the differential equations as a basic principle of the mechanics. The solving of differential equations in many cases is impossible, except in those cases where the geometrical, loading, and boundary conditions of the problem are very simple, and makes possible direct integration, Mecitoglu [16]. On the other hand, the solving of a mechanical problem where the geometry and loading condition are relatively complex is impossible to solve by analytical methods.

This problem successfully can be solved by employing numerical methods. FEM belongs to the class of numerical methods and is one of the more powerful methods for solving a wide-spectrum of engineering problems.

The exact period of early development regarding FEM is very difficult to determine, Sorić [17]. The first publication on FEM appeared from J.H. Argyrisa in 1954. The number of publications referring to FEM is relatively large. Between 1967 and 1999, a total of 467 books were published regarding FEM, Mackerle [18]. According to Sorić [17] and Mackerle [18] the first computer program based on Finite Elements was introduced between 1960 and 1970 and by 2002, 1538 FE codes had been registered.

The design task utilized by Finite Element Analysis (FEA) is to investigate the behavior of a structure which is subjected to specific boundary conditions and loads. In order to make an analysis of the mechanical structures using FEA, the real geometry of the structure first needs to be split into discrete portions, which are known as Finite Elements (FE). Each FE is formed by joining points known as nodes. FE and nodes form a grid so-called a mesh. The quarter suspension system of the terrain vehicles performed by discrete FE is shown in Figure 2.

Usually a FE is a non-linear formed by the joining of two nodes. Each node has the capability to move within six degrees of freedom (when three are displacements and three are rotations), Figure 3.

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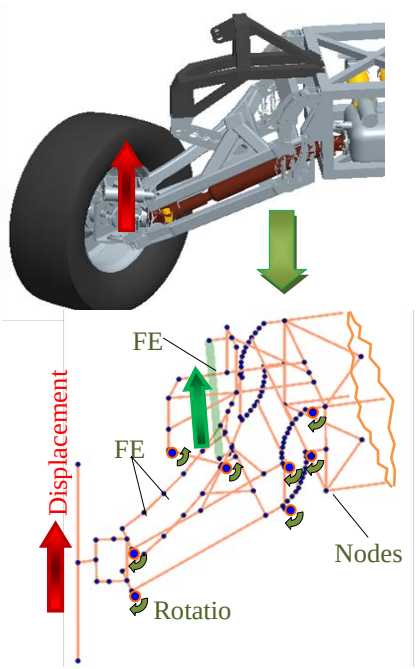


***Figure 2**. Modeling of a quarter of the suspension system - FE*

The relation between the stiffness matrixes, vector displacement, and the applied force in nodes is determined by the global equation of FE. The global equation of FE is described by the following expression:

$$[\boldsymbol{k}]\cdot\{\boldsymbol{u}\}=\{\boldsymbol{f}\}, \tag{1}$$

where **[*k*]** denotes the global stiffness matrix of a structure, **{u}** is the global nodal vectors displacement, **{f}** introduces the global nodal vectors of the applied forces, $u_i$, $v_i$, $w_i$ are the termed vectors displacement of nodes $i_{th}$, $q_x$, $q_y$, $q_y$ define the rotational vectors of nodes $i_{th}$ in the axes $x$, $y$ and $z$ and $i$ = 1, 2, ... , $n$ are the presented nodes.

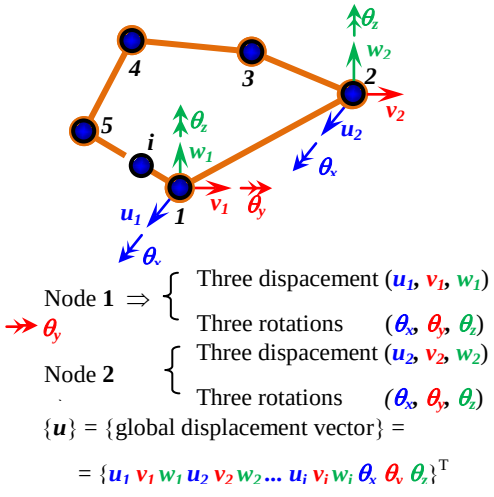


***Figure 3**. Moving capabilities of FE mapping of nodes*

Recently, an improved performance by computers has allowed the rapid development of software packages for solving mechanical problems that are based on FEM.

This software enables modeling, analysis, and optimization, as well as modifications of designs for various engineering problems over a short time. Numerical analysis, dynamic simulation, and optimization can be performed by employing software packages such as STAKx, MATLAB, Working Model, MathCAD, iGOx-i, etc. The tasks of each FEA software is based on FEM formulation of a model, and the correct defining of input data. In practice, FEA software is usually divided into three parts: pre-processing, processing, and post-processing. A flowchart showing the organization of FEA software, is shown in Figure 4.

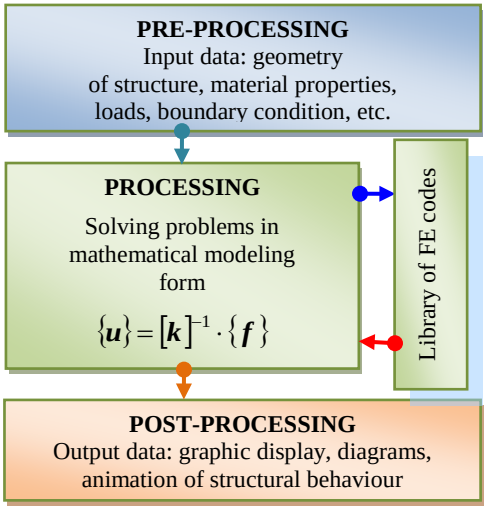


***Figure 4**. Flowchart diagram of FEA process, [16],[17] and [18]*

where $[\boldsymbol{k}]^{-1}$ denotes the global inverse stiffness matrix of a structure. The pre-solver formulates the mathematical model by reading data from pre-processor, the processor computes solution by solving global equation of FE, while in the post-processing stage are presented obtained results and their interpreting.

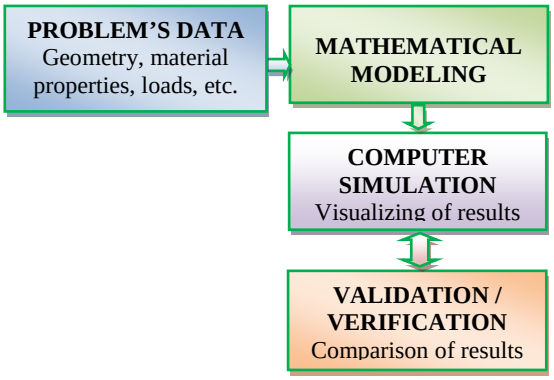


***Figure 5**. Flowchart of the mathematical modeling and simulation processes*

Although mathematical modeling describes just a part of the reality it can be very useful for analyses and design. In most cases when modeling and simulating mechanical systems described using mathematic expressions, software packages such MATLAB/ Simulink, MathCAD are used.

## *4. Optimization of the mechanical systems*

Optimization techniques for mechanical systems play an important role. The purpose of this is to find the best ways of deriving maximum benefit from available resources. Over recent years, several optimization methods have been developed (e.g. Gradient, numerical, Genetic Algorithms, etc.). Optimization methods based on Gradient platform are widely used in mechanical optimization systems. These methods have favorable convergence properties and computation effort is very small. However, the optimization method based on Genetic Algorithms is a stronger tool for finding the global optimal point without any requirement on the gradient and the Hessian Matrix. While optimization of the suspension parameters can be done by employing Multi Objective Genetic Algorithms, and the Hooke-Jeeves methods.


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***Numerical optimization methods*** that are used in engineering are usually divided into the following three groups, Lenart [19]: conventional, shape and topology optimization methods.

The conventional optimization method is a numerical method and is one of the more popular optimization methods due to its easy usage. This method is based on a modest modification such as the geometric parameters of individual finite elements (e.g. cross-section, thickness, etc.). In other hand, the topology optimization methods are probably the most complex methodology for optimizing mechanical systems and when working intensively to develop. Sometimes shape organization is used between conventional and topological optimization methods. The key problem before shape optimization is the selection of suitable ways for geometric parameterization. The parameterization process used for the optimization of a suspension system is already complex enough. The main reason for this is the fact that the conventional optimization process does not require substantial changes in preparation data for the analysis of the structure. The situation is totally different when optimizing the shape of the suspension mechanism or other structure. Automatically changing FE mesh requires a different concept for preparing geometric data. In this situation, it is necessarily to have several FE codes that have been tested and applied in various applications, and will be used for optimizing the geometry of the suspension mechanism. In this case, the geometric data prepared for modeling the suspension mechanism are so-called project elements obtained from FE codes. These project elements are prepared in ways that depend on the design variables. Design variables, within this context, can therefore be considered as a form of parameterized FE mesh, and the whole approach is called the concept of suspension mechanism parameterization.

## *5. Optimization method based on a Genetic Algorithms*

The Genetic Algorithms (GAs) used for optimization of the mechanical system are stronger tools for finding the global optimal point without any requirement on the gradient and the Hessian Matrix. GAs are used for global search methods that are based on Darwin's principle of natural selection and genetic modification. GAs consists of *initial population, fitness function, selection function, crossover, and mutation.*

Therefore, based on the wider number of publications and the research done regarding GAs, it can be concluded that optimization of the suspension parameters based on the GAs platform provides suitable results, Likaj et al. [20]. The multi-objective GAs optimization method is employed for optimization of passive suspension parameters such as spring stiffness, damping coefficient, tire stiffness, sprung and un-sprung masses of the terrain vehicle.

## *6. Conclusion*

During the modeling process of suspension system, the researchers have to make several attempts in order to be sure that the simulation results are suitable and accurate. By designing a completely new suspension mechanism which was derived by improving a double wishbone with longer equal control arms. Mathematical modeling and solving of equations of motion had been developed by numerical methods for a quarter of it. In order to provide less lateral wheel motion, the Finite Element Methods were employed in order to optimize. The proposed suspension design provides relatively small lateral wheel motion, zero camber angles, and effectively absorbs the vibrations caused by ground excitation.

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