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FACULTY OF MECHANICAL ENGINEERING IN NIŠ

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MECHANICAL ENGINEERING IN XXI CENTURY

PROCEEDINGS

Niš, April 19 - 20, 2018

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PREFACE

More than half a century of tradition, high standards in education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognisability, position the Faculty of Mechanical Engineering, University of Niš, as the leader in the field of engineering sciences and technologyical sciences, not only on the territory of the Republic of Serbia, but also in the wider region of the Western Balkans.

The proceedings of the 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering, University of Niš, celebrates its fifty eighth anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on May 18, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programmes and to develop and perform scientific and professional work in the field of engineering sciences and technology. Its vision is to be recognisable in the European and global academic environment in the areas of mechanical engineering and engineering management.

More than 100 teachers and associates, around 45 members of non-teaching staff, as well as numerous teachers and associates from other faculties and from the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering, University of Niš, is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering sciences and technology. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is a scientific research institution, in addition to being an educational one. There are 11 international scientific research projects within the framework of FP7, TEMPUS, CEEPUS, DAAD, bilateral and cross-border programmes, as well as 24 national scientific research projects, being implemented at the Faculty this year. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for the presentation of latest results, basic and developmental research and application within the topics of:

- Energetics, Energy Efficiency and Process Engineering,
- Mechanical Design, Development and Engineering,
- Mechatronics and Control,
- Production and Information Technologies,
- Traffic Engineering, Transport and Logistics,
- Theoretical and Applied Mechanics and Mathematics,
- Engineering Management,
- Future of work, engineering and professional ethics in the era of globalization.

The Conference will also host the assembly meeting of Serbian Association for the Promotion of Mechanism and Machine Science (SAToMM), as well as the meeting of the National Science Board for Mechanical Engineering and Industry Software, will be held.

One hundred and eight papers, whose authors come from 10 countries, are published in these Proceedings. The papers present the research results of numerous projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects.

The main goal of the Conference is to bring together researchers from scientific and industrial institutions so that they can present and communicate their newest results, create personal contacts, promote research within the area of mechanical engineering, and stimulate the exchange of results and ideas within the fields encompassed by the Conference.

As Dean of the Faculty of Mechanical Engineering in Niš, I am honoured to greet all participants of the Conference and wish them very successful work.

Dean of the Faculty of Mechanical Engineering,
University of Niš

Prof. Dr Nenad T. Pavlović

Niš, April 2018

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Parametric Optimization of the Structures Using Finite Element Method

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***Abstract*—The paper presents the theoretical basics of parametric optimization of constructions as well as its application using the Femap with NX Nastran. On a subject of complex geometry construction for the transport of materials was given the principle of parametric optimization in with the goal of mass reduction. The procedure which is shown is very suitable for the optimization of complex structures because it allows great time efficiency. The results of repeated analysis show that the optimized structure satisfied all the set criteria, although mass reduction was achieved. This paper gives a good basis for further researches, developments and fastening the procedure of optimization and analysis of structures using the finite element methods (FEM).**

***Keywords*— parametric optimization, finite element method, crane, Nastran**

I. Introduction

Optimization techniques are used for improving of design construction as well as for manufacturing process. More precisely, the optimization presents the improvement of design construction with maximum saving in material and the time for design, but also achieves maximum functionality.

The finite elements method (FEM) as numerical method is used for checking of various dimensions of construction exposed to different loads, without need for creating of prototypes. The designers must confirm every change, in order to check whether a new design satisfies all conditions regulated by standards. This process can be very boring, but it can be automated by using of the optimization [1]. The optimization is the process of improving of design by finding the best results under given conditions. There are three kinds of structural optimization: parametric optimization, shape optimization and topology optimization [2]. Shape optimization implies dimensions and shapes change in existing functions, and topology optimization means the creating of new functions, mostly of free-form openings for even distribution of stresses. Unlike the shape and topology optimization, parametric optimization indicates the change of construction dimensions but without change of geometry [3].

In this paper parametric optimization is applied on the construction of the crane, intended for transporting the material with the aim of achieving a certain mass reduction. Based on CAD model, the FEA model in software package Femap with NX Nastran [4] is created. Strength analysis achieved results, in relation to, maximum permissible stress. Under parametric optimization of certain construction dimensions, whereby the change of dimensions must be in accordance with all load cases to which the construction is exposed. Achieved values of stress after optimization cannot exceed the values of maximum permissible stress regulated by relevant standards. In this way saving is achieved in mass construction, what is of great importance to the producers because it leads to manufacturing costs reduction. In order to understand the process of parametric optimization, the basic theory of optimization is given in further text, with special attention to the application of gradient methods as the most frequently used method.

II. Basic Concepts of Optimization

The main aim in optimization is to maximize the efforts towards achievement of the goal or to maximize profit. Any effect can be quantitatively expressed as the function which depends on one or more variables so the optimization can be defined as the process of finding the conditions (variables values) whereby the minimization of investing or the maximization of profit expressed as the minimum or the maximum of function values [5].

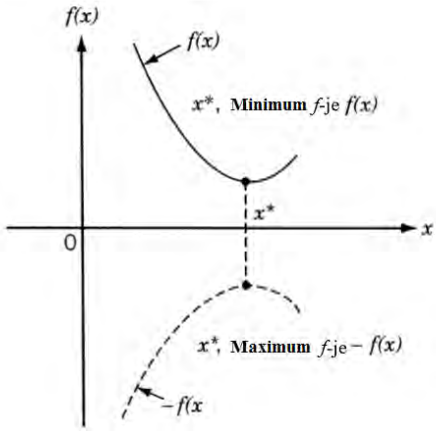

Fig. 1 Minimum and Maximum of functions *f(x)* and - *f(x)*

In the Figure 1 it is shown that the point x presents the minimum of function *f(x)* and the same time presents the maximum of the functions -*f(x)*, because the maximum of function can be found by finding the minimum of negative function.

Mathematical operations such as multiplication and the addition of functions with an arbitrary constant C can be performed in such a way that they do not affect the value of the optimal process optimization. There are lot of methods to solve all optimization problems, and optimization techniques have been developed and contributed to make it as efficient as possible.

Optimization process can be defined as the process of finding the vector $x=\{x_1,x_2,...,x_n\}$ which minimize the function *f(x)* under boundary conditions, defined by equations (0.2), (0.3) and (0.4).

$$x=\{x_1,x_2,...,x_n\} \quad (0.1)$$

$$g_j(\vec{x}\le 0), j=1,2,...n_g \quad (0.2)$$

$$h_k(\vec{x})=0, k=1,2,...,n_k \quad (0.3)$$

$$h_i^I \le x_i \le x_i^U, i=1,2,...,n \quad (0.4)$$

Vector $x=\{x_1,x_2,...,x_n\}$ is *n*-dimensional vector of variables and the function *f(x)* presents criteria function. The equation (0.2), (0.3) and (0.4) presents which are called inequity constraints, equity constraints and side constraints, respectively. The number of variables and the number of constraints is not generally connected in any way. Quantitative values for description of certain engineering system present the variables of system during the creating or system components. Variable of the system suggest that all those values which don't have predetermined constant values in the process of system creating. It can be expressed through *n*-dimensional vector of variables shown in (0.1).

In the course of determining of variables which effect the final design of the product, it is important to take care of all constraints with which the constructor is encountering during development. Constraints which must be satisfied during creating of the accepted design of product are called boundary conditions.

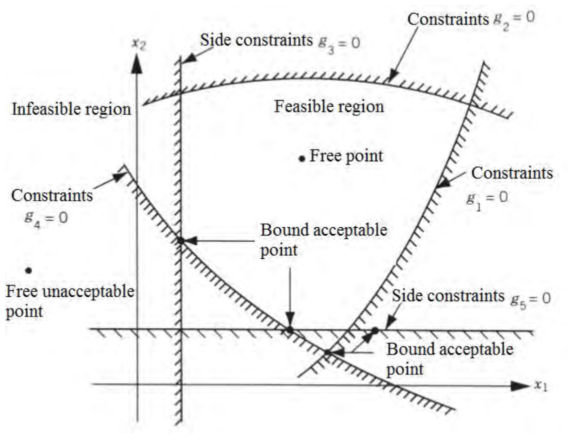

Fig. 2 The illustration of limit state hypersurface and its elements

In further paper just the case of inequity constraints $g_j(\vec{x})=0$ will be considered. By solving the equation $g_j(\vec{x})=0$ the set of variables values are given which forms limiting hypersurface. Constraint surface divides the designed space into two parts, the first part satisfies the solutions of equation $g_j(\vec{x})<0$, the other part is defined by the equation $g_j(\vec{x})>0$ The set of variables values which forms hypersurface is defined by the vector of variables $x=\{x_1,x_2,...,x_n\}$.

From the Figure 2 we can see the points which satisfy the equation $g_j(\vec{x})<0$ belong to the region and can be an optimal solution which the engineer is trying to find while the points which satisfy the equation $g_j(\vec{x})>0$ are not acceptable.

In the course of finding of the optimal solution during design it is very important that the solution satisfies all relevant criteria. Since there is just one solution which is available to the given design construction, the optimization is very useful tool, because the best of possible solution has to be found. Criterium function helps us with that, because through it the optimized solution in the function of the variables, which describe the design [6]. It can be said that the selection of a criterion function is one of the most important tasks in the optimization process, since most often there are several conditions that must be met. In the case when several criteria must be met, the optimization process is called the multi-criteria optimization process. The simplest way to solve the problem is to form a new criteria function, which is presented as a linear combination of opposing criteria functions

$$f(\vec{x})=c_1 f_1(\vec{x})+c_2 f_2(\vec{x}) \quad (0.5)$$

where $f_1(\vec{x})$ and $f_2(\vec{x})$ represent the criteria functions of the first and second required criteria, respectively. The values of the constants c_1 and c_2 define the significance of one criterion function relative to the other, in the action on the global criterion function.

When the surfaces of the criterion function in the workspace are determined, but in order to meet all the given constraints, an optimal solution can be found. The problem arises when there are more than three variables. With three variables it is possible to draw surfaces but they are much more complex. When there are more than three variables, it is not possible to draw surfaces, but the entire optimization process must be solved purely mathematically.

III. Parametric Optimization

Parametric optimization is most frequently applied to lattice structure where the main goal is to optimize the values of cross-section plates. So, it can be considered that parametric optimization is simplified variant of topology optimization. Parametric optimization also encompasses varying thickness of the elements in order to determine the optimized thickness of the plates in the model what will be shown further [6]. Parameters are the components which describe the design of observed system in the case of the crane, the parameters are thicknesses plates. Parametric optimization is the process of finding of optimal solution of the problems that have one or more constraints. Traditional approach to the optimization means the method of examining and error, where the engineer relies on his own knowledge and experience. During the process of parametric optimization of crane model, the process must be rapid and more effective because it saves time and reduces the costs of final product [2].

Algorithm of traditional approach of optimization and software approach is shown in the Figure 3 [2].

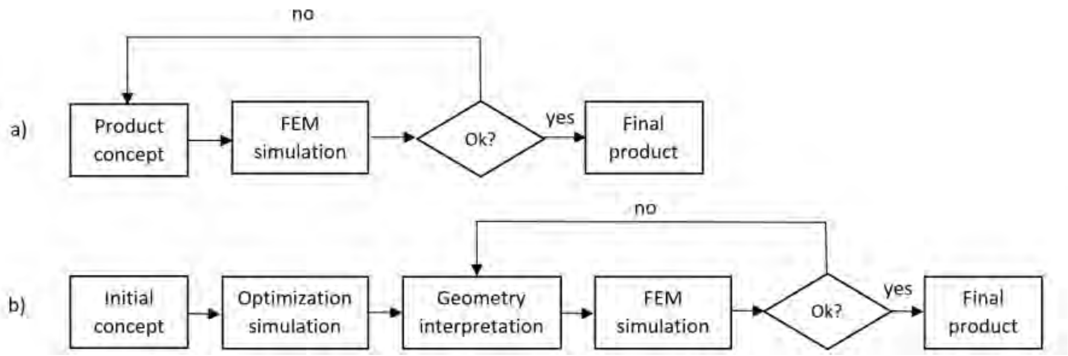

Fig. 3 Types of approaches to optimization: a) Traditional approach; b) Software aided approach

IV. CALCULATION RESULTS

The crane is the type of the construction designed for transport of the loads. It is used for lifting as well as for lowering of the materials and for their transportation on horizontal surface. It is mainly used for lifting of heavy materials and for transporting to other place.

In accordance to CAD model, the crane is modelled using the Femap software with NX Nastran solver, which operates based on the finite element method. According to the construction type, shell elements of the appropriate thickness and 3D elements were used for creating the finite element mesh. The structure is modelled in details with 29794 elements and 30419 nodes. General element side length is about 30 mm. The Figure 4 shows the finite element mesh of the crane. Colours in Figure 4 match the various thicknesses of shell elements.

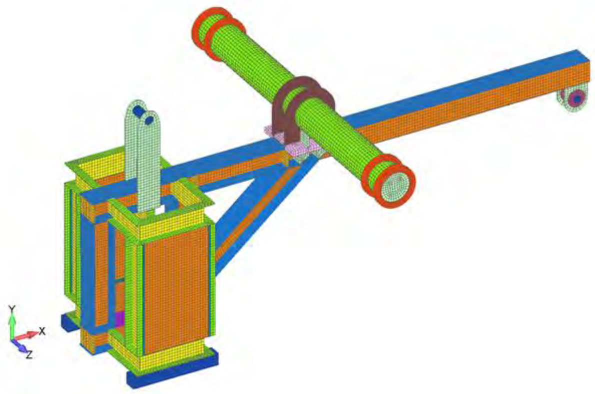

Fig. 4 3D model of crane - finite element mesh

Structural analysis is carried out using the software NX Nastran [4]. Permissible stress are defined according to regulations defined by standards EN 10025-2:2004 [5], DIN 15018-1 [7], and DIN 4132 [8]. The crane is designed as welded construction, so for maximum permissible stress it is used 150 MPa and this value will present a referential value during parametrically optimization Static linear analysis was performed for material S355J2 with physical and mechanical characteristics given in accordance to EN 10025-2:2004 [5].

Structural analysis were performed for four load cases, with a focus on plate thickness of the crane. The paper shows in details the results for the most unfavorable load case shown in Figure 5, but parametric optimization was done for all load cases.

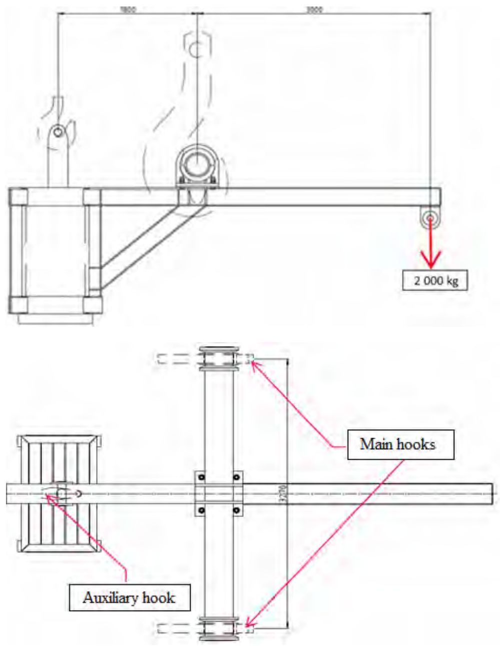

Fig. 5 The most unfavorable load case of the crane

According to the loading scheme of loadings, strength calculation with initial plates thickness of crane was done. Figure 6 shows field of von Mises equivalent stress on the model before optimization. Significant loaded zones are shown in the Figure 7. Maximum value of the equivalent stress is 126.5 MPa. FEM analysis shows that maximum values of calculated stress is concentrated on certain regions and the rest of the crane are unladen.

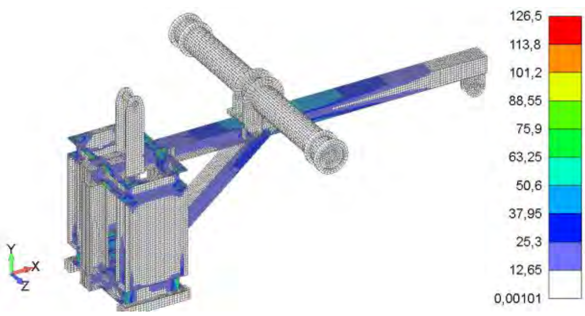

Fig. 6 Von Mises equivalent stress field before optimization

Regarding the values of maximum permissible stress defined by relevant standards [5], [7], [8] and maximal calculated stress it can be noticed that it is possible to carry out parametric optimization of construction in order to prove the given design. Initial crane design satisfies all constraints, so we used it as starting point for our optimization procedure. Optimization was performed for every load case. It showed us a great variation of minimum required plate thickness depending on load case. The plate thicknesses and total mass of crane before and after optimization are shown in the Table I.

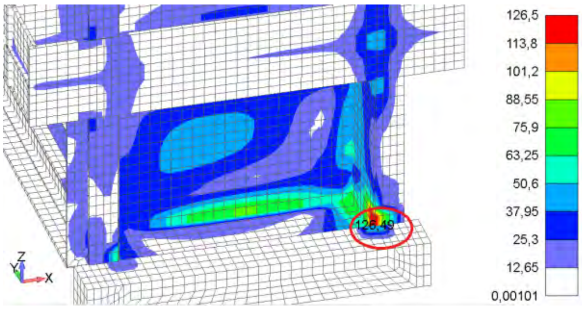

Fig. 7 Maximum Von Mises equivalent stress; significant loaded zone before optimization

TABLE I ILLUSTRATION OF INITIAL AND OPTIMAL PLATE THICKNESS.

Initial plates thickness (mm)	**Plate thickness - optimized (mm)**
9.5	8.5
10	8
13	10
15	10
17	15
20	16
23	20
25	22
27	24
30	27
35	31
47	45
50	45
Initial mass of crane (t)	**Mass of optimized crane (t)**
3.17	2.47

For purpose of demonstration of successfully done parametric optimization strength calculation with optimized plates thickness of crane was done. Figure 8 and Figure 9 show field of von Mises equivalent stress on the model after optimization for all model and significant loaded zones respectively for the most unfavourable load case. Maximum value of the equivalent stress is 146.1 MPa which is bellow permissible stress

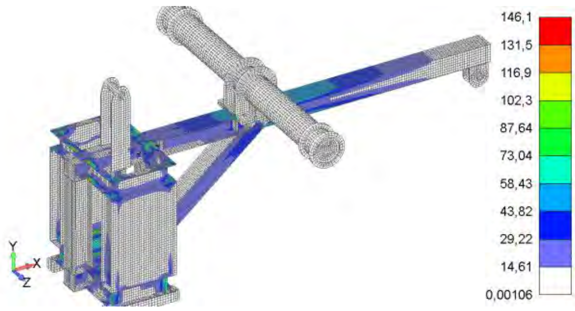

Fig. 8 Von Mises equivalent stress field-optimized crane

According to obtained results after optimization it can be noticed that all plate thickness of crane for all load cases after parametric optimization, given in Table 1, satisfy strength proof according to [5], [7], [8]. It can be seen from Table 1 that construction mass is reduced by parametric optimization for 13.57%.

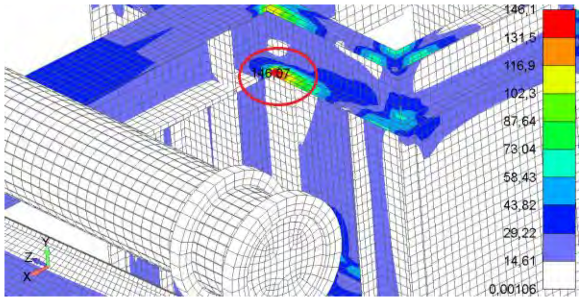

Fig. 9 Maximum Von Mises equivalent stress; significant loaded zone of optimized crane

V. CONCLUSION

This paper describes the implementation of parametric optimization in design process of a complex structures, which uses FEM results to determine the best combination of plate thickness which satisfy criteria defined by appropriate standards. It presents much faster and simpler way of optimization because it can be done in a few steps to avoid a long iterative process of hand made change in parametric construction. Reviewing the savings in the mass it can be seen that the total weight of crane is reduced by parametric optimization. Thus, it can be concluded that parametric optimization is useful tool in the process of product design. According to presented results good basis for further researches was created in the field of optimization and strength analysis of structures using FEM.

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