Iacob-Liviu SCURTU, Sanda Mariana BODEA, Ancuta Nadia JURCO

DESIGN OPTIMIZATION METHOD USED IN MECHANICAL ENGINEERING

Abstract: *This paper presents an optimization study in mechanical engineering. First part of the research describe the structural optimization method used, followed by the presentation of several optimization studies conducted in recent years. The second part of the paper presents the CAD modelling of an agricultural plough component. The beam of the plough is analysed using finite element method. The plough component is meshed in solid elements, and the load case which mimics the working conditions of agricultural equipment of this are created. The model is prepared to find the optimal structural design, after the FEA study of the model is done. The mass reduction of part is the criterion applied for this optimization study. The end of this research presents the final results and the model optimized shape.*

Key words: *topological optimization, shape design, finite element analysis, agricultural tools.*

INTRODUCTION

In the last decade the rapid growth of the mechanical industry required use the structure optimization method. Structural optimization is the process of determining the best design shape of the structural part. The shape of the model resulted after applying some optimization criteria such as: maximum strength, maximum rigidity, minimal displacement, minimal cost, minimum weight, etc.

The beginning of the optimizations was founded by Pythagoras of Samos (569 BC to 475 BC). It was a Greek philosopher with many contributions in mathematics, astronomy and the music theory [1]. After developing the computational system, the mathematical algorithm of optimization was programmed.

In this research is presented the topological study of an agricultural plough component. At the beginning beam is modelled in CAD software and the geometry is exported for pre-processing. In pre-processing the surface of the model is prepared to discretization in finite elements. After the part volume is meshed, the material is assigned and load case creations are completed, this is run in Optistruct solver.

1.1 Concept of the optimization process

To determine the optimal shape of the structure is developed a base computational model. For this model it defines one or more design parameters, named design variables and the restrictions value. These design parameters are given by the fabrication cost, weight of the model, dimensions, the material, etc.

The optimization process should determine the minimum value of the function dependent on design variables. This function, called objective function, must be minimized to lead a design model with minimum weight, maximum strength and minimum displacement. After determining the optimization objective function is reduced to find an extremely of this function [2].

Because the objective functions contain components of the system behaviour under the load case created by the user, evaluations of the functions for a specific set of the design variables requires solving of the border elements problem.

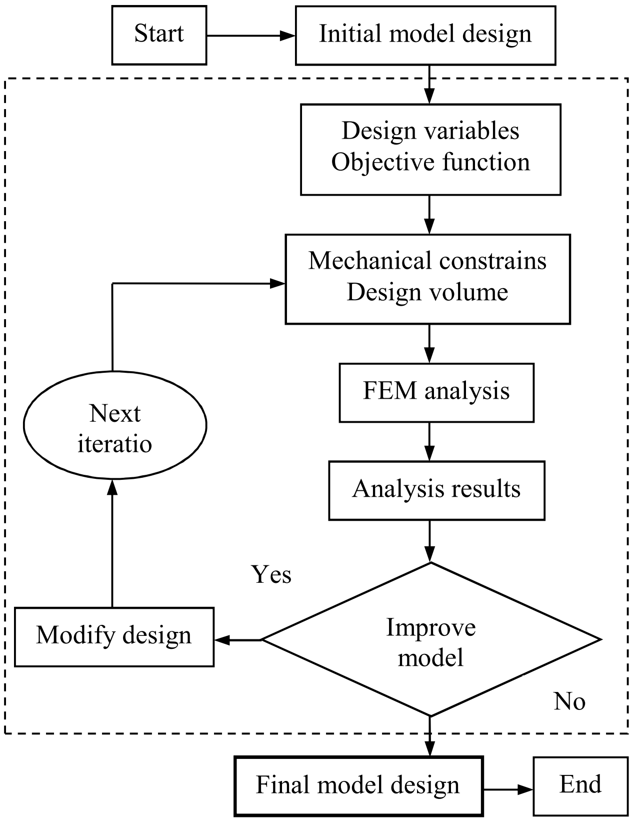


Fig. 1 Flowchart of the optimization process

The optimization process is a component of the design and manufacturing process. The final optimized structure must satisfy the conditions and imposed restrictions. In the optimization process can appear other restriction like technological, transportation, ecological, assembly restriction, etc.

These restrictions limit have a range of variation in the design space where is seeking the optimal shape of the model. Technological restrictions can be solved by the designer, which can make some improvements of the product. In figure 1 is presented the flowchart of the optimization iterative process.

Assembly conditions of the model are fulfilled if the structure of the model can be realised. The start point of the process is given by the initial model design space. After design variables and the objective functions are given the model load case is created.

Analysing the results of the finite element analysis have to decide if the model design is sufficiently optimized or not. If the model design must be improved the design of the model is modified following the next iteration of the process.

In the flowchart presented before the rectangle drawn with hidden line delimited the optimization loop. After completing all iterations, the final geometry of the model is generated.

2. DESIGN OPTIMIZATION METHODS

Due to requirements imposed in design of the mechanical parts, implementation and use of the designed products have developed optimization methods [3], [4]. Some of the optimizations methods are described below:

- Topological optimization – this method is based on mathematical techniques who determine the material distribution into a given volume. The aim of this method is reducing the material weight and the increase the rigidity of the optimized part;
- Topographical optimization – using this method it generated a new shape of the model which can contain the ribs and the reinforcement patterns;
- Free size optimizations – the optimized design are based on the mathematical method witch generate a thickness distributions of the material;
- Shape optimizations – this is an automatic geometry modification method based on the shape variable.

A finite element analysis study of the rotary tillage tool system components is studied [5]. The blade of this tool system is analyzed determining the vonMises stress maximum displacement and the blade shape is optimized.

Topological optimization of the bracket is studied determining the maximum vonMises stress and the optimal shape is generated using Ansys software [6].

Optimization algorithm can be also used in furniture design [7]. In that paper is presented the topological optimization algorithm for a furniture support and the topographic optimization for a furniture connector.

3. CAD MODEL DESIGN

Modelling the geometry of the part is the start point to create an optimization study. Three-dimensional base model proposed for optimization is done using SolidWorks software. This software is a very important tool for mechanical engineers, which has a friendly interface, allowing easy use with a high level of engineering performance.

Using modelling techniques, the model is generated. In figure 2 is presented the base model of plough used in agriculture.

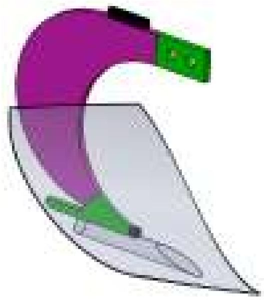


Fig. 2 The base model of the plough

In the following paragraphs the beam of these tools will be analysed and structural optimized.

4. TOPOLOGICAL OPTIMIZATION MODEL

In this section are presented the necessary steps to determine the new topological optimized shape of the plough beam. The mass of the base beam model has 11.31971 kg and volume equal 0.00145 cubic meters. The topological optimization process is solved using Optistruct solver integrated in Altair Hyperworks. This software was founded by James R Scapa, George Christ and Mark Kistner in 1985 [8]. The objective function of this optimization is to reduce the weight of the plough beam.

4.1 Discretization model

The surface geometry of the beam is imported in Optistruct software. The geometry is cleaned using the tool available in this software. The model is meshed in 3150 hexahedral elements with a length 8 mm.

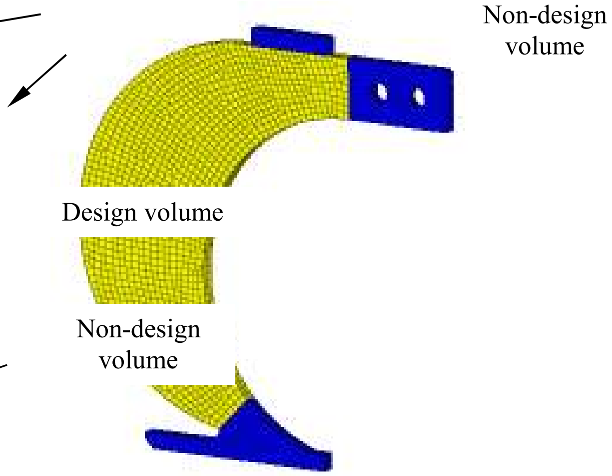


Fig. 3 The meshed model of the plough beam

In order to assembly the part from the plough, the model proposed is divided in two components: design and non-design volume.

In design volume the optimization algorithm can find the optimal shape, and in non-design the geometry still unchanged, allowing a proper connection between components. In figure 3 is presented the meshed model of the beam.

Design space is discretization in 2510 elements and non-design pace in 640 elements.

4.2 Material model

The important point of this optimization study is choosing the material of the model.

Table 1

Mechanical properties of material

Initial density	$7.85e^{-6}$ Kg/mm3
Poisson ratio	0.3
Hardening exponent	0.5
Young modulus	210 GPa
Hardening parameter	0.5 GPa
Failure plastic strain	0.3

The assigned material is steel, from card MAT 1, available in Optistruct. In table 1 is presented the mechanical properties chosen for this material [9].

4.3 Load case creation

The model is rigid connected from the two holes and from the superior side of the part. The force is placed in the bottom of the part in non-design space. Figure 4 shows the point of the application force and the support.

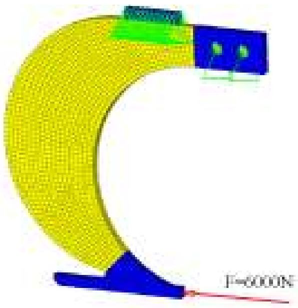


Fig. 4 The model load case

The value of the force is 6000 N. This value of the force is chosen approximately, according to the cutting force of the soil.

5. SIMULATION AND RESULTS

Simulations of the beam plough are done. Maximum displacement is located of the force application point. In figure 5 is presented the maximum displacement.

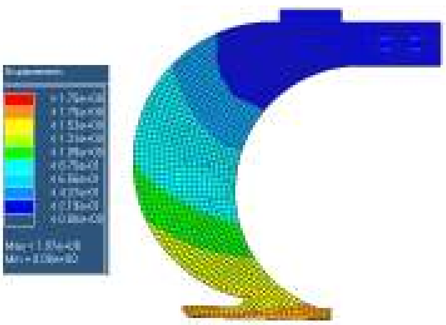


Fig. 5 Maximum displacement

Maximum displacement resulted in this load case is 1.75 mm.

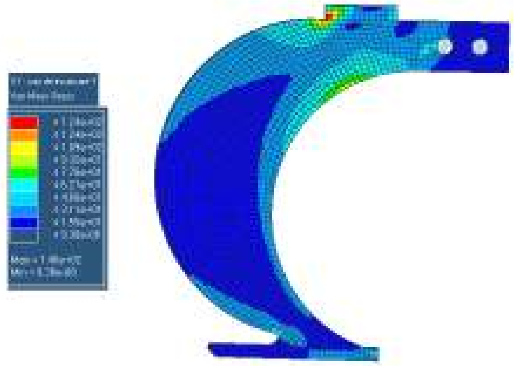
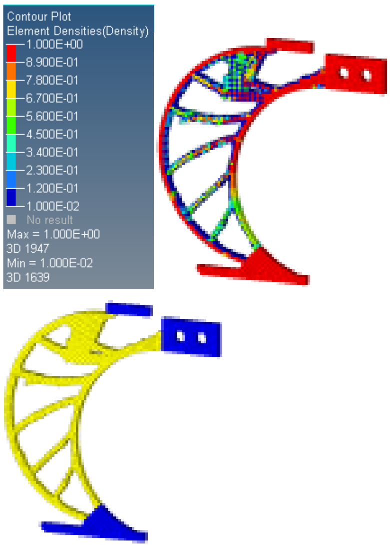


Fig. 6 Equivalent stress distributions

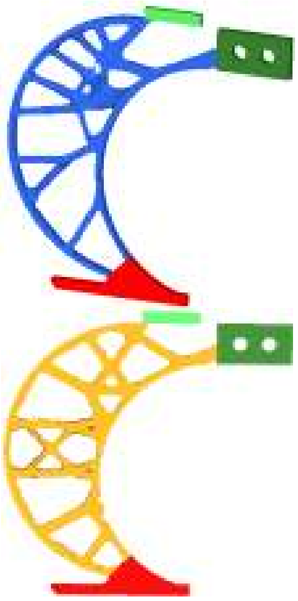
In figure 6 present the vonMises stress distribution in design space of the analysed model. It can be observed that maximum von Mises are placed on the upper side of the beam.



a) b)

Fig. 7 Element distribution in design space

In figure 7 are presented the results of the element distribution in design space.



a) b)

Fig. 8 New design of the beam using symmetric plane

Using the symmetric plane options from the Optistruct software is determined a new distribution of the material. In following figure is presented two design shape resulted of the beam model.

In table 2 is presented the masses and volume of the base model and from shape optimization from figure 8.

The weight of the first optimized model decreased with a percentage of 42 %. The second optimized model decreased compared to the base model with a percentage of 54 %.

Table 2

Masses and volume of the base model

	Base model	**Optimized model 1**	**Optimized model 1**
Mases (kg)	11.31971	4.81701	6.09436
Volume (m^3)	0.00145	0.00062	0.00078

Figure 9 shows the comparison of the base model and the optimized model.

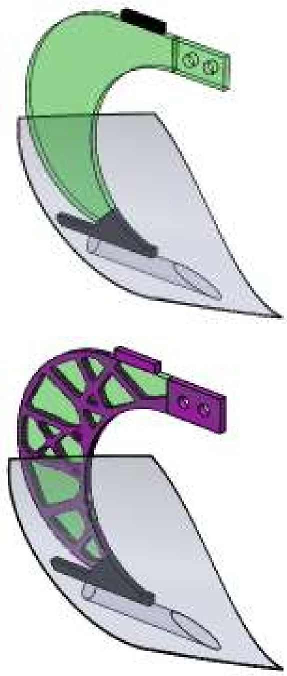


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Fig. 9 Comparison between the base model and the optimized model

To determine the optimized shape were driven 29 iterations. The study was ruled on the HP Z400 Workstation, with an Intel Xeon Processor W3550, 3.07GHz, with 16 GB installed memory and NVidia Quadro FX 3800 graphic card.

6. CONCLUSIONS

Optimization techniques and procedures have been imposed in the past decade as a very valuable engineering resources and instruments in order to achieve the strong, effective and competitive structure.

Employing advanced software solution, the topological optimization process and results are presented. The result of this paper shows the advantages of using the optimizations method for agricultural mechanisms.

Today, the mechanical optimization methods are widely used, especially in the automotive industry. The weakness of optimizations methods is given by the requirements of a better workstation and more computing time for complex parts assemblies. By point of view of manufacturing components technology, the weight optimization is suitable for high volume series. The geometry of the resulted shape is in most case complex and difficult to manufacturing by conventional technological procedures. Usually in these cases the components are manufactured from 3D printers or CNC machines.

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Authors:

Lecturer Liviu-Iacob SCURTU, Technical University of Cluj-Napoca, Dept. of Automotive Engineering and Transports, liviu.scurtu@auto.utcluj.ro, tel. 0264401610

Assoc. Prof. Sanda Mariana BODEA, Technical University of Cluj-Napoca, Dept. of Automotive Engineering and Transports, sanda.bodea@auto.utcluj.ro, tel. 0264401610

Asist. Prof. Ancuta Nadia JURCO, Technical University of Cluj-Napoca, Dept. of Automotive Engineering and Transports, ancuta.jurco@auto.utcluj.ro, tel. 0264401610