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APPLICATION OF TOPOLOGICAL METHODS

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Abstract: The following article briefly summarizes the design aids currently in use, such as topology optimization and generative design, which are common in integrated CAD systems. The results provided by these methods are presented and compared based on a case study.

Keywords: *machine design, design theory, topology optimisation, generative design*

1. INTRODUCTION

When creating machines and structures, the design task can be done in different ways. These methods include the knowledge and steps of design methodology developed in the last century and goes under continuous development. Various procedures and techniques related to the University of Miskolc play an important role in terms of machine design [1], [4]–[7]. Each design method has its own advantages and disadvantages, but the most appropriate one is determined by the qualification of the design staff and the type of task in question. The process is greatly influenced by its resource requirements, but efforts must be made to maintain the technical and technological level of the present age and to create the best use of it. It can be observed that in many areas of industry, the proportion of human labour is decreasing compared to the work of machinery and other means of production. This is inherent in the development process, in the hope of which we can provide a solution to a given task faster, more accurately and, if necessary, at less cost. A system where one merely communicates information and makes decisions while the equipment is working, seems to be a favourable way. Similar processes are taking place in the field of product design, thanks to the generative design module that is widespread in integrated CAD systems, which serves as an example of the philosophy mentioned above. Design engineering is limited to providing accurate information and selecting from the results obtained.

2. PRESENTATION OF THE REFERENCE PART

The case study demonstrates the design of a component made up of simple geometric elements using the design methods provided by the present age, such as generative design. The initial part is a console, which is screwed to a specific plane. A load can be hung in the mortise in the part, so the console is subjected to tensile stress.

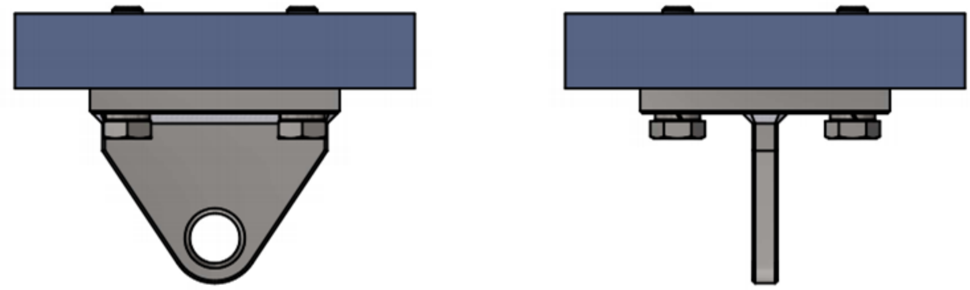

Figure 1. *Installation of the reference part*

It can be clearly seen in *Figure 1* that the part is fixed to the horizontal plane with four M12 screws. During the test, it is assumed that the screw connection used is suitable to withstand the resulting stress states. A hook or pin can be inserted into the hole in the bottom of the part. The console consists of two 10 [mm] thick plates joined together by a welded joint. When creating the model, the effect of the welded joint is neglected.

Table 1

Material properties of the part

Material properties	
Name	stainless steel 1.4125
Yield point	689 [MPa]
Tensile strength	861.25 [MPa]
Young modulus	206.7 [GPa]
Poisson factor	0.27 [-]
Shear modulus	83900 [MPa]
Density	7.75 [g/cm^3]

In order to make the results comparable, a preliminary finite element simulation is performed on the initial workpiece, so that the load capacity of the part becomes known. For finite element analysis, we used Autodesk Inventor. During the test, the value of the maximum stress and the maximum displacement due to the fact that the load is sought.

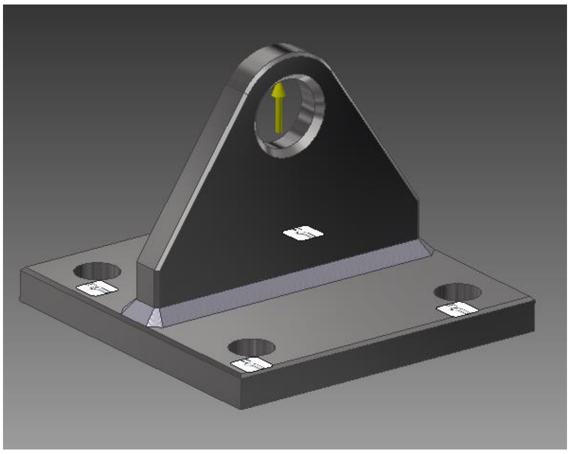

Figure 2. *Place of the load and fixing points*

The point and direction of application of the load applied to the component is indicated by the yellow arrow in Figure 2. From the point of view of component geometry, the direction of the specified load is considered to be critical. The load is considered static with a magnitude of 50 [kN]. The preparation of the part continues with the determination of the fixing points, which are defined at the centres of the mortises, which are symbolized by the white padlocks shown in the figure.

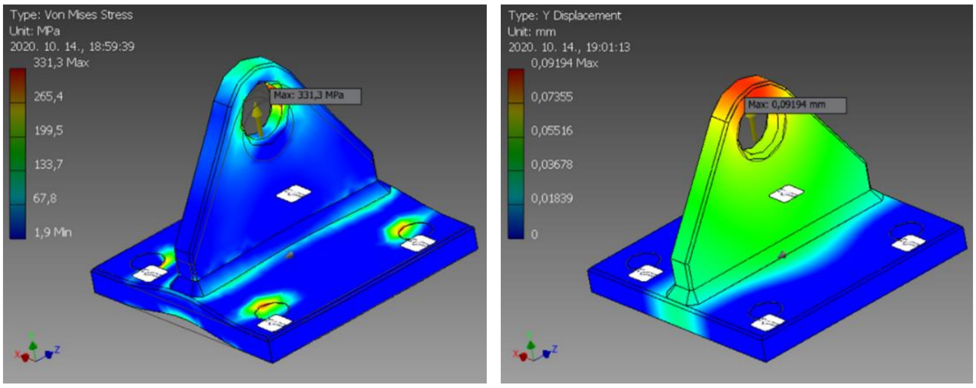

Figure 3. *Stress and deformation state on the reference part*

Based on the results of the study, shown on *Figure 3*, the maximum stress measured in the reference model under the influence of the load force is 331.3 [MPa] and the maximum displacement is 0.091 [mm].

3. Application of Topology Optimization

Topological optimization requires a preliminary body model provided in the present study by the modified geometry of the reference part [8]–[11].

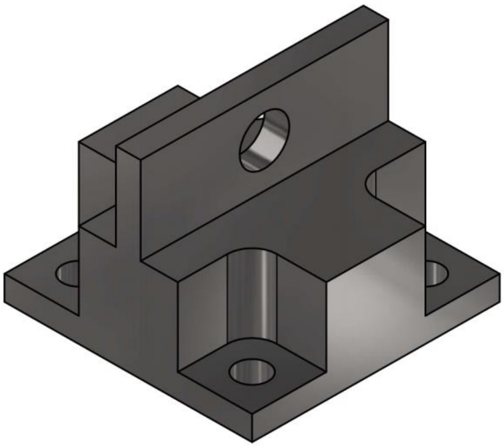

Figure 4. *Modified model of the reference part*

The modifications are shown in *Figure 4*, which overall increased the volume of the original model, taking care of not to interfere with the performance of the functions and to allow the installation tasks to be performed properly. The material selected during the operation is the same as the 1.4125 (440C) stainless steel used so far. In a similar way, a loading force of 50 [kN] was applied, the direction of which was unchanged. In the following, the fixing points are determined, which are the same as the previously used ones. Due to the individual mortises, it is necessary to define so-called fixed volumes, which remain unchanged solid bodies during the optimization [2], [4]. In order to obtain comparable results, it should be considered to give fixed volumes with the same parameters during topological optimization and generative design. This practically meant that cylinders with a diameter of 20 [mm] were fixed for the mortises with a diameter of 13 [mm] and a cylinder with a diameter of 36 [mm] for the mortise with a diameter of 20 [mm]. These solutions are illustrated with green bodies. The software allows the specification of a plane of symmetry or minimum network settings, the proper selection of which can reduce the computation time.

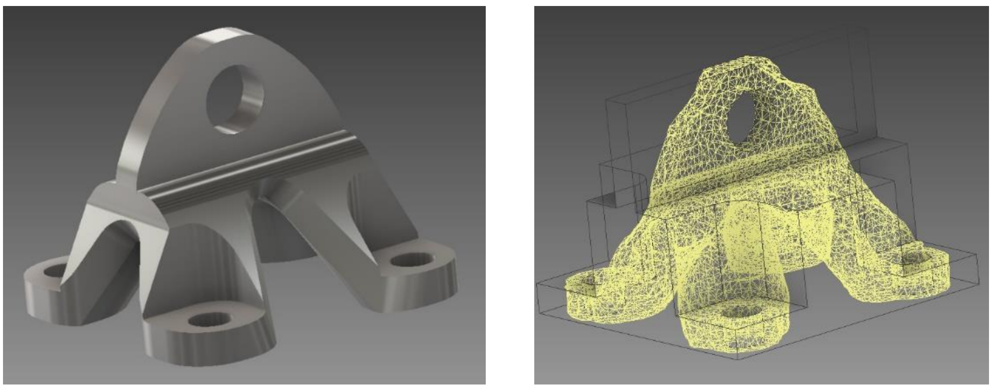

Figure 5. *The result of topological optimization*

Figure 5 shows the results of the optimization process. During the design, we set the weight reduction as an optimization goal, the value of which can be given in percentage. The results were obtained with a weight reduction of 13% compared to the original model, corresponding to a part weight of 0.91 [kg]. The networked model shows that the surface is very uneven. For machining by cutting, the individual ranges were approximated by planes. One of the most important aspects is whether the formed geometry is suitable to withstand the desired loads. In the following, we search for the answer to the given question using finite element simulation.

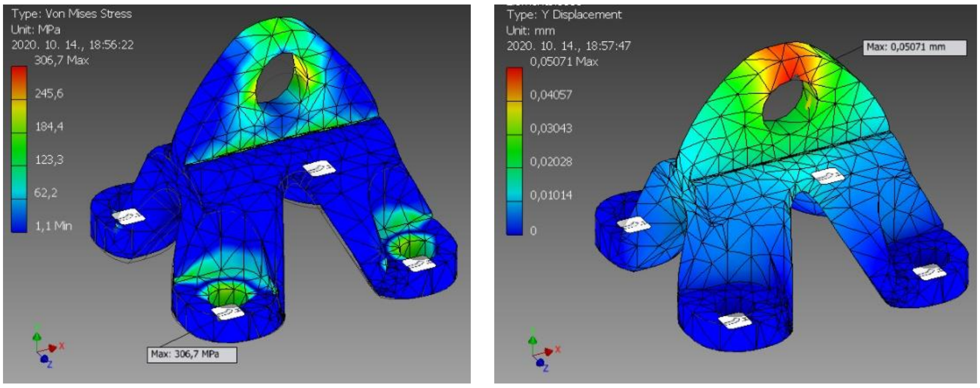

Figure 6. *Stress and deformation state on the optimized part*

Figure 6 shows that the maximum stress generated by the load is 306.7 [MPa], which is adequate for the safety factor used. The maximum value of the deformation is 0.05 [mm].

4. Production of the Part by Generative Design

In the next section of the article, the process of constructing the part produced by the generative design method and the evaluation of the obtained results are presented. Preparations for the process, such as modelling and recording design, non-design, and fixed volumes, were made in Autodesk Inventor, and then the generative design module was applied in Autodesk Fusion 360. We have to go through a substantially similar process as with topological optimization. The individual settings are fully in line with those previously used, so that the geometry limiting the design, the material to be used, the constraint and the magnitude and direction of the load force are the same as the previously defined parameters. Once the appropriate values have been set, a check function must be started in the next step. It goes through the settings and report any deficiencies or inconsistencies to the user of the program [2], [3]. The software will notify the user if not all entered properties of the material are properly defined, or if we have not selected a suitable material for the selected machining. It is a good idea to run a preview command to check that the design volumes are selected correctly for more complex parts. After these control functions, the design process can be started, which takes place entirely in a cloud-based storage. Accordingly, the computer can even be turned off after startup.

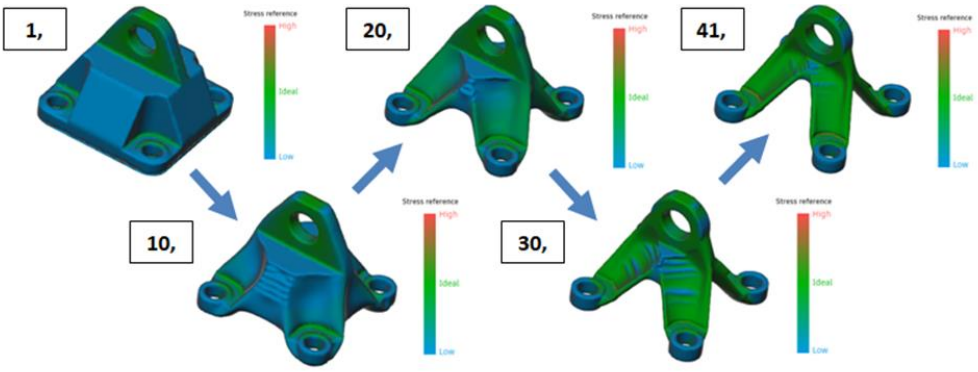

Figure 7. *Iteration steps of the generation process*

It is worth mentioning that many materials and manufacturing technologies can be selected, so the number of solutions is quite large. It is advisable to filter the various solutions as soon as possible. If the generation of solutions starts in a certain direction, it should be treated as a component, so after opening the result of iterations on that logical thread can also be viewed and treated as a possible solution. It may be that the direction of solution generation is favourable for us, but the final result does not fully meet the expectations, then an intermediate element of the process can be used. *Figure 7* shows the evolution of the components undergoing iteration. It is possible to monitor the stress state, which allows us to obtain information concerning the mechanical properties of the given iteration results without further investigation.

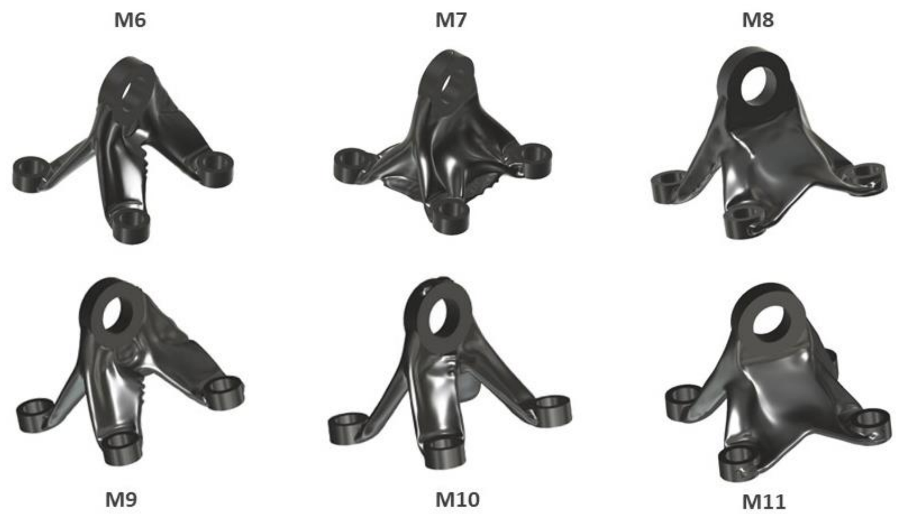

Figure 8. *Results of the generative design process*

The course of the generation resulted in six components shown in *Figure 8*, during which the software mapped two hundred and thirty iteration steps, each of which is a complete component. In the next step, the most suitable variant was selected. The program has a built-in comparison function in which different conditions can be assigned to each coordinate axis and the program evaluates every solution.

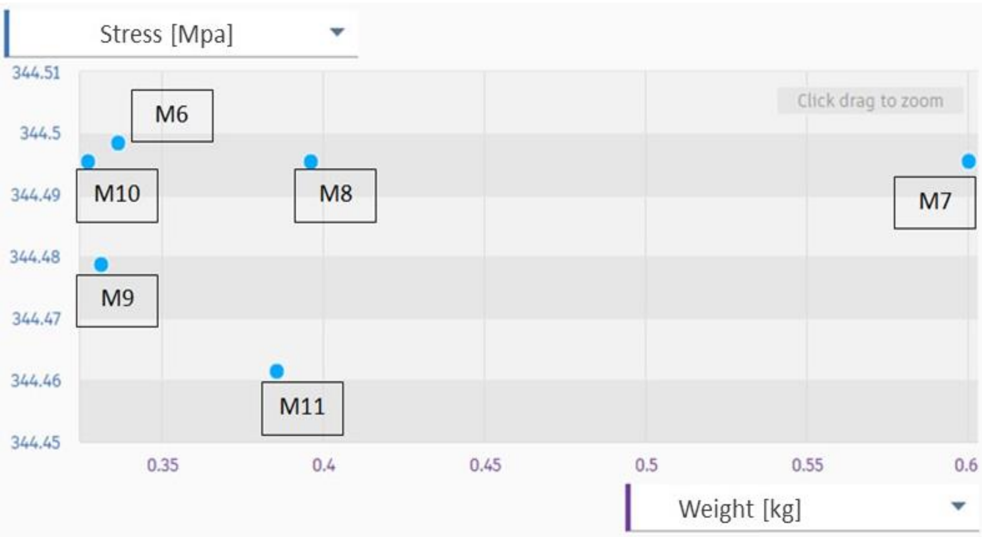

Figure 9. *Classification based on stress condition and mass*

Figure 10. *Classification based on production cost and weight*

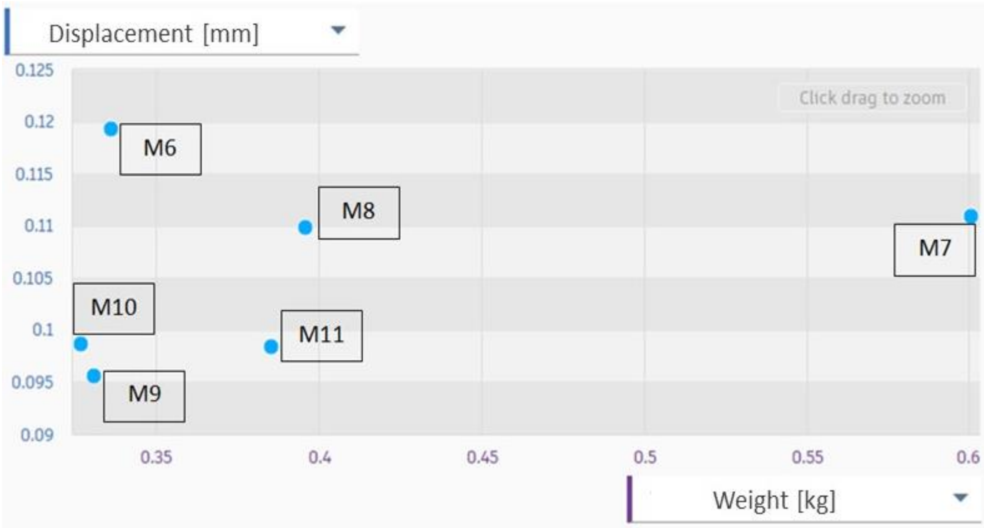

Figure 11. *Classification based on deformation and mass*

Based on the evaluation *(Figures 9–11)*, the M9 and M10 solutions proved to be similarly advantageous constructs. They show a minimal difference based on the maximum displacements, on the other hand the weight and manufacturing cost of the M10 solution are lower. Accordingly, for the part produced using the generative method, the selected construction fell on the serial number M10. Based on the results obtained during the study, *Table 2* summarizes the properties of the components created by the different methods.

Table 2

Summary of the results

	Traditional design	**Topology optimization**	**Generative design**
Quantity	Large series	Small series	Unique
Variations	1 [pc]	1 [pc]	230 [pc]
Machining	Cutting and welding	Milling	Additive manufacturing
Strength	331 [MPa]	306 [MPa]	344 [MPa]
Deformation	0.09 [mm]	0.05 [mm]	0.09 [mm]
Weight	1.07 [kg]	0.91 [kg]	0.32 [kg]
Weight loss	0%	17%	70%
Amount of waste	Medium	Big	Minimal
Cost	10,000 HUF	50,000 HUF	200,000 HUF

5. Summary

The case study provides an insight into the process and issues of contemporary product design. The article makes a comparison of three components that use different methods, in different software, but meet the same boundary conditions. The component designed by the classical method is suitable if the product is to be produced in large series and weight reduction is not important. The production of a part designed using topological optimization is realized on a multi-axis milling machine, the productivity of which is significantly lower compared to the traditional design. The amount of waste generated during production is high, so the use of a component designed in this way is recommended for small series, where the additional advantage is weight reduction. In many cases, the production of a component designed by the generative design method can only be carried out with additive technology, which has low productivity but high cost. The positive thing about production is that waste generation is low. Thus, the use of the generative design method is recommended when achieving significant weight reduction or when using difficult-to-cut materials.

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