Proceedings of TEAM 2015

7th International Scientific and Expert Conference
of the International TEAM Society

14–16th October 2015, Belgrade, Serbia

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CONTENT

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TOPOLOGY OPTIMIZATION USED TO REDUCE WEIGHT OF FOUR-AXLE BOGIE FREIGHT WAGON

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Abstract

The goal of this paper is to show the application of topology optimization for reducing the weight of different types of construction, especially freight wagons. In the first part of this paper a short introduction on optimization techniques is given and characteristics of analyzed model are discussed. In the second section process and results of topology optimization applied on freight, four-axle bogie wagon are given. Final part of the paper includes discussion about achieved results and comments about usefulness of topology optimization.

Keywords: Optimization, topology, wagon

1. Introduction

Maximum speed of freight wagons is limited by the weight of wagons and cargo and their high center of gravity, because the centrifugal forces could cause derailing in short radius curves [1]. In order to have a competitive product in an ever demanding market, engineers must pay attention to weight reduction during design process, which lowers wagon center of gravity, material used, and unit production price [2]. Before exploitation starts, wagons must satisfy rigorous safety standards [3]-[6]. Numerical methods such is the Finite Element Method (FEM) are used to test various shape configurations, and wagon response to different loading condition without need to create prototype which reduces design time and improves overall wagon characteristics [7]. Designers must verify every change they make with a series FEM analysis to check if the new design satisfies all loading conditions prescribed in the standards [3]-[6]. This process can be very tedious, but it can be automated using optimization [8]. Optimization is the process of design improvements by finding best results under given conditions.

In railway industry optimization is not implementted enough, but in recent years, several examples of optimization implementation are published, such is management of freight wagon distribution [9], material selection [10], or composite material design [11]. These examples do not refer to changes of wagon structure, but to the other aspects of wagon design and implementation.

Optimization of wagon structure is given in [12], where parametric optimization is used to reduce freight wagon mass. There are three kinds of structural optimization: parametric (size) optimization (which is presented in [12]), shape optimization and topology optimization which is presented in this paper (Fig. 1)

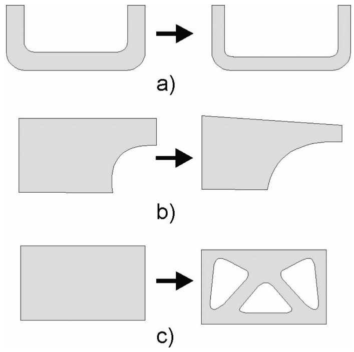

Figure 1. Structural optimization: a) parametric optimization; b) shape optimization; c) topology optimization

Parametric optimization changes only properties of the structures while geometry remains the same [13]. Shape optimization changes dimensions and shape of existing features, and topology optimization implies creation of new features, mostly free shape openings for even stress distribution. Shape and topology optimization are much more complicated and more difficult to implement because it performs changes to object geometry which requires changes in FEM mesh [14] or creating new design analysis model according to which topology optimization is done. Changes of geomerty during topology optimization results in new FEM mesh at the end of the optimization process [15]. In this paper results of topology optimization of freight wagon arepresented. Reduction of mass is achieved by creating and changing geometry of holes that are cut out of the heavy supporting structure where internal stresses are significantly lower than maximum allowed stress defined by mentioned standards.

2. Description of the used model

Wagon analyzed in this paper is freight, four-axle bogie wagon, and it is designed to transport gravel and iron ore. To satisfy condition defined by standards total of 18 analysis using FEM Method are done to confirm static and fatigue strength.

The wagon is modeled 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 (for modeling of the support plate, compensating ring, traction stop) were used for creating the finite element mesh. The structure is modeled in details with 236658 elements and 234700 nodes.General element side length is about 35 mm. Figure 2. shows the 3D model of the whole wagon without bogies.

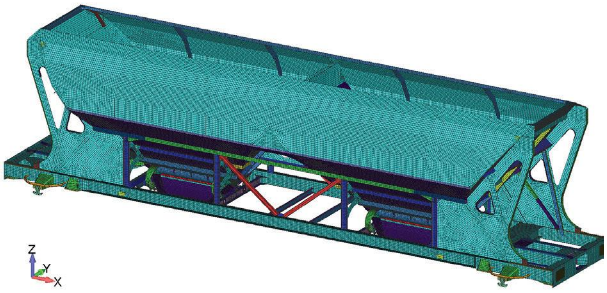

Figure 2. 3D Vehicle model

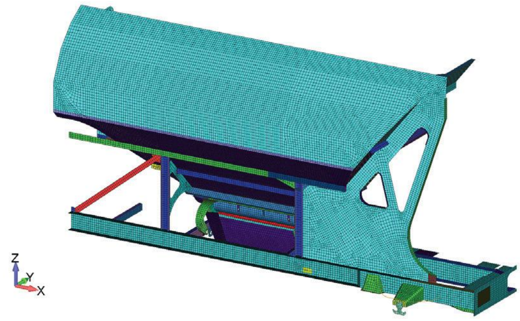

Figure 3. 3D Vehicle model – one quarter

Colours in Figure 2. match the various thicknesses of shell elements. Figure 3 shows a quarter of the model, which will be used, taking in consideration correspondent symmetry of the load cases.

Full model was used for unsymmetrical load cases and a half model for analysis of wagon lifting.

The Models shown on Figure 2. and Figure 3. are final experientially optimized models used for finial analysis and correspond to the real construction. However, the goal of this paper is to show advantages in using advanced software as a tool in engineering practice during problem solving and optimizing the design of products.

3. Topology optimization and its results

Topology optimization is a process of searching for the optimal solution of problem which has one or more constraints involved. Traditional approach to optimization implies a method of trial and error, where engineer relies on his own knowledge and experience. With the application of topology optimization process on optimizing construction of wagons, process itself can be accelerated and more efficient, saving time and reducing the cost of final product. Algorithm of the traditional approach of optimization and software aided approach are shown in Fig. 4.

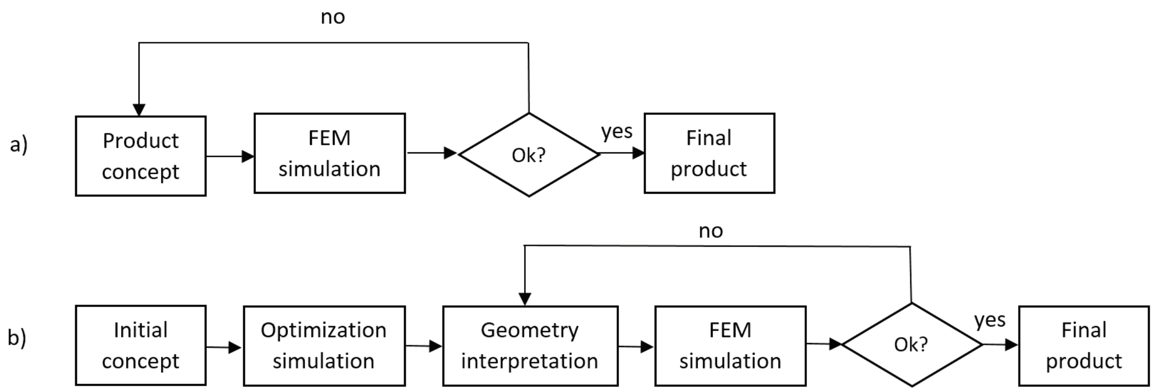

Figure 4. Types of approaches to optimization: a) Traditional approach; b) Software aided approach

Results and principle of study will be shown on one quarter of the wagon due the better visualization and the existence of symmetry. The goal of optimization is the mass reduction because the construction before the optimization exceeded the maximum allowed mass. Initial mesh used for representation of corresponding geometry is shown in Fig. 5.

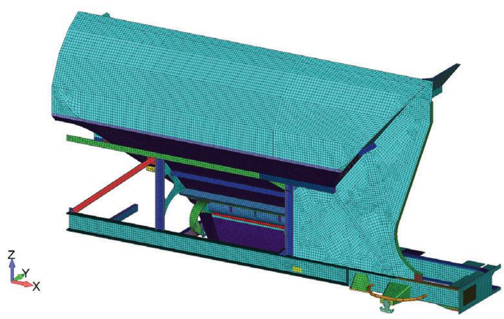

Figure 5. 3D Vehicle model – Initial configuration

The surface shown on figure 6 is chosen as a surface suitable for topology optimization, because it can be seen experientially that there is a large unused area on which, except in some regions, there is no high values of equivalent stress field.

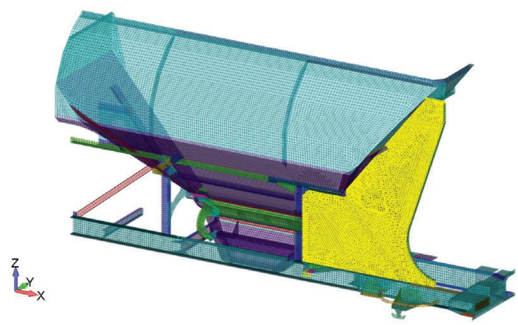

Figure 6. Surface chosen for optimization

When defining the topology optimization parameters, multi set option is used which takes into account existence of all types of loading and all types of constraints.

Volume reduction up to 50% is set as a goal function, while keeping the same stiffness of construction is a constraint. After setting all the parameters, the fallowing results were obtained.

Modified shape of optimized surface in comparison to the initial configuration is shown on Fig. 7.

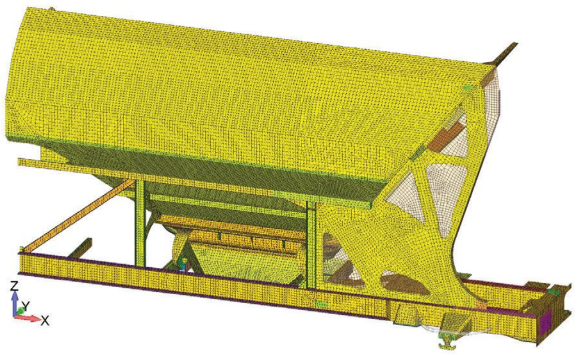

Figure 7. Optimized shape of the chosen surface

Process of topology optimization in NX Nastran is iterative and uses a gradient based algorithm. Function that shows decrease of volume per iteration is shown in Fig. 8.

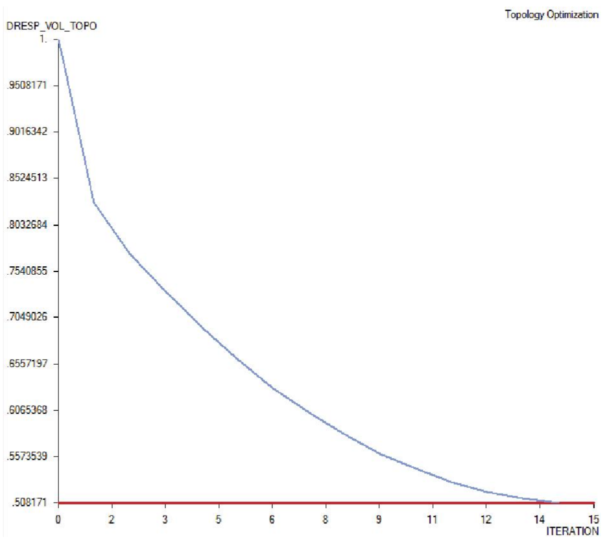

Figure 8. Volume decrease per iteration

From Figure 8. it can be seen that optimizer managed to find optimum of it`s goal function and reduce volume to 50%.

Besides the volume reduction, optimizer had to keep stiffness at the same level or to increase it if possible. The value of stiffness during the iterative procedure of decreasing the volume is shown on Fig. 9. From this figure it can be seen that there were no stiffness reduction, but on the contrary the value of stiffness has increased by 14%. Final optimizer suggested model is shown on Fig. 10.

From Figure 10. it can be seen that the suggested optimized shape of surface is not ideally technological and for finial construction geometry of new openings must be represented on some more suitable way.

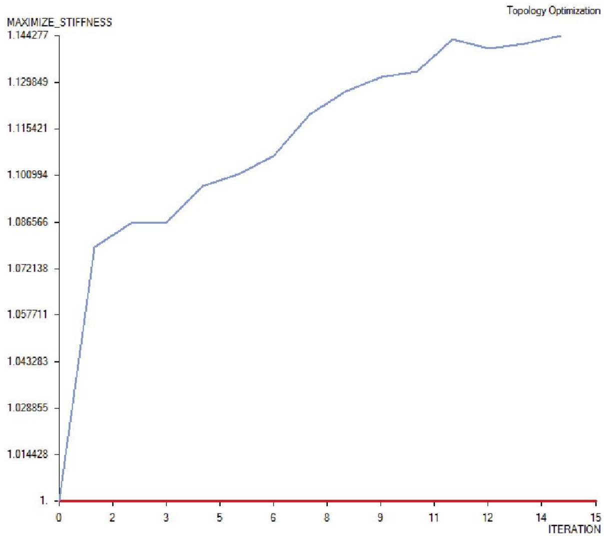

Figure 9. Value of stiffness per iteration

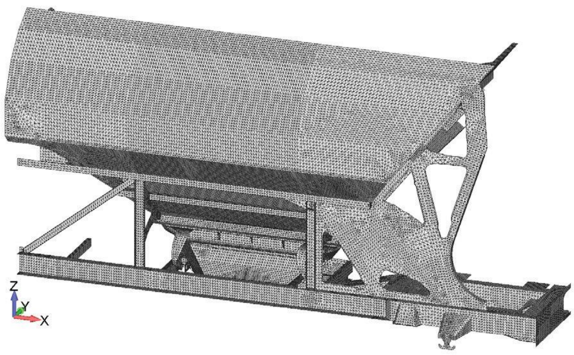

Figure 10. Optimized shape suggested by optimizer

4. Difference between topology optimized and experiential model

Parallel disply of the experientially and topology opimized shape is shown of figure 11.

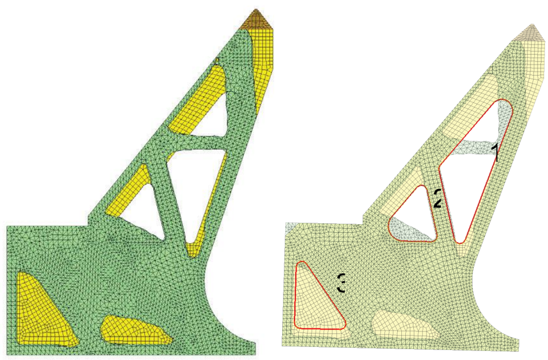

Figure 11. Experientially and topology optimized shape of surface

In Fig. 11 experientially created openings are shown with the red line for better visualization. Opening, labeled with the number 3, is later removed due the customer request, because they planed to put there a panel with description of wagon.

According to the obtained results, it can be seen the big similarity between the experientially and topology opimized shape. Positions and size of openings in both cases are approximately the same. The biggest difference is in time spent on getting the satisfactory results. Time used for topology optimization is much less than time spent for trial and error method. Savings in the mass are given in Tab. 1.

Table 1. Mass of the optimized surface

Initial configuration [kg]	Topology optimized [kg]	Experientially Optimized, [kg]
122.21	69.08	89.6

It can be seen from Table 1 that saving of 26.68% is achieved in the final configuration. The difference in mass on one quarter is 32.61kg and multiplied by 4 is 130.44kg for entire wagon.

5. Conclusion

Reviewing the savings in the mass it can be seen that the total weight of wagon is not significantly reduced by this optimization, nevertheless it should be remembered that this is just one surface optimized with possibility of optimizing much more. In that way of thinking it can be seen that the accumulation of this kind of savings brings to much more weight reduction.

Although once started optimization runs independently from the engineer, validity of results completely depends on the engineer. This is because the parameters of the optimization: goal function, constraints, types of loads, etc. are something that engineer chooses based on his knowledge. The optimizer can not change input parameters or to examine if they are properly chosen by the engineer. Thus, it can be concluded that optimization is useful tool in the process of product design.

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