CZASOPISMO TECHNICZNE M
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ

z. 3-M/2008
ISSN 0011-4561
ISSN 1897-6328

MICHAŁ HAWRYLUK*

OPTIMIZATION OF HEAVY LOADED RAILWAY CAR

OPTYMALIZACJA PLATFORMY KOLEJOWEJ O DUŻYM UDŹWIGU

A b s t r a c t

The following paper presents the results of optimization of the carrying structure of the railway car designed for higher than average cargo transport. To conduct FEM analyses Pro/Mechanica program has been used, which is a part of an integrated, parametric CAD/CAM/CAE Pro/Engineer packet.

Keywords: *structure optimization*, *FEM*, *CAD*

S t r e s z c z e n i e

W niniejszym artykule zawarte zostały wyniki optymalizacji konstrukcji nośnej platformy kolejowej przeznaczonej do przewozu ładunków ponadnormatywnych. Do wykonania analiz MES wykorzystano program Pro/Mechanica będący częścią zintegrowanego, parametrycznego systemu CAD/CAM/CAE Pro/Engineer.

Słowa kluczowe: *optymalizacja konstrukcji*, *MES*, *CAD*

*Michał Hawryluk, V year student, supervisor: Edward Lisowski, PhD, DSc, prof. of CUT, Cracow University of Technology.

1. Introduction

In the article I have presented the results of optimization of a railway car structure: batch Uaai, type 603Z, designed for higher than average cargo transport. Cars of this type are used by production, overhaul and specialized transportation companies. Railway, in spite of its long history, is still a modern means of transport and one can assume that it is going to maintain its significant position on the market. One can be sure that the development of railway will be concentrated on these types of transport which best utilize its advantages, i.e. heavy cargo transport and combined transport [1].

In the optimization process I have used Pro/Mechanica program which is a part of CAD/CAM/CAE Pro/Engineer packet, version Wildfire 3.0. I have chosen this software due to full integration of its packet modules as well as its parametricity. It is also worth noting here that this software enables exporting models to many formats which may be helpful when solving the problem by means of other FEM packets, e.g. ANSYS.

2. The object of research

Car 603Z is a 16-axle platform. Cars of this type are used for transportation of cargo which is very big in size and weight (turbogenerators, transformers, large vessels, heavy duty machines, chemical apparatus). The maximum mass of this cargo is 210 tons and the construction mass of the car is 110 tons. The car structure is presented in Fig. 1. The platform is made of two main carrying elements (2) connected by means of intermediate beams (4). The carrying elements of platform have the highest ratio of weight to strength and therefore these have been analysed first.

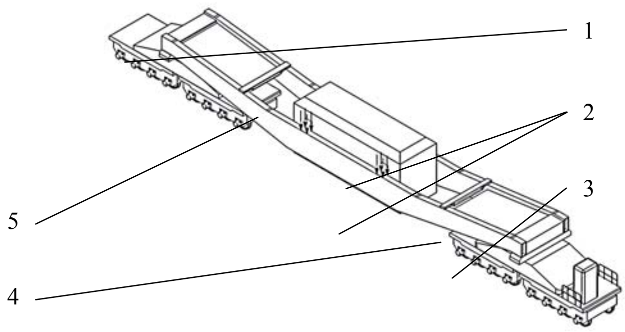

Fig. 1. Scheme of 603Z car: 1 – bridge, 2 – carrying structure, 3 – frame, 4 – intermediate beam, 5 – cargo

Rys. 1. Schemat Platformy 603Z: 1 – most, 2 – struktura nośna, 3 – rama, 4 – belka pośrednia, 5 – ładunek

3. Strength Analysis

For the purpose of FEM analysis it was assumed that the carrying structure leans on two supports, put under the load of two forces *F* of 525 000 N each, located symmetrically at some distance from the vertical symmetry plane. Fig. 2. presents a block diagram of the procedure followed during the strength analysis of the structure in its original form and during its optimization.

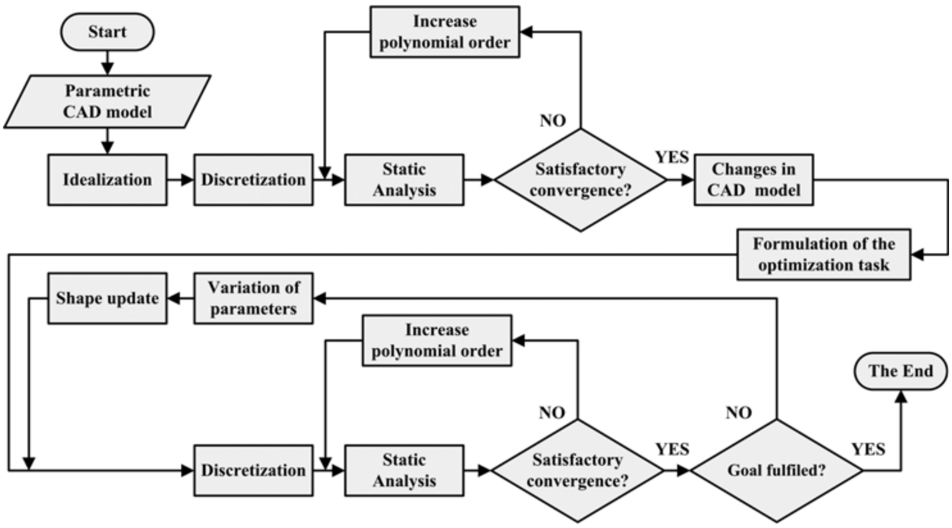

Fig. 2. Block diagram of the procedure followed
Rys. 2. Diagram blokowy procedury optymalizacji

I have created a parametric model of the structure which for the sake of the FEM analysis has undergone an idealization consisting in replacing the solid elements with the shell ones. All the structure walls have been compressed to a respective middle surface. In the next step, a finite elements mesh with shape functions which are polynomials of the maximum ninth degree have been generated (*p*-method).

The static analysis of the currently existing carrying structure as well as the buckling analysis have yielded the following results

$$m = 16{,}45 \text{ t}, \quad \delta_z = 64{,}67 \text{ mm}, \quad \sigma_{\mathrm{HMH}} = 155{,}9 \text{ MPa}, \quad F_{\mathrm{kr}} = 12{,}29F \text{ N}$$

where:

m – mass,
δ_z – maximum displacement towards vertical axis z,
σ_{HMH} – maximum Von Mises stress,
F_{kr} – critical force.

Von Mises stress distribution map over the currently existing structure is shown in Fig. 3.

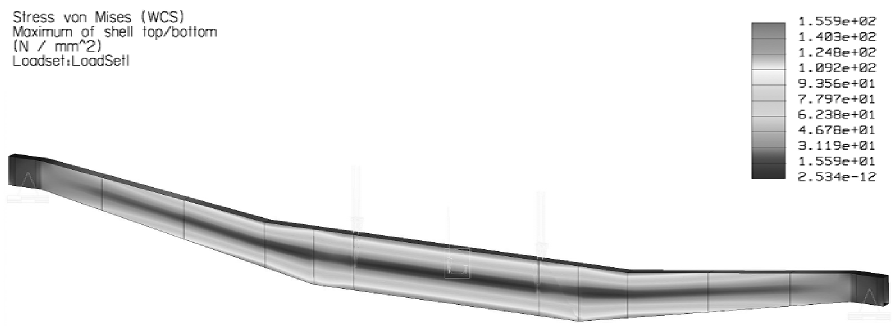

Fig. 3. Von Mises stress distribution over the currently existing structure
Rys. 3. Naprężenia według hipotezy H-M-H przed optymalizacją

4. Structure Optimization

In the optimization process I have used the Pro/Mechanica program as well as the GDP algorithm (Gradient Projection).

Due to technological and strength concerns the car carrying structure is divided by ribs into 13 sections. After a series of initial analyses I have decided to cut nine, different size, holes on the sides of the structure, within the sections. There are 16 parameters describing their shape and location. Five of them are constants for this optimization process.

The task limiting values are: the maximum acceptable Von Mises stress of 175 MPa, and the maximum acceptable displacement of the carrying structure of 68 mm. For the target function, which is an optimization criterion, I have chosen mass.

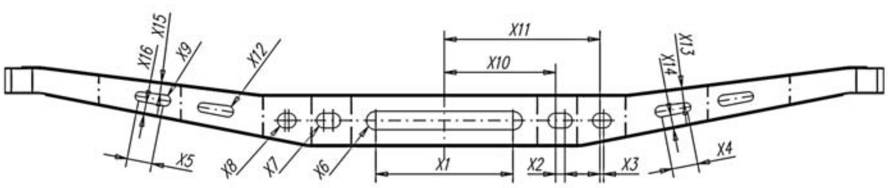

Fig. 4. Shape and location parameters
Rys. 4. Kształt i położenie parametrów stosowanych do optymalizacji

For each decision variable Xi a variability range has been determined

$$Xi_{\min} \leq Xi \leq Xi_{\max}, \quad i = 1, \ldots, 11$$

The static analysis for the initial values of decision variables has given the following results

$$m = 15{,}00 \text{ t}, \quad \delta_z = 65{,}13 \text{ mm}, \quad \sigma_{\mathrm{HMH}} = 164{,}76 \text{ MPa}, \quad F_{\mathrm{kr}} = 6{,}91F \text{ N}$$

Von Mises stress distribution for the parameters initial values is shown in Fig. 5.

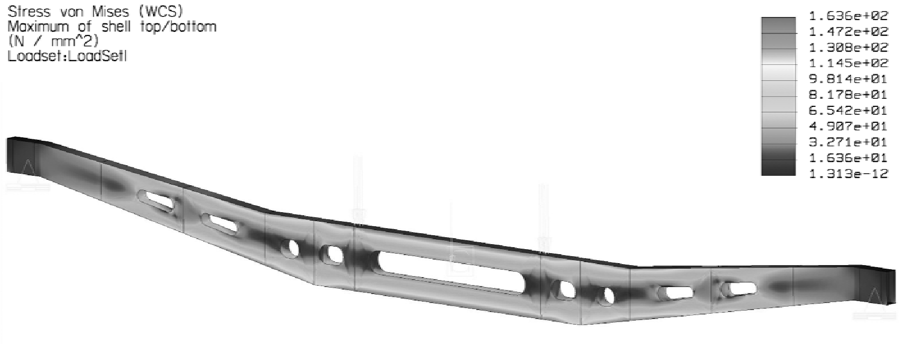

Fig. 5. Von Mises stress distribution for the parameters initial values
Rys. 5. Rozkład naprężeń H-M-H na początku procesu optymalizacji

The next stage consisted in solving an optimization problem in the acceptable set defined by the degree of the parameters variability, maximum acceptable Von Mises stress and an acceptable vertical displacement.

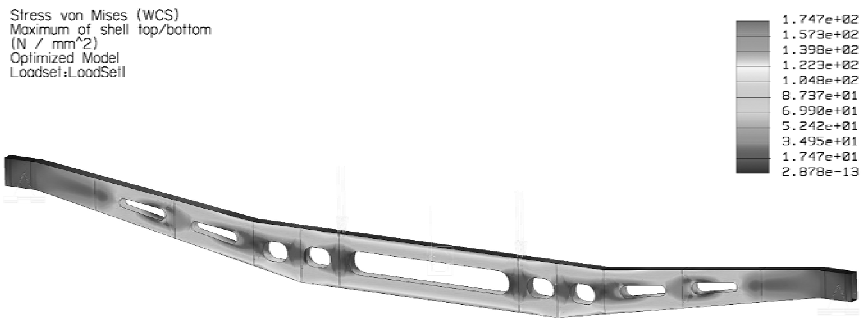

Fig. 6. Von Mises stresses distribution for the parameter values found in the optimization process
Rys. 6. Rozkład naprężeń H-M-H po optymalizacji

Here are the results for optimized values of the decision variables

$$m = 14{,}47 \text{ t}, \quad \delta_z = 65{,}95 \text{ mm}, \quad \sigma_{\mathrm{HMH}} = 174{,}75 \text{ MPa}, \quad F_{\mathrm{kr}} = 6{,}13F \text{ N}$$

In comparison with the currently existing structure the mass has been successfully reduced by 12,04 %. Graph of the structure mass changes in the course of the optimization process is shown in Fig. 7.

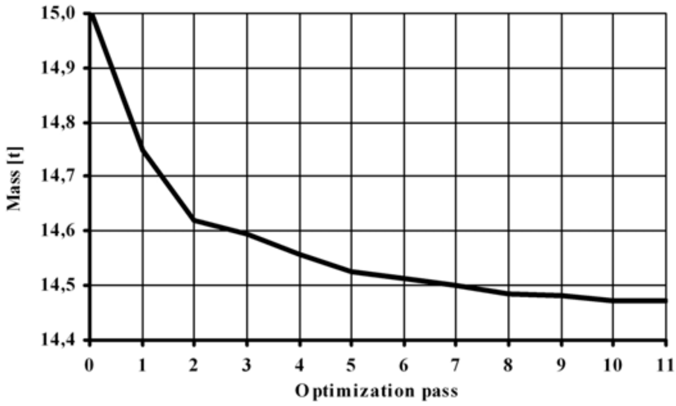

Fig. 7. Graph of the structure mass changes in the course of the optimization process
Rys. 7. Przebieg zmian masy w strukturze nośnej w trakcie procesu optymalizacji

5. Conclusion

In the article I have presented the results of the optimization of the type 603Z railway car structure. The aim of the FEM analyses was to minimize the mass of the platform structure. In this process I have used eleven decision variables with their respective variability ranges and two task limiting values: the maximum acceptable Von Mises stress and the maximum acceptable displacement of the carrying structure.

The employment of the fully parametric software enabled automatic optimization (changes in the values of the decision variables, changes in the model structure, discretization and static analyses).

Thanks to the optimization, the structure mass has been reduced by 12,04 %.

Parametric CAD/CAM/CAE tools, supporting engineering tasks already at the designing stage, not only optimize the use of the material available but also it possible to obtain the advantageous ratio of structure strength to its weight.

References

[1] Bogdaniuk B., Massel A., *Podstawy transportu kolejowego*, Wydawnictwo Politechniki Gdańskiej, Gdańsk 1999.
[2] Lisowski E., *Modelowanie geometrii elementów, złożeń oraz kinematyki maszyn*, Wydawnictwo Politechniki Krakowskiej, Kraków 2005.
[3] Neumann T., *Wagony i hamulce kolejowe*, WKiŁ, Warszawa 1976.