VANES SHAPE OPTIMIZATION OF VENTILATED DISC BRAKES FOR HEAVY DUTY VEHICLES

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Abstract
Braking system represents a very important system for all types of motor and trailer vehicles. The basic task of the braking system is reducing the vehicle speed until it stops or slows down to a lower speed. Furthermore, the braking system should also ensure that the vehicle is kept in a steady state. To achieve that the vehicle has a shorter braking distance, it is necessary to reduce the flywheel masses. The purpose of this paper is to reduce the weight of the venting disc, which is partly responsible for the value of braking distance achieved. Besides that, it must be ensured that deformations and stresses remain in the limits. Optimization is performed by ANSYS software package. The application of virtual experiments gives quick answers in developing a new or improving the already existing part. It also enables corrections of the product itself, as well as competitiveness on the market.

Keywords: *braking system, flywheel masses, braking distance, competitiveness on the market*

1. INTRODUCTION

Optimization is defined as the science for determining the "best possible" solution [1]. Having the best solution, or solution that is close to the best, leads to savings in material and energy (whose resources are limited) or achieving financial profit or achieving the highest reliability or safety in operation. Optimization aims to minimize negative effects (effort, costs, etc.) or to maximize positive effects (profit).

The optimization process for a particular system can be formally separated into two levels. The first level represents the need for a uniquely defined problem and the establishment of the exact relations of influence parameters and solutions in the conditions in which it should function. The second level is the choice of some of the known or the development of a new methodology for solving the problems.

The braking system is one of the most important parts of motor and trailer vehicles. As a motor vehicle cannot function without drive unit, it can also not be imagined without a braking system. In addition to stopping and slowing down the vehicle, the braking system also has other tasks, and above all, together with other systems, allows the control of the vehicle speed in accordance with traffic conditions, driver's wishes and other circumstances [2].

Disc brakes are a typical example of axial brakes, in which the pressure on the friction surface is realized in the direction of the axis of the rotational element. Due to the already emphasized importance of the brake system for vehicle safety, it is necessary that the vehicle users comply with the manufacturer's recommendations; otherwise different problems arise during the exploitation. Often in practice, the common requirement for selecting such parts is a lower price, which should not have a decisive role in selection. Friction pairs made of disc and brake pads should be selected so that when activated, such a friction coefficient in the contact surface is achieved, which will ensure a fast and safe slowing or stopping [3].

Agnihorti and Chopra [4] were looking for the best materials and the best design in order to reduce heat loads. While Kajabe and Navthar [5] analyzed how changing the shape of the disc brake affects the braking, mass, manufacturing costs, stresses, and the heat dissipation into the environment. Amouzgar et al. [6] are analyzed the disc brake for the heavy-duty vehicles. Their goal was to reduce the mass, as well as the maximum temperature that is a by-product of the braking. The variables that are analyzed are the braking load, the Yang module and the thickness of the back plate. Furthermore, the shape of the rib affects the mass, as well as the accumulation of heat on the disc itself. One such study was carried out by Kumar et al. [7].

The aim of the research presented in this paper is to reduce the mass of the braking disc. The disc brakes together with the wheel, rotates and with their moment of inertia affect the braking distance. Of course, the influence of other rotary masses cannot be ignored. Thus, in braking, the inertial force of the brake disc together with the wheel, as well as other rotary masses, continues to tend to have the same angular velocity as before the activation of the braking system. In this paper, consideration is given to the reduction of the mass of the braking disc. As the disc mass is larger, the inertial force is larger too, so it is necessary to reduce it in any way. Some of the ways to achieve this goal are the use of aluminum for the construction of the lid, then the optimization of the construction itself, as well as the reduction of constructive parameters. By reducing the weight of the brake disc, the mass of one of the rotating bodies would be reduced, as would the braking distance. The optimization of the parameters of disc ribs– constructive parameters is performed in the paper.

2. 3D MODEL OF DISC BRAKE FOR HEAVY DUTY VEHICLES

Disc brake model is created in CATIA software package, show on *Figure 1*. Assembly itself consists of a large number of parts, so it has a large mass. That's why it is very important to reduce the mass in any way. A part that is very interesting and for can be said to have the greatest influence on the braking distance, unlike the other parts, is a brake disc.

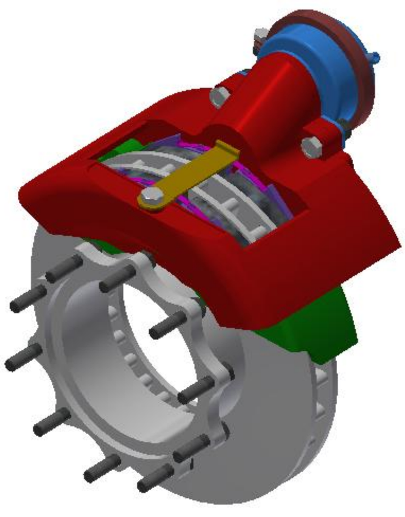

Figure 1 Vented disc brake for heavy-duty vehicles

The maximum diameter of the brake disc for heavy-duty vehicles can be up to 430 mm. The diameter of the analyzed disc in this paper is 430 mm; the disc height is 130 mm, and the disc thickness of the disc with ribs is 45 mm [8]. A disc with roll-shaped ribs is observed (*Figure 2*), while the diameters are marked with letters; the dimensions of the diameters are shown in *Table 1*. The disc is made of steel (*Table 2*). One such disc with the characteristics of the materials that are shown in *Table 2* has mass of the 23.523 kg.

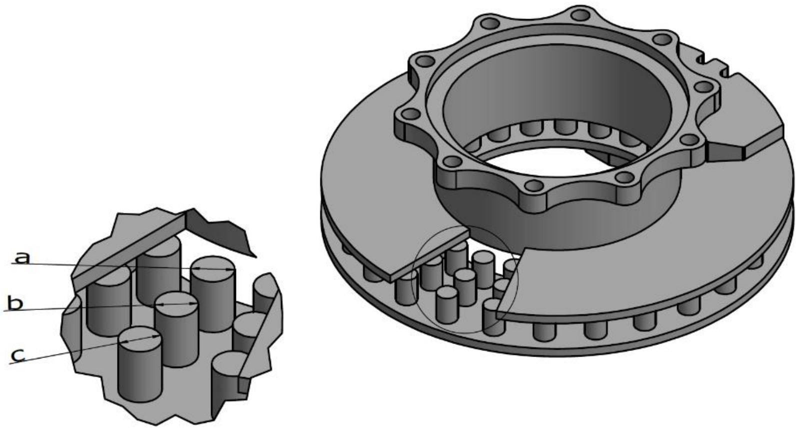

Figure 2 Vented braking disc with detail

Table 1 Ribs diameter of braking disc

Letters	**Diameter, [mm]**
a	15
b	20
c	25

Table 2 Material characteristics of friction pair [9]

	Disc	**Pad**
Density, [kg/m^3]	7250	1400
Young's module, [GPa]	138	1
Poison ratio, [-]	0.28	0.25

Before starting the analysis, it is first necessary to define boundary conditions. The conditions in which the analysis was carried out: an ambient temperature of 22ºC, vehicle speed before braking is 80 km/h, which corresponds to an angular velocity of 41.89 rad/s, the coefficient of friction occurring in the friction pair is 0.336 [10].
The size of the final elements in part regions where the material is not taken away should not be so fine, compared with the parts where the material is taken away. In this case, the size of the final elements of the brake discs should be fine (fine discretization), so for this reason the number of nodes and elements is slightly higher. The mesh consists of 318654 nodes and 197662 elements.
When optimizing shapes, it is necessary to choose where materials can be taken away, and where it is not. In this case, the material may be taken away from the ribs, while it is not allowed from other regions.

3. RESULTS

The goal of optimization is to reduce mass of the brake disc, without compromising other characteristics of the part itself. Such a braking disc, obtained using the Shape Optimization Module

in ANSYS software package, should meet the same conditions that it had before the optimization itself.
As the diameters of the outer rolls are the largest, it can be noticed in *Figure 3 (a)* that most of the material is taken away from them. After the optimization, the rollers would have hollow cross-sections, with most of the material being taken off in roll-disc plate connection region, while in the middle, their cross-section will remain unchanged. *Figure 3 (b)* shows the disc after optimization, the removed material is displayed in red.

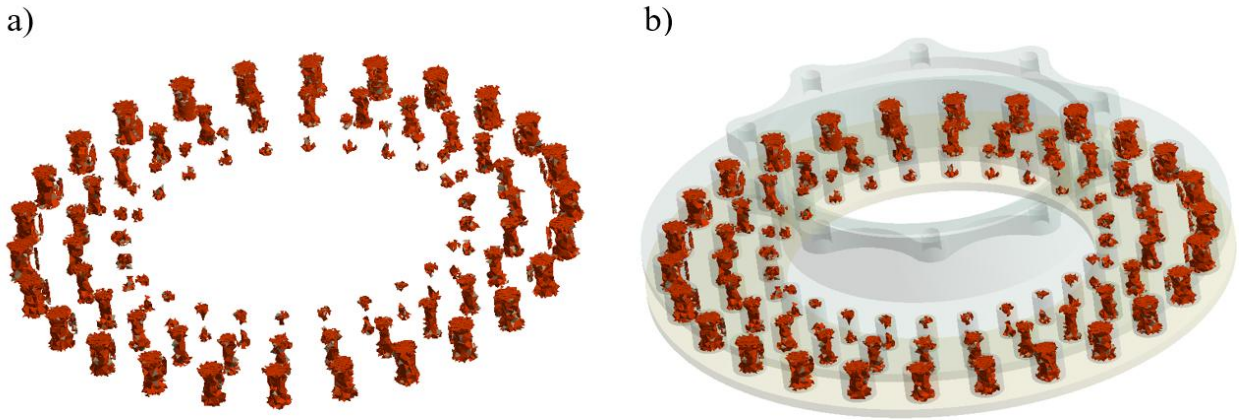

Figure 3 (a) Display of roller mass reduction by 20%, (b) A detailed view of the brake disc on which it takes off 20% of the material

For the application of Shape Optimization Module, it is necessary to define how many percentages it takes to reduce the mass, in this case the braking disc. *Table 3* shows how much the brake disc's mass decreases by 4%, 5% and 6%.

Table 3 Braking disc's mass after optimization

	Braking disc's mass after optimization, [kg]
4%	22.6654
5%	22.3647
6%	22.0728

The display of the ribs of the brake disc with material that is taken away is given in *Figure 4 (a)* where 4% of the total weight of the brake disc is taken, while in *Figure 4 (b)* 6%.

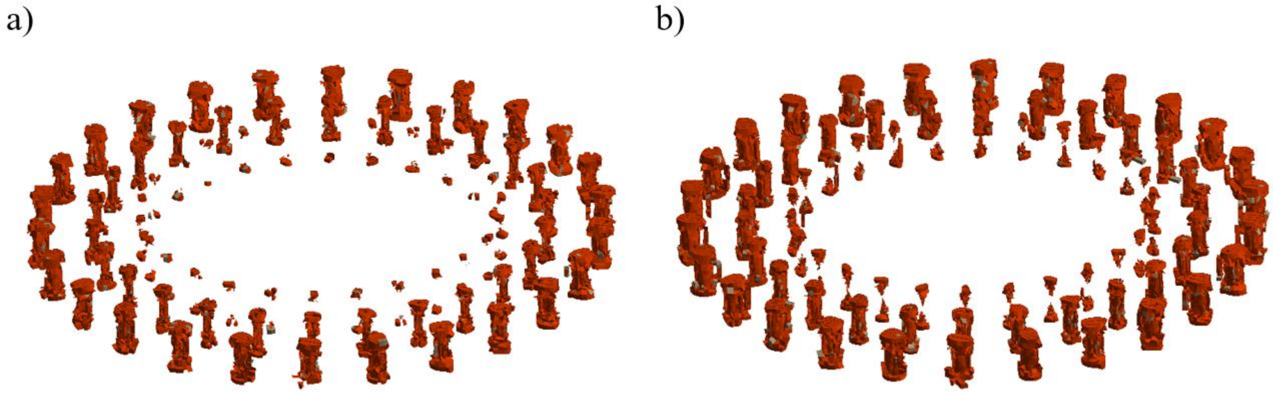

Figure 4 (a) Display of mass reduction of 15%, (b) display of mass reduction of 25%

It can be concluded that as the percentage of removal of material from the disc ribs is increased, material removed from the central and inner ribs increases, while it can be said that from the outer ribs that the material removed from the outer ribs is almost not changed with the increase in the percentage of the reduction in the mass of the brake disc.
The deformation and stress condition of the brake disc, in relation to the reduction of mass is shown in *Figure 5*. The initial value of the deformation and stress on the diagrams corresponds to the values recorded before the optimization of the brake disc.

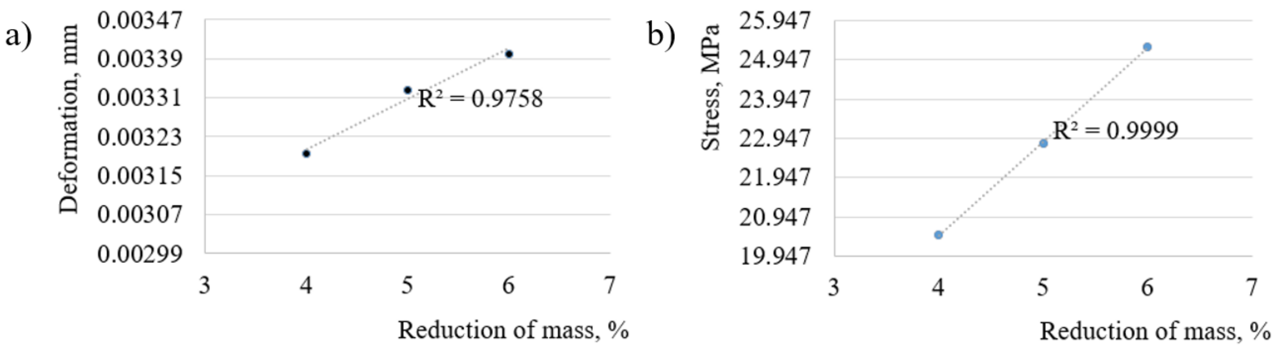

Figure 5 (a) Deformations in function of mass reduction, (b) stresses in function of mass reduction

By analyzing *Figure 5 (a)* and *(b)*, it can be noticed that deformations and stresses increases linearly with decreasing of mass. The deformation values do not change to the extent that a brake disc can break. Furthermore, as can be seen from *Figure 5 (b)*, the stresses do not exceed the yield strength limit value, so there will not be plastic deformations of the brake disc. In case the stresses exceed the values of the yield strength, a distortion of the brake disc would occur, and when braking, the braking pads would not fit the entire surface of the disc. This would further negatively affect the braking distance as well as the stability in the braking process, and this would impair the safety of a driver as well as other traffic participants.

CONCLUSIONS

The brake disc's mass obtained by the optimization process is still high; however, the weight is essentially reduced. Heavy duty vehicles can have 2, 3 or 4 axles (they can have more), so that on each axle we have two brake discs, the weight can be reduced up to 11 kg. Comparing the mass of a 10t-weighted vehicle with reduced mass achieved through the optimization process of the brake discs is insignificant. Regardless, reducing the weight of the brake discs has a major influence on the braking distance value.
Further research would be based on experimental research, where it is necessary to make such a disc that is obtained after optimization and examine how it behaves in different exploitation conditions.

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