# STRUCTURAL AND THERMAL ANALYSIS OF HEAVY VEHICLES' DISC BRAKES

*Nadica Stojanović*[1]*, Jasna Glišović*[2]

**UDC:629.017:536.212**

## INTRODUCTION

Development of the brakes, as one of the key elements of vehicle's active safety, is based on the main requirement to keep a pre-set braking distance under various operation parameters. Experiences gained based on previous developed technologies have enabled the evolution of modern systems.

Disc brakes are a typical representative of the axial brakes, where the pressure on the friction surface is realized in the axis direction of the rotating element. As a disc rotates in free space, the assembly which is located in the calliper must be tightly closed and protected from contaminants from the environment and from water when driving in rainy weather. The caliper is in contact only with one part of the disc and not to the rest of the disc surface, which is of extreme importance because in this way provides efficient cooling [2].

The air braking system was originally designed for the railway vehicles [1]. They are today mounted on different types of heavy trucks, because of increased effectiveness in comparison to other brake systems. Here are just a few advanced features of air disc brakes:

- Brake solutions for all vehicle applications
- 20% to 30% better stopping performance and improved fade resistance over drum brakes
- Thicker pads mean enhanced durability and longer service intervals
- Proven durability and reliability for lower life cycle costs (longer pad and rotor life, less time to replace pads, environmental sealing integrity).

The friction pair - brake pad/disc has the basic task to produce the braking torque necessary to slow or stop the vehicle. However, in the braking process, the heat is generated. Brake pads absorb only a small amount of heat. This phenomenon is very useful in the braking process because it provides protection of the brakes and its internal components. The most of the heat generated during stopping is absorbed and temporarily stored by the disc but the disc capacity is limited. In order to maintain proper brake function, the disc also has the role of acting as a heat exchanger. Thereby, the disc may be able to dissipate the heat that is created in the process of braking into the environment. Solid disc has a limited, lower ability to remove heat. As a result, this simple design of disk has a smaller application on commercial vehicles. Ventilated discs with straight radial vanes and cross-drilled discs have been used in this type of vehicles. These elements allow air flows inside the disk and thus provide better heat dissipation.

[1] *Nadica Stojanović, PhD Student, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, nadicasto@gmail.com*
[2] *Jasna Glišović, Assistant Professor, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, jaca@kg.ac.rs*

## THERMAL BOUNDARY CONDITIONS

Based on the first law of Thermodynamics, during braking, kinetic energy is converted to thermal energy. One of the main problems when designing brake is heat dissipation caused by friction that occurs in contact between brake pads and the brake disc. As can be seen from Figure 1, when the temperature of disc exceeds 700ºC, the coefficient of friction decreases rapidly, and it further leads to longer stopping distances [3]. At such high temperatures, pads suffer from a loss of effectiveness called “fade” because of a reduction in the kinetic friction coefficient. High interfacial temperatures can lead to a decrease in shear strength of the pad and consequently a decrease in frictional force which induces fade.

Due to friction between the main components of disc brake (pads and disc) the conversion of energy takes place. Initially, the generated thermal energy is transferred by conduction to the components in contact and next by convection and radiation to environment. In braking process, the temperature field changes input heat flux, and heat exchanges conditions. The input heat flux is mainly relevant to a disc coefficient of friction, the angular velocity of brake discs, while heat exchange is connected with the friction pair materials and external environmental factors.

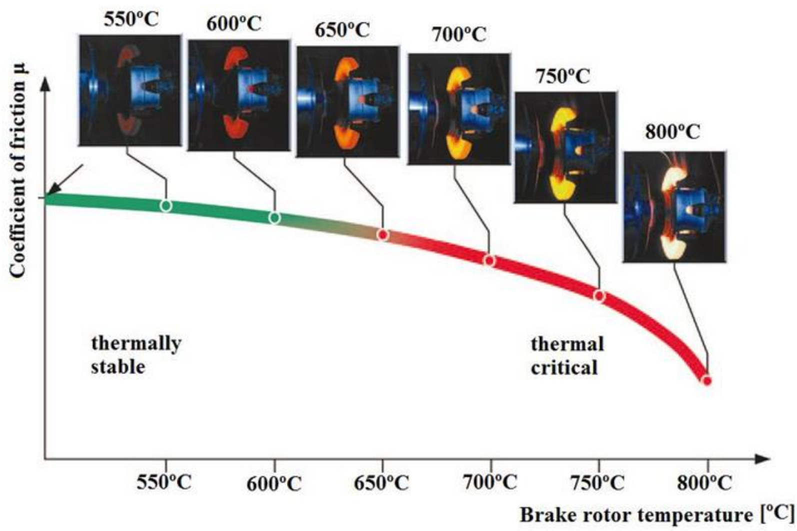


*Figure 1 Influence of temperature on coefficient of friction [3]*

## STRUCTURAL AND THERMAL ANALYSIS

### *Stress condition of the disc at the effect of centrifugal force*

Structural and thermal analysis was performed in the software package CATIA. Brake discs are exposed to a variety of loads during their use. While driving without braking the disc is affected only with the centrifugal force. When the brake process starts, two additional forces affect the disc. These forces represent the force from the brake calliper and the force from the heat impute (as a result of friction).

The material characteristics of the brake disc are shown in table 1.

*Table 1 Material characteristics of venting disc [4]*

| | Ventilated disc |
|---|---|
| Young's modulus, $E_d$ | 195 GN/m$^2$ |
| Poisson's ratio, $\upsilon$ | 0,27 |
| Density, $\rho$ | 7600 kg/m$^3$ |

In the beginning of the analysis, the brake disc is simplified. Only one section of the whole disc is used. Considering the systems edge conditions and the symmetry of the disc, only 1/4 of the disc is chosen.

The greatest stresses are in the zones where the disc is connected to the wheel with bolts, as well as on the inner surface of the disc, as shown in Figure 2.

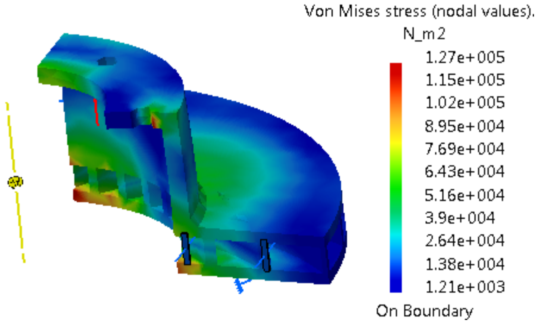


*Figure 2 Stress on Von Mises that occurs as the effect of centrifugal force*

### *Analysis of disc brake assembly*

The ventilated disc is lighter than the solid disc, and additional convective heat transfer occurs on the surface of the vent hall. Thus, the ventilated disc can control its temperature rise and minimize the effects of thermal problems such as the variation of the pad friction coefficient, brake fade and vapour lock. The ventilated disc, however, may increase judder problems by inducing an uneven temperature field around the disc. Also, the thermal capacity of the ventilated disc is less than that of the solid disc, and the temperature of the ventilated disc can rise relatively faster than that of the solid disc during repetitive braking. Therefore, thermal capacity and thermal deformation should be carefully considered when modifying the shape of the ventilated disc.

Material properties friction pairs are given in Table 2, the angular speed of the disc is 200rpm.

*Table 2 Material properties of friction pairs* [5-7]

| | Rotor | Friction material |
|---|---|---|
| Young's modulus, $E_d$ | 195 GN/m$^2$ | 3 GN/m$^2$ |
| Poisson's ratio, $\upsilon$ | 0,27 | 0,23 |
| Density, $\rho$ | 7600 kg/m$^3$ | 2750 kg/m$^3$ |
| Coefficient of friction, $\mu$ | 0,4 | 0,4 |
| Thermal expansion, $\delta$ | 0,0000121 mm/K | - |

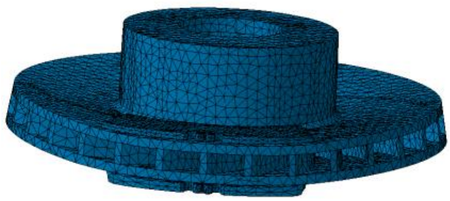

Figure 3 Deformations of friction pair

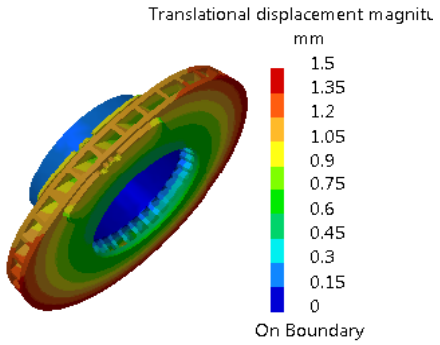


Figure 4 Translational displacement

Deformations of the disk are created as a result of thermal and mechanical loads. As shown in Figure 3, it can be noticed that disc under loads forms a specific shape that is known as the "umbrella effect". The effect of the umbrella is typical for integrally made discs. This phenomenon is a result from the heating of non-parallel paths of friction with respect to the initial position. Besides, the pads are also deformed. The internal pad is, contrary to the outside, less deformed. This occurs because the same pressure acts on the outer and the inner pads, and thereby the surfaces of the disc that are in contact with pads are deformed in direction of the wheel (to the outer side of the vehicle). As the disc deforms and begins to take the shape of the umbrella, the external pad has no room for an increase in cross-section direction, so this leads to the appearance of the compression. One can say that the deformation of the pad following the deformation of the disc.

The greatest translational displacements occur at the periphery of the disc, as a result of centrifugal force. In the case of brake pads, the largest translational displacement occurs in the upper part. Respectively, they follow the deformation of disc. More specifically, the inner pad is deformed outward, and this displacement is larger related to the deformation of the external pad, and as a consequence of disc deformation, the free space is remained, and pads take possession of it. The pressure acts on the outer pad on one side, and the disc being deformed acts from the opposite side. Due to the structural properties of the pad material, it follows the disk, and is deformed in the areas above the piston where it is pressed and thus enables it to fit on the disc. Translational displacement is higher for internal compare to external pad, Figure 4.

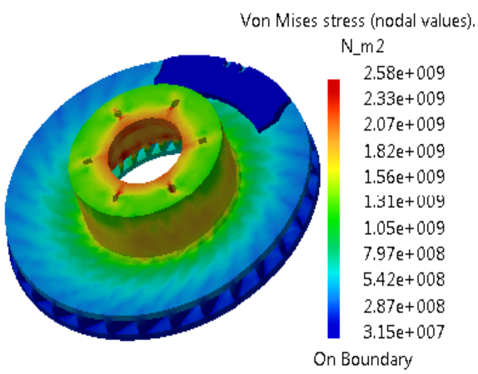


Figure 5 Von Mises stress of disc

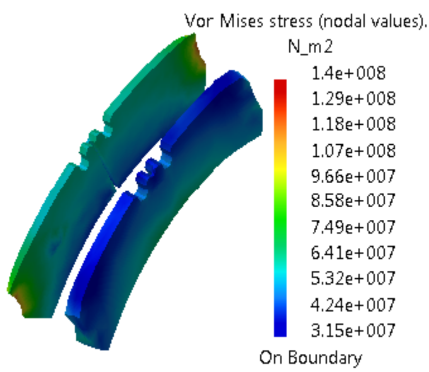


Figure 6 Von Mises stress of brake pad

The highest values of stresses occur in areas where the disc is in contact with the wheel and shaft, Figure 5. That is where the disc is screwed to the wheel flange and where it is in contact with the shaft. In these areas, the highest values of stresses occur because the wheels and shafts under the force of inertia tend to continue turning, until the disc along with the pads and the rest of the brake system does not allow. More precisely, it comes to the appearance of torsion.

Analysing the Figure 6 showing both the pads, apparently the highest stresses occur in the upper part of one pad, while in the other pad they occur in the bottom part. The reason is precisely the effect of an umbrella. This means that one pad with its upper end makes pressure and rest against with the disc, while the other pad rest with the bottom end and thus the braking force is transmitted from the pad to the disc.

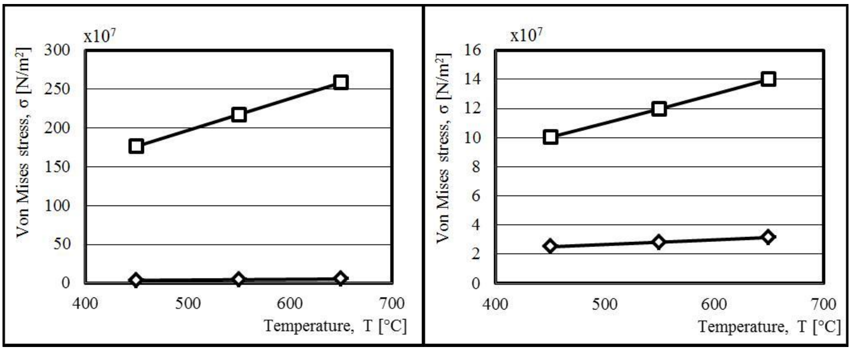


*Figure 7 Min and Max Von Mises stresses that occur on the disc (left) and pads (right) in dependence of temperature change*

By analysing the curves shown in Figure 7 it may be noted that the minimum values of Von Mises stresses for both the disc, and pads show a trend of the moderate increase with increasing temperature, and regarding the maximum value, that is not the case. So with an increase of the temperature, the maximum values of Von Mises stresses for disc and pads are rising rapidly.

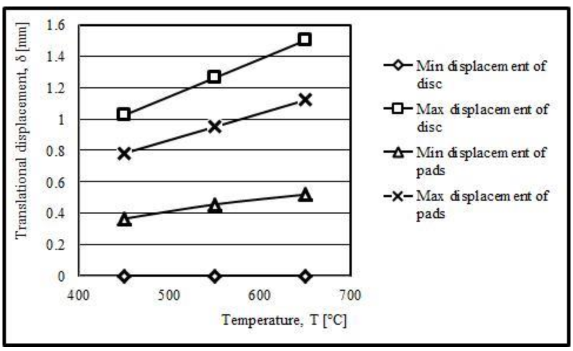


*Figure 8 Min and max displacements that occur in the friction pair during temperature change*

It can be concluded based on Figure 8 that the translational displacements increase with temperature. Minimum translational displacements of the disc are constant and they are equal to zero.

## CONCLUSIONS

By analysing obtained results, it was found that disc due to the effects of high temperature and pressure (mechanical and thermal loads) that occur in contact between the pads and the disc, takes the form of the umbrella. It would be relevant for the further research to study in detail what would happen with integral ventilated discs. Furthermore, the air flow between disc's vanes is not taken into account in this paper i.e. the analysis was performed at room temperature, so it would be useful in future studies to take this aspect into account.

The data analysis has shown that the different stress values occur on the outside and inside pads, as well as translational displacements, and this can be considered. So it is possible to get stresses that occur on the inside and on the outside side of the pad. The same applies for translational displacement.

The analysis was carried out for the disc and pads, but for further research, it would be necessary to include other elements within the disc brake assembly, in order to determine the ways in which the heat is transferred to the other elements, by conduction, and convection. Of course, since the testing was performed on the disc and the brake pads made of most common materials for disc brakes of commercial vehicles, it can be analysed the influence of applying the new composite materials for disc and/or pads. In doing so, it would not be changed only the structural properties of the material, but also the coefficient of friction, thermal conductivity, etc.

## REFERENCES

[1] European braking systems; Internet address: http://www.europeanbrakingsystems.co.uk/history, accessed 03.04.2015.
[2] Bendix Spicer Foundation Brake LLC; Internet address: http://www.foundationbrakes.com/media/documents/airdiscbrakes/awhitepapercaseforairdiscbrakes.pdf, accessed 03.04.2015.
[3] Breuer B., Karlheinz H. B.: Bremsenhandbuch-Grundlagen, Komponenten, Systeme, Fahrdynamik, Springer Fachmedien Wiesbaden, 2012, ISBN 978-3-8348-1796-9
[4] Ibrahim A., Analysis of disc brake squeal using a ten-degree-of-freedom model, International Journal of Engineering, Science and Technology Vol. 3, No. 8, 2011, pp. 142-155
[5] Parab V., Naik K., Dhale A. D., Structural and Thermal Analysis of Brake Disc, International Journal of Engineering Development and Research, Vol. 2, Issue 2, 2014, pp. 1398-1403
[6] Bayas E., Aher V., Coupled Field Analysis of disc Brake Rotor, International Journal of Advanced Research in Science, Engineering and Technology, Vol.02, Issue 01, 2012, pp. 06-09
[7] Lakkam S., Koetniyom S., Optimization of constrained layer damping for strain energy minimization of vibrating pads, Songklanakarin Journal of Science and Technology, Vol. 34, Issue 2, 2012, pp. 179-187