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FINITE ELEMENT PARAMETRIC STUDY OF THE INFLUENCE OF MATERIAL PROPERTIES AND STRUCTURAL MODIFICATIONS ON DISC BRAKE NOISE PHENOMENA

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Abstract

Noise pollution is a growing environmental concern in urban areas. Road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 decibels (dB) Lden (day-evening-night level), including more than 37 million exposed to noise levels above 65 dB Lden. The vehicle components most involved in noise production and most exposed to vibration are tires, motor, outer panels of the car body, the brakes, electronic components, equipment in the inner part of the car. In the last few years, brake noise and vibration has become one of the key issues for the rating of vehicle brake systems in the automotive industry. All methods for brake noise reduction can be sorted into three categories:
(1) modification of the structures of the brake parts, e.g. geometry and shape of brake components; (2) modification of the materials of some of the brake parts, e.g., the use of non-negative friction coefficient (vs. velocity characteristics) lining materials; and (3) modification of the vibration characteristics. A parametric study is carried out to study effect of changing material properties and structural modification on brake noise generations. Optimization of disc brake is performed in ANSYS software package. Application of virtual experiments in the development of products allows us savings in the production and elimination of defects.

***Key words**: urban area, noise pollution, optimization, ANSYS.*

1 INTRODUCTION

Noise and judder of road vehicles' braking systems are of great importance both for manufacturer and for the customer. High noise level causes environmental pollution, especially in urban areas, and during braking process, sound can be so irritating for the drivers and can lead to a traffic accident. This noise is regarded by vehicle users as symptomatic of a fault in the braking system, i.e. an "error state".

Vehicle customer experiences a brake noise as the most annoying sound. In many cases, the noise has small or don't has at any influence on braking performances. But this phenomenon greatly affects the quality and level of satisfaction. Large amount of money is being spent on the warranty and repair costs occurring due to the brake noise and vibration issue as the failure state has to be covered under the vehicle's warranty. Depending on the influence, manufacturers are looking for the ideal brake in which there will be no such problem.

Despite the large number of working hours that the engineers have invested in order to reduce brake noise, this is still a largely unsolved problem. Of course, it cannot be said that no progress has been made. All researches conducted, whether an experimental or numerical, indicated the main causes of these problems.

Trichers M. et al [1] are performed the brake noise measurements on the inertial brake dynamometer. The measurements were carried out on the conventional brakes. The application of constrained layer materials to add damping to the brake system can be considered as an efficient solution to reduce squeal noise problem and the measurement showed reductions about 20 dB for some frequencies.

During the optimization process Lü and Yu defined the thickness of nonwear component, young's module, material density and the brake pressure are treated as probabilistic variables, while the friction coefficient and the thickness of wear components are treated as interval probabilistic variables [2]. The lower bounds of the functions related to system stability, the mass, and the stiffness of design component are adopted as the optimization constraints. Although the reliability of the constraints at the initial design parameters violates the design requirement, while it satisfies the design requirement at the optimal values, this method can be considered as potential method on improving system stability and reducing squeal propensity of a disc brake under hybrid uncertainties.

High frequency noise that occurs in braking system during the braking process is a consequence of an unstable behaviour. There are plenty of structural modifications for the reduction of the brake squeal. Galhe and Wakchaure [3] considered the braking pressure as a parameter for reducing brake squeal-friction induced vibrations. They are tested braking rotors made from grey iron, high carbon grey iron and compact graphite iron. They are concluded that compact graphite iron requires a lower pressure for braking action and in this way the brake squeal is minimized.

Contrary to numerous analyses which are mainly performed for passenger car brakes, Suranarayana and Reddy [4] analysed an air disc brake of Volvo trucks. They analysed brake discs made from different types of materials by Ansys software package. Materials used for disc brake rotor are high carbon steel, grey iron and manganese. During the research, they are concluded that best suitable material for disc brake rotor is grey iron.

The objective of this paper is to investigate the effect of material properties and structural variations of the disc brake components on the squeal propensity using a detailed three dimensional finite element model.

2 3D MODEL

Before creating a 3D model of disc brake, or importing already formed model from other multi-platform software suite for computer-aided design (CAD), it is necessary to select the appropriate modules in Ansys software that are required for performing an analysis. Modules used for analysis in this paper are the Static Structural Analysis and Modal Analysis.

Disc brake rotor and brake pads are modelled in Ansys software package. Disc brake rotor is shown on Figure 1. This software is much more complicated for parts modelling, unlike commercial 3D software whose main task is to create parts. The most important reason for the modelling in Ansys software is to define the parameters that will later be used for optimization. The analysis was performed for a completely new disc - no traces of wear. Disc brake rotor diameter is 430 mm, height is 131 mm and thickness of area with vanes is 45 mm [5]. Detailed view of the brake disc vanes, with nominal diameters of a, b and h is also shown in Figure 1.

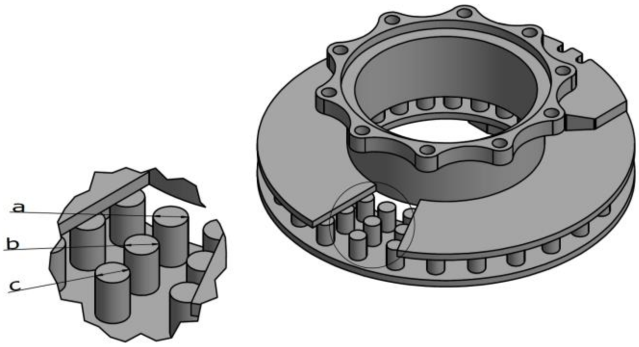


Fig. 1 *Disc brake rotor and brake pads*

Table 1 Material properties [6]

	Density [kg/m^3]	Young's module [GPa]	Poisson's ratio [-]
Brake disc	7250	138	0.28
Brake pad	1400	1	0.25

In addition to defining the characteristics of materials (Table 1), it is necessary to define the size and type of finite elements. For mash forming, the tetrahedral finite elements have been used. Mesh consists of 39067 nodes and 19428 finite elements.

2.1. Boundary conditions

Next step is based on defining the boundary conditions. Boundary conditions are defined in Static Structural module, and some of them are shown in Figure 2.

An environmental condition, corresponding to the conditions in which the real vehicle is operating, defines with the ambient temperature of 22˚C. The initial vehicle speed is 20 km/h and the vehicle brakes until it stops. Based on the initial speed of the vehicle and the tire diameter, calculated angular speed of wheel is 10 rad/s. From many experimental researches, it is established that squeal noise usually occurs at slow rotational speeds towards the end of a stop.

Braking process cannot be achieved without the influence of friction that is present in contact pair, between brake disc and brake pads. Adopted value of friction coefficient is 0.336 [7]. Furthermore, for braking process, it is necessary to form pressure acting on the brake pads and that transferring to the brake disc. Value of braking pressure is 1 MPa.

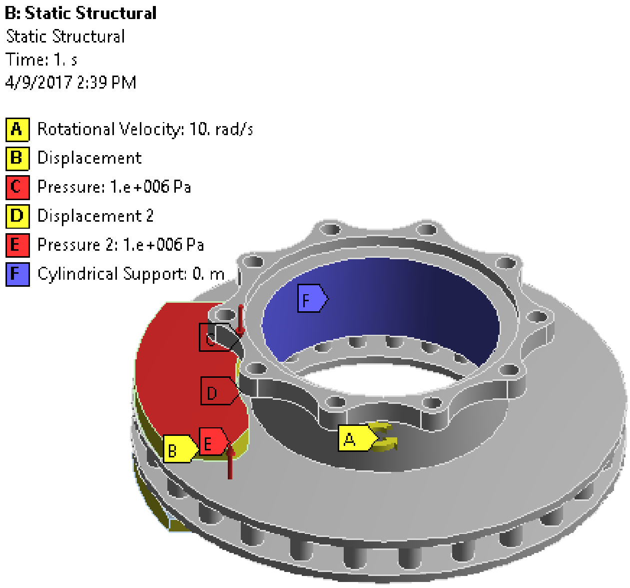


Fig. 2 *Boundary conditions and pressure on the disc-pad friction pair*

2.2. Modal analysis

Modal analysis is the process of determining the basic dynamic properties of the structure, such as natural frequency, damping and modes of oscillation, order to formulate the dynamic behaviour of the model. The analysis is based on the fact that the vibrations of the nonlinear dynamic system can be represented by the sum of simple harmonic motion. This fact is based on the Fourier theory, where all the complex modes of oscillation may present a sum of sine and cosine modes of oscillation, the appropriate frequency, amplitude and phase constants [8].

After defining the boundary conditions, the solver is started to perform an analysis of originally created model of the brake disc and the brake pads. Modes values are obtained, and as output, the maximal value of frequency is taken. Maximal value of frequency is shown in Figure 3, and at this frequency 9 modes are occurred.

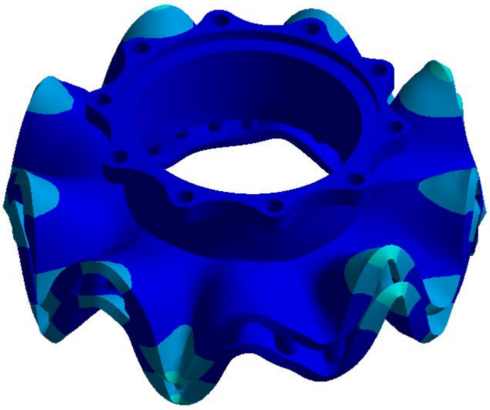


Fig. 3 *Mode shape 9 at a frequency of 6431.1 Hz*

2.3. Optimization

Optimization is defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit. Furthermore, optimization is obtaining the most important information about some product, while changing any of the parameters. This approach allows the manufacturer to open the possibility for their product to be competitive on the market. Optimization was performed in Ansys software package, by using Response Surface Optimization module. It represents a relationship between changing parameters of construction and effect, more accurate between stress and deformation that is obtained during the numerical analysis [9].
Applied optimization method is Screening method, which can be used for surface optimization and direct parameter optimization. This allows the generation of a set of samples and sample sorting on the basis of the set target. This method gives us a possibility of generating discreet values of parameters. Specific values for each input parameter are defined in Table 2. Thus, defined parameters are inputs in analysis, where the program creates all possible combinations and then calculates the value of frequency for each combination.

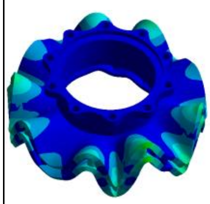
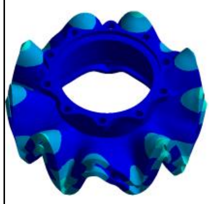
Table 2 The values of the input parameters

Inner roller diameter *a* [mm]	Central roller diameter *b* [mm]	Outer roller diameter *c* [mm]	Number of vanes *n* [-]
15	18	20	21
16	19	21	22
17	20	22	23
18	21	23	24
19	22	24	25
20	23	25	26

2.4. Results and discussion

The outcome of the optimization process is to get the lowest possible frequency, as well as the mass of the brake disc. Number of combinations is 1296, where each combination represents one value for each parameter that is given in Table 2.
After the completion of the optimization, program shows two or three best ranked combination, in this case, these two combinations, Table 3.

Table 3 The values of the parameters of the best ranked candidates

Inner roller diameter	15 mm	15 mm
Central roller diameter	18 mm	18 mm
Outer roller diameter	20 mm	20 mm
Number of vanes	21 mm	22 mm
Disc mass	21.8 kg	21.951 kg
Disc frequency	5852.2 Hz	6031.4 Hz
		

Analyzing the results given in Table 3, it can be seen that the maximal frequency of the disc is smaller than the initial, with the same number of modes. In addition, the second goal is met because the mass of the disc is reduced. The initial value of the disc's mass was 23.523 kg.

3 ALTERNATIVE MATERIALS FOR DISC

In general, the grey cast iron is used for producing brake discs; however, AMMC (Aluminum Metal Matrix Composite) is used on some vehicles, such as trains, which can develop the speed of 200 km/h and at the same time have large masses. No matter if discs are made from grey iron or AMMC, from them is required to have a good performance and reliability. However, these discs cannot be combined with any brake pads, but with pads that are of organic origin. Characteristics of materials for brake disc made from AMMC and brake pads of organic origin are given in Table 4.

Table 4 Material properties for alternative materials [10]

	Density [kg/m^3]	Young's module [GPa]	Poisson's ratio [-]
Brake disc	2903	113	0.24
Brake pad	2595	22	0.25

The development of composite materials originated from the need to achieve in many structures as higher strength and stiffness, and with the least possible mass. AMMS promise reducing the weight for 50-60% from total mass of brake disc [11]. Advantages of AMMS are next [12]:

- Increased strength;
- Increased stiffness;
- Less weight;
- Improved properties at high temperatures;
- The possibility of controlling the coefficient of thermal expansion;
- Resistance to abrasion;
- The possibility of reducing vibration.

3.1. Results and Discussion

Modal analysis of disc brakes made from alternative materials showed good results. The reason for this conclusion is that the same number of modes occurs at lower frequencies. Value of the frequency is 342.73 Hz, while the disc appearance is shown in Figure 4. The best ranked disc is analysed, Table 3. Mass of the disc is now smaller almost three times. The weight of the disc, if it was made of alternative materials (MMC) is 8.729 kg.

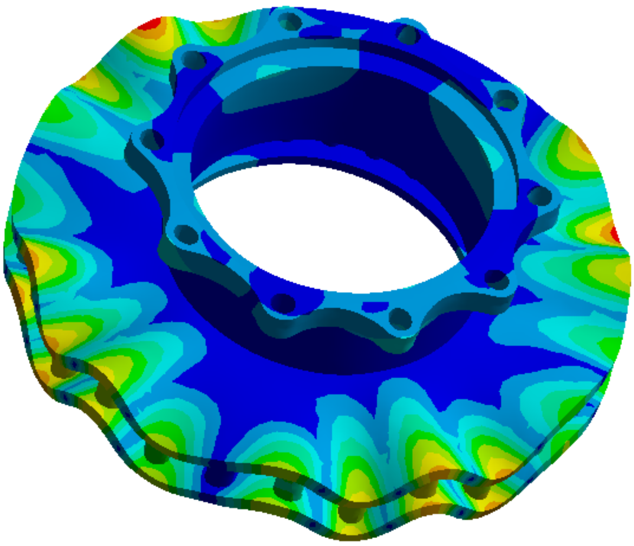


Fig. 4 *Ventilated disc brake from AMMC*

In this way, both conditions are satisfied that we have considered during the optimization of the disc that is made of cast iron.

4 CONCLUSION

Parameter optimization is main part of the development process for each machine element. Furthermore, in addition to parametric optimization, today are very actual these alternative materials used for the production of some of the parts.

The main indicator of good braking performance is the shortest stopping distances, and one of the important factors for achieving this goal is the weight of rotating masses. Also, the weight of rotating parts increases the weight of the vehicle, and this may be reflected in higher fuel consumption. Greater fuel economy entails higher emission.

Also, the weight has been reduced by optimizing the disc which is made of cast iron, and the maximum noise level that occurs in the process of braking is reduced, too. While using the alternative material, the weight is decreased three times, and the noise level even more.

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