INFLUENCE OF BREAK SHOES WEARING IN DRUM BREAK – NUMERICAL APPROACH

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Abstract

Braking system is one of the key components influencing passenger safety. Today, a design process of brakes is usually experience – driven, based on brake manufactures know – how. Using this approach, it is fairly difficult predict the brake components exact working condition or durability – parameters still more often required in a modern design process, what results in a rising demand for an exact simulation of a braking process. This paper presents numerical analyses of a drum brake. Both static and dynamic FE analyses were conducted in order to verify behaviour of numerical procedures affecting the braking process. The phenomena of heat generation by friction forces and the influence of a wear pattern was emphasized during dynamic calculations, while static analyses were focused on sensitivity to thermal properties of materials. FE models, including loads and boundary conditions, are described in details. Some of the data used during the simulation were taken from experiments. These laboratory tests are also briefly described in the paper. Based on the obtained results, it is shown that a numerical procedure converting sliding energy coming from friction to heat used in a coupled mechanical – thermal dynamic calculation works properly, but is very sensitive to material thermal properties. Proper FE modelling of the contact area and contact forces is also crucial. Unfortunately, due to lack of real material data, the presented results have quantitive character only.

Keywords: *road transport, simulation, brakes, thermal dynamic computations*

1. Introduction

The principle of brake operation is well known and rather simple to explain: to press fixed shoe against rotating counter body and generate friction force. Friction force will act against wheel rotation slowing it down. At the same time, some of the energy taken from a wheel will be dissipated via heat generation. Despite rather easy description, braking phenomena is very challenging from the numerical simulation point of view. One of the inconveniencies is the fact that friction process and heat generation via friction is characterized by many parameters, which are difficult to collect. On the other hand, proper FE simulation is the key to predict wearing, to optimize a system, to check new materials behaviour, to name a few benefits. These advantages and the requirement for a cheaper and better performing design are the main reasons why a demand for accurate FE simulation of brakes is still rising.

In this paper, an attempt to adopt FE tools to describe effects of wearing is presented. The performed simulations are based on SIMPLEX type drum brake. It is a typical brake layout, and it is showed in Fig. 1. The system consists of the rotating drum connected to the wheel; shoes; fixed bolts acting as axes of rotation for shoes; a clamping device responsible for spreading shoes and a spring shifting shoes back to a non-working position.

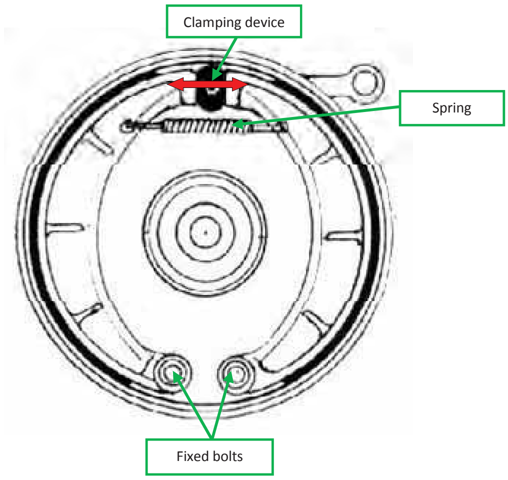

Fig. 1. SIMPLEX type drum brake

2. Analytical model

Forces acting in the drum brake are shown in Fig. 2. Friction force T_B can be divided into two forces: F'' acting towards fixed bolt axis and F' pressing a shoe to the drum (leading shoe) or pulling the shoe from the drum (trailing shoe).

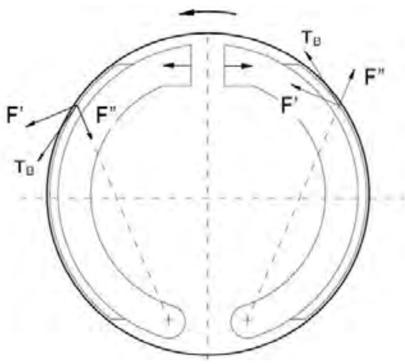

Fig. 2. Forces acting in SIMPLEX type drum brake [1]

These forces generate pressure distributions described by Koessler (see Fig. 3). Based on assumed pressure distribution one can analytically predict the braking moment and forces values by solving a number of mathematical equations [1].

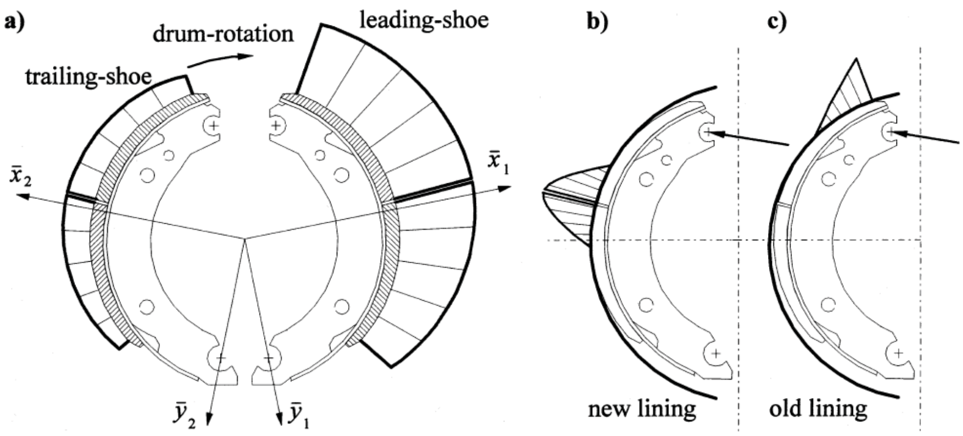

Fig. 3. Normal pressure distribution assumed by Koessler (a), for a new (b) and an old lining (c) [1]

3. Real-live tests

To collect parameters necessary to describe material properties, a number of real-live tests were performed. Fig. 4 shows a test stand with a wheel mounted in a working position. The wheel is pressed against a runway (a cylinder seen at the lower part of the image). The runway starts to rotate up to rotational speed which is equivalent to the assumed vehicle velocity. Once the rotational speed is stabilized, the brake is triggered and measurements take place. Hydraulic pressures acting in the braking system, braking moment, rotational speed are measured among the others.

Fig. 4. General view of testing stand [6]

4. Finite Element model development

Finite Element model of the brake is shown in Fig. 5. It consists of 359328 solid elements and 408419 nodes. Geometry Boundary conditions reflecting testing stand behaviour were applied to the model: constrains in x direction at the bolt holes; values of point forces simulating clamping derived from pressure in the brake system; initial rotating velocity equivalent to speed 100 km/h; initial temperature of 20 K. Constant friction coefficient $\mu = 0.4$. was defined between a drum and a lining. Contact analysis was performed using a penalty algorithm [2, 3].

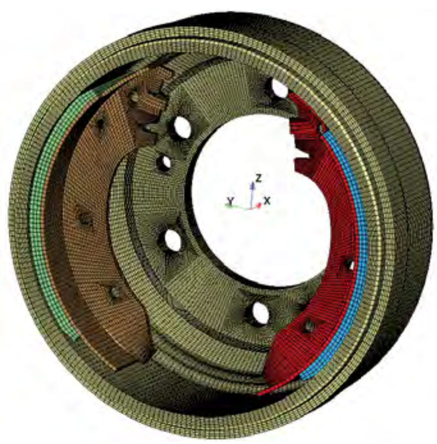

Fig. 5. FE model of the brake

Heat generation by friction forces was also calculated assuming full (100%) conversion of mechanical work done by friction forces F_f to heat energy:

$$F_f \frac{dS}{dt} = mc_p \frac{dT}{dt}, \tag{1}$$

where:
F_f - friction force,
S - braking distance,
t - time,
m - mass,
c_p - specific heat,
T - temperature.

Analyses were performed using so called a “direct integration procedure”, called colloquially an “explicit integration” with a finite difference algorithm [3].Two different FE models were prepared and analyzed. The first model was generated basing on ”perfect“ geometry, where drum and lining surfaces had a constant curvature. In the second model, small imperfections of lining surfaces were modelled according to one of the typical wearing patterns described in [4] (see Fig. 6).

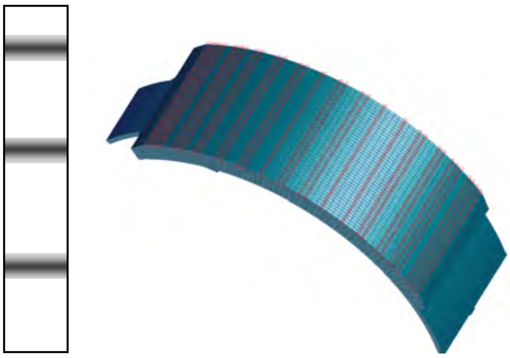

Fig. 6. Wearing pattern implemented in the „imperfect“ FE model

Unfortunately, at the time of analyses the real material properties taken from the brake were unavailable for the authors. Thus, it should be stressed out that material properties were taken from literature studies [5]. This fact had a huge influence on the obtained results, especially for the thermal part of the analyses.

5. Results

Typical results for a brake with perfect contacting surfaces are shown in Fig. 7 to 8, where stress and temperature distribution in the drum and the lining are shown respectively.

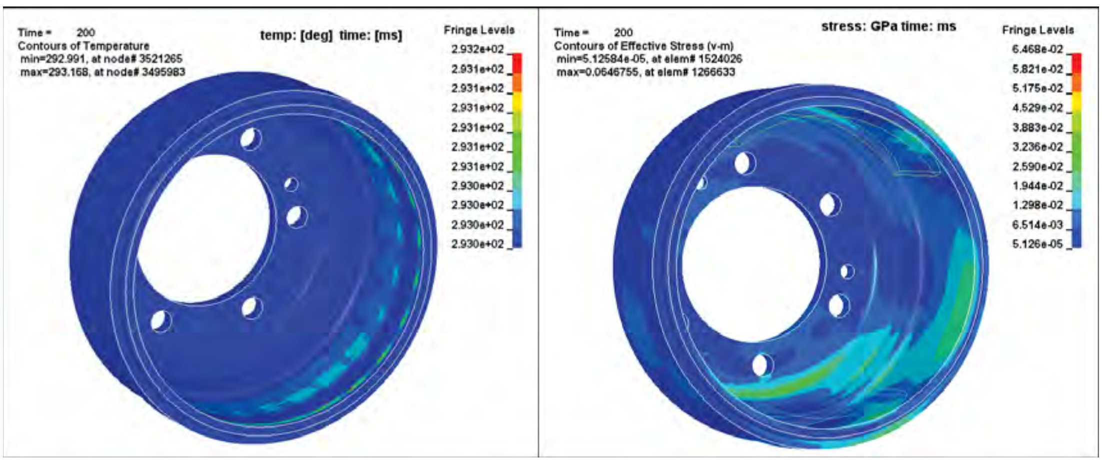

Fig. 7. Temperature and stress distribution in the drum for different times

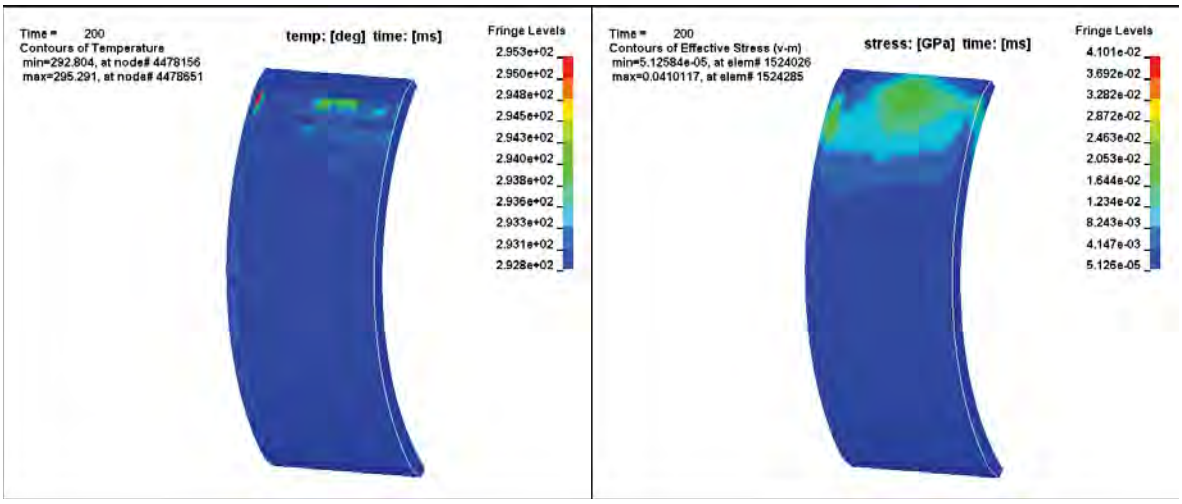

Fig. 8. Temperature and stress distribution in the shoe for different times

Temperature and friction force transient changes for one of the drum nodes are shown on the graph below (Fig. 9). Points A, B and C point out full rotations of the drum (360°). A repeatable pattern of a temperature change correlated with drum rotations can be easily observed. Friction force changes are also repeatable and correlated with the temperature pattern too. All above factors drive to a conclusion that a numerical contact algorithm, with friction and heat generation included, works well. Unfortunately, temperature values seen on the graph cannot be compared against real live test data due to lack of an accurate materials description.

Typical results for a brake with imperfect contacting surfaces are shown in Fig. 10 to 11, where stress and temperature distribution in the drum and the lining are shown respectively.

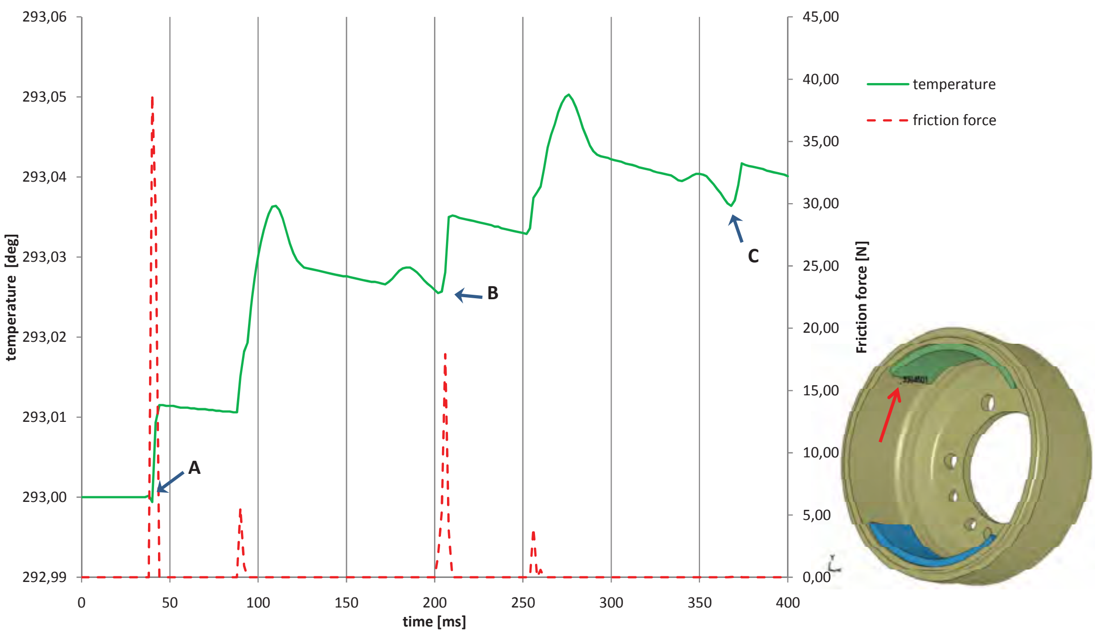

Fig. 9. Temperature generation based on the contact model

Temperature variation over time, for the same point as earlier, is shown on the graph below (see Fig. 12). Again, repeatable changes correlated with drum rotations can be seen clearly. The main difference between a perfect and imperfect structure is much higher temperature values and gradients. The reason of such a difference is a smaller contact area leading to higher contact interface forces and a bigger amount of heat generated by these forces.

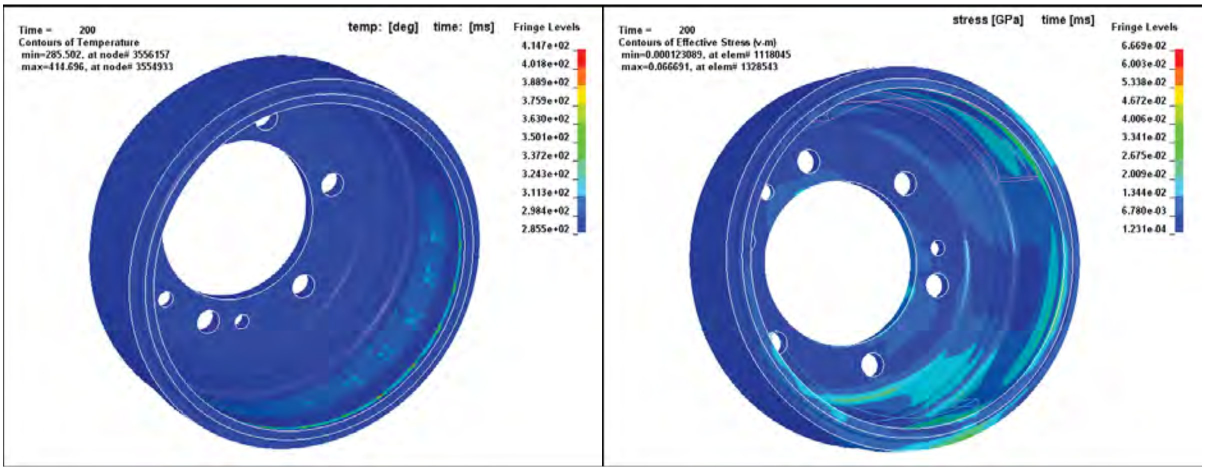

Fig. 10. Temperature and stress distribution in the drum for different times

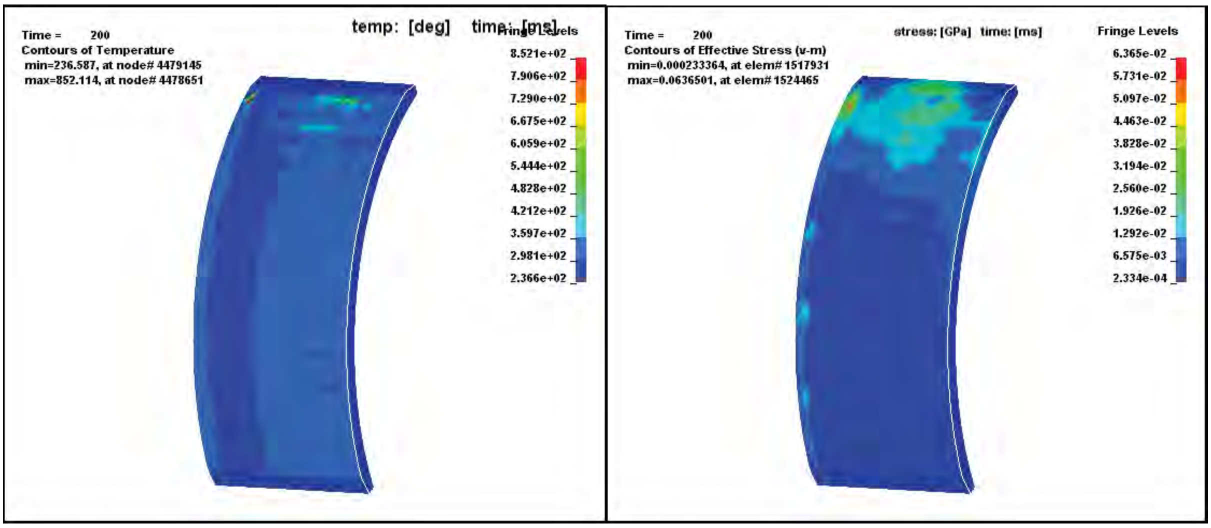

Fig. 11. Temperature and stress distribution in the shoe for different times

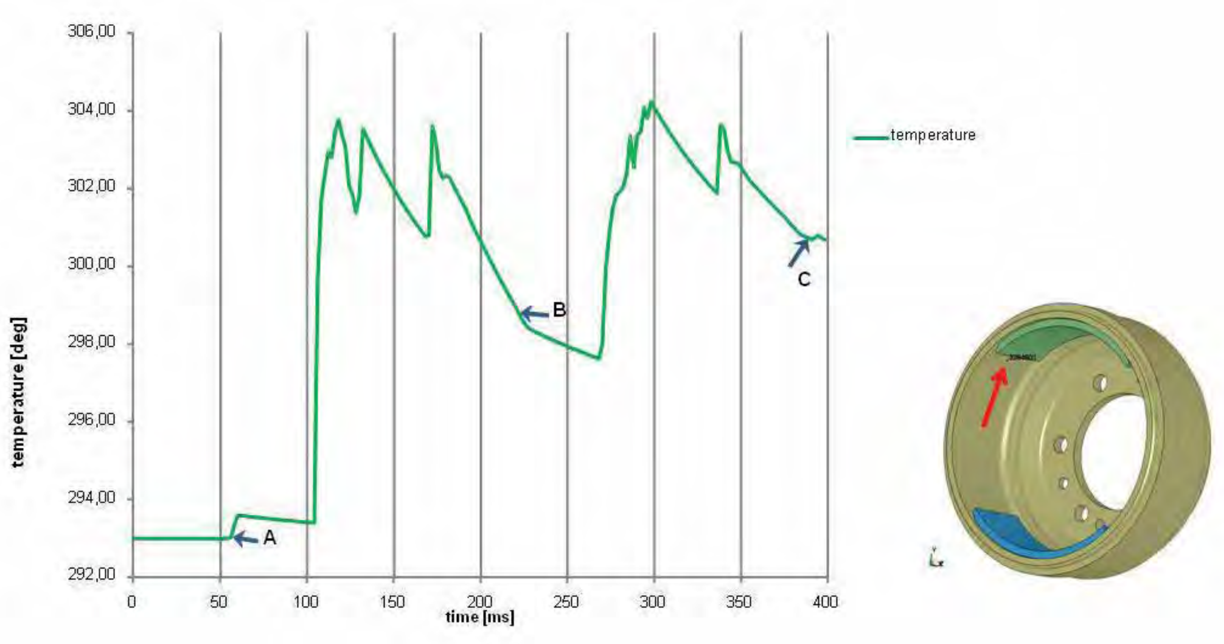

Fig. 12. Temperature generation based on the contact model

6. Conclusions

The presented study is a part of a more complex work aimed to simulate brake behaviour, including wearing. Because of very time consuming computations only outcomes for two rotations at this moment are shown. Computational efficiency is strongly dependent on the integration time step which in this study is close to 1.e-7 *s*.

Based on the presented results, it can be stated that current FE algorithms are capable to handle phenomena of heat generation by friction forces. A repeatable rise of temperature and proper model “reaction” to implemented imperfections shows that physics of the process is handled properly. It should be stressed out, though, that proper material data is a key factor influencing the analysis results.

The other issue of high importance is an accuracy of the FE model of contact interface, which means dense enough discretisation of contact surfaces. In the case of any friction brake, this leads to a very dense mesh of the whole drum or the disc and short integration steps (in the case of explicit solvers). On the other hand, the kinematics of the problem, large rotations namely, drives to very small time increments used during simulations (in the case of implicit solvers). This leads to a very intense usage of computational resources and very long simulation times, even in the presence of modern multi – processor systems.

The next step towards a better simulation of brake behaviour would be to characterize wear process by failure criteria. Such tools are present in many modern FE systems. The problem is to collect proper parameters describing failure criteria and a necessity of a very dense mesh, with the element size comparable to the size of a lining grain.

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