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THE DOWNHILL BRAKED RAILWAY WHEEL STRUCTURAL ANALYSIS

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СТРУКТУРНИЙ АНАЛІЗ ЗАЛІЗНИЧНОГО КОЛЕСА ПРИ ГАЛЬМУВАННІ НА СПУСКУ

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Article deals with the detection of reduced stress in a braked railway wheel based on thermal transient analysis on virtual models, because they influence the characteristics of the railway wheels. Structural analysis was performed by means of the ANSYS Multiphysics program system package. Thermal transient analysis deals with the detection of temperature fields which are result of braking by brake block. The applied heat flux represents the heat generated by friction of brake block. It is applied to the quarter model because of the acceleration calculation. This analysis simulates two braking with subsequent by cooling. Distribution of the equivalent stress was detected in the cross section railway wheel, at selected points. The input parameters were used from the thermal transient analysis. These equivalent stresses result due to thermal load.

Keywords: *railway wheel, brake block, residual stress, transient thermal analysis.*

Introduction

The brake system of railway vehicles is an important subsystem in terms of driving safety. Investigated issue is process of non-stationary temperature fields spreading, generated by the braking railway vehicles [1, 2]. Thermal load of railway wheels arises when braking the brake blocks. The contact stressess of crucial values arise. There arises the need for their analysis and presupposition by means of analytic tools too [3, 4, 5]. It has significant share of the impacts that lead to wear - modifications of the driving wheel profile and damage to the wheel tread. We have to investigate the influence of railway operation to the modification of the wheel profiles analytically [6]. There are different methods, they are usefull for this investigation [7, 8, 9,10]. We have to consider two factors in the process of braking. Railway wheel is overheated by the brake block at the point of contact. The wheel /rail contact phenomena influence the geometry parameters. From the long life, continuous and intensive reaserch is clear, that contact geometry and contact stresses are connected very close. There were performed works for decreasing of contact stress parameters and vehicle ride behaviour by modification of contact profiles [11, 12]. It is loaded by the normal [3, 7, 10] and tangential [8, 9, 10] stress, which is the source of the braking process. Brake blocks are structurally designed as adhesive brakes. The braking effect of the vehicle with respect to the track is carried out in the wheel-rail contact via the contact surface. The combination of vehicle wheel loading from thake blocks braking and rolling on the rail is for analytic simulation very complicated. The great advanture comes with the experimental laboratory research.

Professional public must pay attention to studying [14, 15] the effects of thermal and mechanical loading wheels of railway vehicles of reasons: the operation of vehicles, protection of life and health of the traveling public, reliable transport material and minimizing the negative effects of rail traffic on the environment.

Article deals with the detection of reduced stress in a braked railway wheel based on thermal transient analysis. Railway wheel is loaded by heat flux, which is applied on the contact surface. This topic is discussed in more detail in mentioned literature and references.

1 Residual stresses

In design and computational practice a material is usually considered as homogeneous isotropic continuum.

The deformation of bodies and stress occurrence happens mainly due to:

Mutual power action of bodies.

Action of field of temperature,

- Homogenous (tension appears when thermal dilatation of body is restrained),

- Non - homogenous (tension appears even if thermal dilatation of body is free).

If the plasticity condition is not satisfied, active tensions occur in elastic area and after removing of causes of their formation it completely disappear.

If formation of elastic plastic state arises in any point of a body, then after removing of formation causes (power, distortive and thermal), some residual stresses stay in a body.

1.1 Consequences of the residual stress state

Certain residual state of stress remains almost always in structural materials due to their production technology.

Residual stresses can be:

Helpful – e.g. peening are introduced compressive stresses in the surface layer, leading to prolongation of lifetime.

Harmful – cracking, corrosion stress, reduce fatigue limit or brittle fracture resistance (especially negative effect on tensile residual stresses).

High tensile stresses, induced, for example in the area of welds cools and phase transformations, may cause rupture even without additional external forces [13].

2 ANSYS program package

The program ANSYS (Fig. 1) uses the finite element method. Modeling of the finite element method belongs to the group of numerical methods. This method develops due to the constant increase in computing power. Its core is the discretization of bodies on the files of finite elements [3]. These elements form analogue after parts field that can be mathematically written [9].

The ANSYS program is generally nonlinear, multiphysics program including structural and thermodynamic analysis, analysis of flow continuum, analysis electrostatic and electromagnetic fields, and acoustic analysis. All these analyzes can be performed individually, but thanks ANSYS multiphysics conceived program can also be included in one common analysis. The ANSYS program allows you to not only check calculations, but also enables optimization and sensitivity analysis due to parameterized computational models, as well as the calculations of reliability.

ANSYS Mechanical product is intended to simulate the structural and thermodynamic tasks. The program includes the complete set of linear and nonlinear simulation with using linear and non-linear elements, material models, and contact non-linear algorithms.

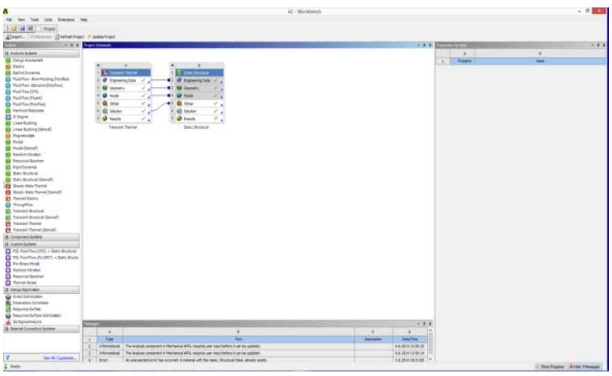

Fig. 1. ANSYS Workbench program system environment

3 Transient thermal analysis in ANSYS program

The problem simulates heating of the railway wheel tread. The railway wheel is braked by the brake block. The heat generated by friction of brake block, represents the heat flux of 40 kW. It is around the circumference of the wheel. The Analysis simulated two braking for time 100 seconds. The heat flux is applied to the tread. Railway wheel cools for 200 seconds after each braking. The value of heat flux is then zero. A quarter model of railway wheel was created using CATIA program and imported into ANSYS program.

3.1 The definition of material properties

Railway wheel is made of steel DIN 40Mn4. The thermal properties used in the simulation are shown in Table 1.

3.2. Definition of boundary conditions

A quarter model was used because of the acceleration calculation. The symmetry has been applied to the model.

The values of the heat flux (power) (Fig. 2) are shown in table 2. Dependence heat flux to time is shown in Figure 3.

Table 1

Thermal properties of materials

Property	Railway wheel	Air
Density ρ $[kg.m^{-3}]$	7850	1.170
Heat capacity C_p $[J.kg^{-1}.K^{-1}]$	486	1100
Thermal conductivity k $[W.m^{-1}.K^{-1}]$	52	0.026
Emissivity [-]	0.28	-
Dynamic viscosity [Pa.s]	-	$1.8 \cdot 10^{-5}$

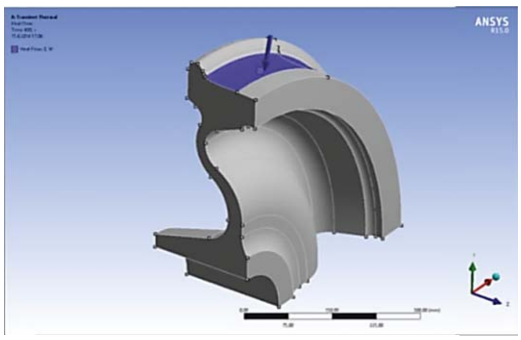

Fig. 2. Heat flux applied to the tread of the rail wheel

Table 2

Dependence heat flux to time

Step	Time [s]	Heat flux [W]
1	0	0
1	10	10000
2	100	10000
3	101	0
4	300	0
5	310	10000
6	400	10000
7	401	0
8	600	0

Six degrees of freedom were taken to the railway wheel. (Fig. 4).

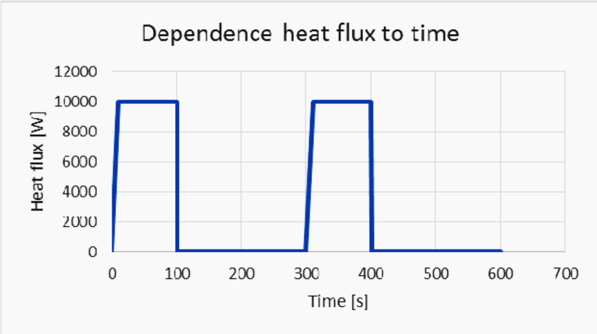

Fig. 3. Dependence of a heat flux to time

Finite element mesh (Fig. 5) was created according to the dimensional parameters with the following parameters:

– element size: 10 mm,
– element type: SOLID 90,
– number of elements: 5075,
– number of nodal elements: 26156.

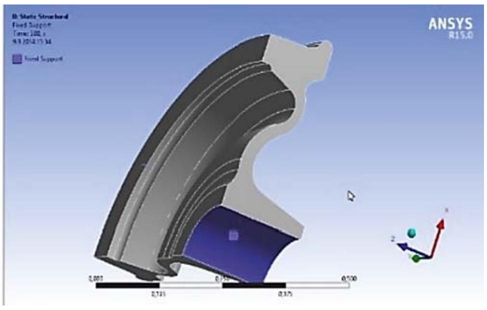

Fig. 4. Applied boundary conditions

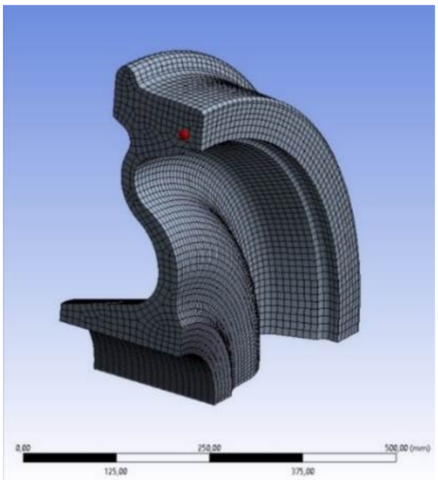

Fig. 5. Finite element model

Setting solver:

- direct solver with fixed setting step and automatic control of convergence.

Computation:

computing parameters:

processor: Intel Core i7 3.3 GHz (6 core),
memory (RAM): 64 GB.
Computation time about 25 minutes.

4 Results

The maximum temperature value was 172°C at the time of 400 seconds (Fig. 6), which is at the end of the second braking. The maximum value of the temperature was 138.8°C at the end of the first braking. The maximum values were detected in the surface layer of the rail wheel.

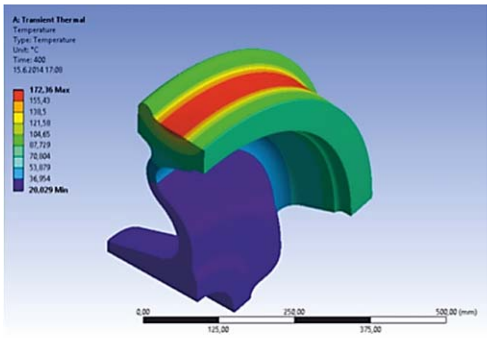

Fig. 6. Temperatures in railway wheel at the end of braking (time 400 s)

The temperatures in the cross section of the rail wheel, at selected points (Fig. 7), are shown in Figure 8.

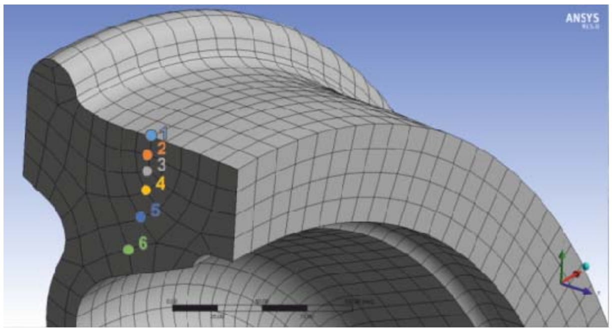

Fig. 7. The selected points, where were evaluated the temperatures and stresses

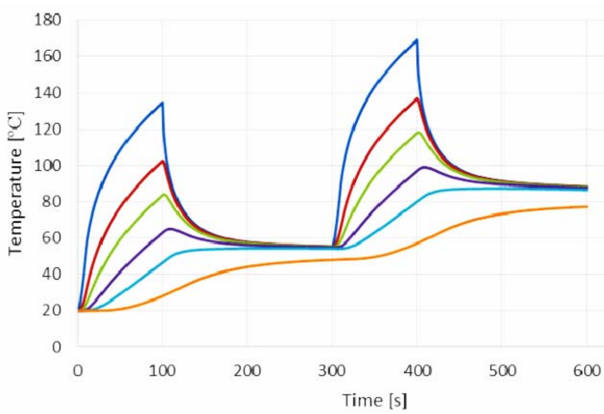

Fig. 8. Dependence temperature to time in selected points

5. Calculation of equivalent stress

Distribution of equivalent stress can be detected based on thermal transient analysis of braked railway wheel. These stresses result due to thermal load. We could use the parameters from the previous thermal transient analysis thanks the ANSYS program.

The maximum equivalent stress (von - Mises) value was 212.55 MPa at the time of 400 seconds (Fig. 9).

The equivalent stress in the cross section of the rail wheel, at selected points (Fig. 7), are shown in Figure 10.

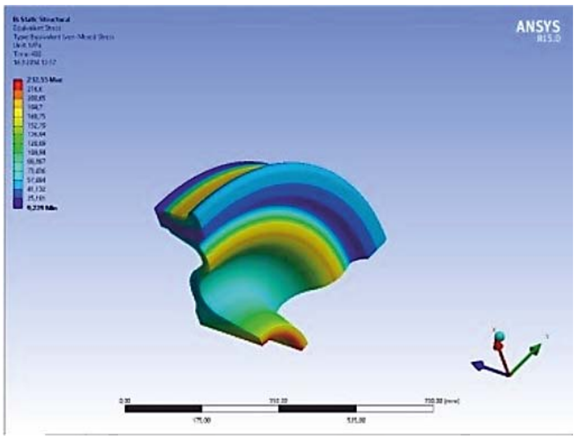

Fig. 1. Equvivalent stress in railway wheel at the end of braking (time 400 s)

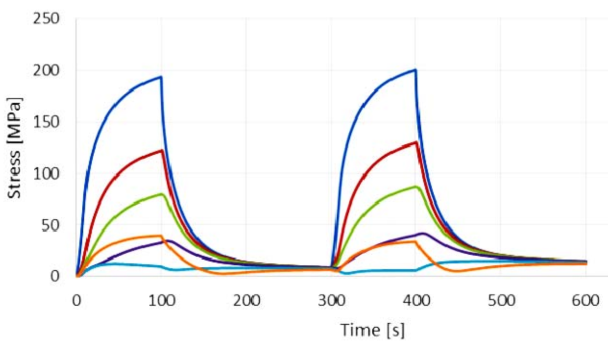

Fig. 10. Dependence stress to time in selected points

Conclusion

One possibility for identifying the impact of thermal and mechanical loading on braked railway wheel is the use of appropriate software and implementation of computer analyzes.

The article deals with the detection of structural properties braked railway wheel using a program that uses the finite element method.

Structural analysis was done on the basis of thermal transient analysis, where it was possible to determine the distribution of temperature fields during braking with constant heat flux. Thermal loads are used as input parameters from the previous thermal transient analysis. Distribution of equivalent stresses are the result of the analysis. These stresses result due to thermal load. This problem was solved in ANSYS program, which was suitable for this assignments.

Acknowledgement

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Суханек А., Гарушинець Й., Лоулова М. Структурний аналіз залізничного колеса при гальмуванні на спуску

Стаття присвячена виявленню сумарної напруги в гальмівному залізничному колесі, яка була визначена на основі аналізу теплового перехідного процесу на віртуальних моделях, оскільки температурні напруги впливають на характеристики залізничних коліс. Структурний аналіз виконувався за допомогою програмного пакету ANSYS Multiphysics. Термічний аналіз перехідних процесів пов'язаний з виявленням температурних полів, які є результатом колодкового гальмування. Тепловий потік утворився в колесі в результаті тертя. Для прискорення процесу розрахунку моделювалася черверть моделі. При дослідженні моделювали гальмування з подальшим охолодженням і далі повторним гальмуванням. Розподіл еквівалентної напруги в колесі досліджувався в поперечному перерізі в обраних точках. Вхідними параметрами для дослідження були результати теплового аналізу перехідних процесів. Еквівалентні напруги виникали в результаті теплового навантаження.

Ключові слова: *залізничне колесо, колодкове гальмо, залишкові напруги, перехідний тепловой аналіз.*

Суханек А., Гарушинец Й., Лоулова М. Структурный анализ железнодорожного колеса при торможении на спуске

Статья посвящена обнаружению суммарного напряжения в тормозном железнодорожном колесе, которое было определено на основе анализа теплового переходного процесса на виртуальных моделях, поскольку температурные напряжения влияют на характеристики железнодорожных колес. Структурный анализ выполнялся с помощью программного пакета ANSYS Multiphysics. Термический анализ переходных процессов связан с обнаружением температурных полей, которые являются результатом колодочного торможения. Тепловой поток образовался в колесе в результате трения. Для ускорения *процесса расчёта моделировалась черверть модели. При исследовании моделировали торможение с последующим охлаждением и далее повторным торможением. Распределение эквивалентного напряжения в колесе исследовалось в поперечном сечениии в выбранных точках. Входными параметрами для исследования были результаты теплового анализа переходных процессов. Эквивалентные напряжения возникали в результате тепловой нагрузки.*

Ключевые слова: *железнодорожное колесо, колодочный тормоз, остаточные напряжения, переходной тепловой анализ.*

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