

Analysis of disc brake temperature distribution during single braking under non-axisymmetric load

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ABSTRACT

This paper aims to study and compare the temperature distributions caused by mutual sliding of two members of the disc brake system basing on two- and three-dimensional FE modelling techniques and complexity of the phenomenon. First step of the analysis based on the previously developed model where the intensity of heat flux was assumed to be uniformly distributed on the friction surface of disc during braking process, and the heat is transferred exclusively in axial direction, whereas during the second, the three-dimensional rotor is subjected to the non-axisymmetric thermal load to simulate realistic thermal behaviour of the brake action. Operation conditions, thermo-physical properties of materials and dimensions of the brake system were adopted from the real representation of the braking process of the passenger vehicle. Arbitrarily selected four values of the velocities at the moment of brake engagement were applied to the models so as to investigate their influence on the obtained solutions of the temperature evolutions on the contact surface of the disc volume referring to two separated finite element analysis. The large amount of heat generated at the pad/disc interface during emergency braking indisputably evokes non-uniform temperature distributions in the domain of the rotor, whereas the pad element is constantly heated during mutual sliding. The obtained results of the original code of three-dimensional modelling technique implemented to the conventional FE software reveal high agreement with the solution of simplified process of friction heating.

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1. Introduction

The sliding contact of the members of disc brake results in kinetic energy conversion into heat at the pad/disc interface. The increase of friction moment is a limited quantity and depends on the coefficient of friction, radius of rubbing path, and forces that act on the pads. The process of slipping leads the increase of temperature, whereas its peak value is one of the most crucial factor in the course of action to occur. The temperature on the contact surfaces of the tribosystem during emergency braking intensified by significant thermal load due to frictional forces as well as the high velocity of the process is, in particular, important to predict in hazardous environments such as coal mines [1–4].

Complexity of the friction and wear processes state major difficulty of formulating universal physical model to determine critical operation conditions for specified case of braking action. Exact analytical solutions of temperature of friction pair may be obtained with restriction to semi-spaces, plane parallel strip or semi-planes.

Typically the heat flux condition is applied at the region of contact. The three-dimensional temperature distributions of a moving heat source problem with a rectangular and elliptic source on a rectangular prism and circular source on a rotating cylinder were proposed in article [5]. The temperature and the thermal constriction resistance as a function of geometric characters and velocity were determined. The temperature and the thermal stresses of the pad (the strip) sliding with the constant retardation on a surface of the disc (the semi-space) both during heating and after the moment of standstill were studied [6]. However these geometric configurations may correlate with actual engineering applications, absence of the exact solutions, primarily application of finite areas of frictional heating systems should be noticed.

Rotating systems such as disc brakes in which pads cover solely the segment of rubbing path of a disc, are intrinsically submitted to non-axisymmetric thermal load. Simplifications of a real three-dimensional modelling techniques into two-dimensionality relating to the heat rate uniformly distributed in circumferential direction were so far accomplished [7–11]. In point of fact they enter simplifications of three-dimensional process of heating, which is omitted in systems where the friction surface of a body

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Nomenclature

c	specific heat, J/kg K
$[C]$	heat capacity matrix
f	coefficient of friction
h	heat transfer coefficient, W/(m ² K)
k	thermal diffusivity, m ² /s
K	thermal conductivity, W/(m K)
$[K]$	conductivity matrix
p	pressure, MPa
p_0	contact pressure, MPa
q	intensity of heat flux, W/m ²
r	inner radius, m
R	outer radius, m
$\{R\}$	heat source vector
t	time, s
t_s	braking time, s
t_s^0	time of braking with constant deceleration, s
Δt	time step, s
T	temperature, °C
T_∞	ambient temperature, °C

T_0	initial temperature, °C
$\{T\}$	temperature vector
V	velocity of the vehicle, km/h
V_0	initial velocity of the vehicle, km/h
Δx	the mesh size (smallest element dimension), m
z	axial coordinate, m

Greek symbols

γ	heat partition ratio
δ	thickness
ε	coefficient of thermal activity
θ	circumferential coordinate, deg
ρ	density, kg/m ³
ϕ_0	cover angle of pad, deg
ω	angular velocity, 1/s
ω_0	initial angular velocity, 1/s

Subscripts

d	indicates disc
p	indicates pad
w	indicates wheel

and counterbody is equal aircraft brakes and clutch systems [12]. Two models of heat dissipation utilizing axisymmetric arrangement of a disc brake: namely macroscopic and microscopic model were implemented in articles [7,8]. In the macroscopic model first law of thermodynamics has been taken into account and for microscopic model various characteristics such as braking time, velocity of the vehicle, thermo-physical properties of materials, contact pressure, and dimensions of a real disc brake assembly have been studied. Green's functions were used to determine temperature distributions in the disc and pad volume [8].

Formulation of the heat flux activity during frictional heating independent of circumferential coordinate θ may cause unrealistic contact conditions and falsify actual, elastic distortions. In order to simulate reasonable emergency braking process, the three-dimensional FE model assuming nonlinear pressure distribution and angular velocity variability was proposed in article [13]. The thermo-physical properties of materials independent on temperature have been used.

Operation of disc brake above the certain range of the velocity may lead to thermoelastic distortions and in consequence to non-uniform pressure distribution due the interchanged moments of contact and its absence during rotation, known as thermoelastic instability (TEI) [14]. The upwind scheme in finite element formulation to prevent possible perturbations owing high Peclet number was developed [15].

The conventional finite element method is well adopted in stationary problems, however three-dimensional modelling of parts being in motion imposes very fine mesh due to high values of Peclet number, which determines the range of the velocity, above which oscillations may occur. The hybrid method combining the finite element method and the fast Fourier transform (FFT) technique, as an alternative approach in order to reduce computational time without loss of the temperature alterations owing the circumference of a disc brake was used [3,4,9,10,15,16]. The temperature distributions during different operation conditions were presented. The review of FEM-solutions of thermal problems of friction during braking is given in the article of Yevtushenko and Grzes [17].

In order to predict the temperature on the contact surfaces of elements of disc brake, experimental examinations including infrared techniques such as two colour pyrometry [18], infrared mapping [3,4] as well as thermocouples [1,19,20] were developed.

In this paper three-dimensional finite element analysis regarding movable behaviour of the disc brake system was developed and compared with the two-dimensional modelling of frictional heating problem derived from previous author's study [11]. In order to assure accuracy of the solution several finite element meshes of the two specified models of the real disc brake was tested. Investigation comprises dissimilar evolutions of the external load during mountain descent with constant velocity and application of single, emergency braking to standstill. For the purpose of comparison of obtained results, dimensions of the disc brake, operation conditions and thermo-physical material properties were adopted from the study developed previously [8]. Special concern is focused on the description of the FE modelling technique of the moving heat source problem corresponding to axial configuration of the same phenomenon.

2. Statement of the problem

The disc brake system comprises in the majority two elements: rotating axisymmetric disc and immovable non-axisymmetric pad (Fig. 1). When the braking process occurs, the hydraulic pressure forces the piston and therefore pads and disc brake are in sliding

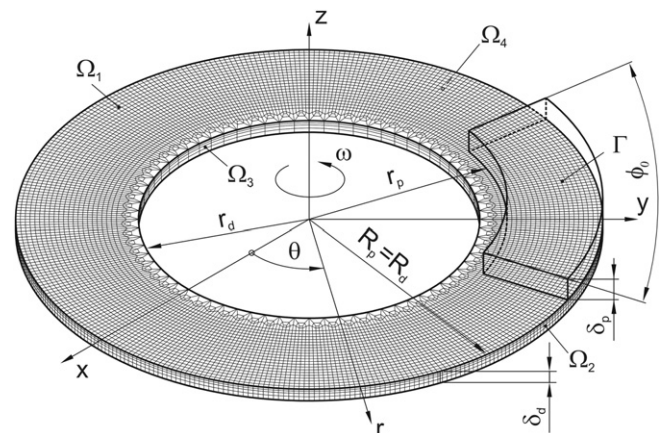


Fig. 1. A schematic diagram with three-dimensional finite element mesh of a pad/disc brake system.

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