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Influence of the pressure fluctuations on the temperature in pad/disc tribosystem ☆

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ABSTRACT

The influence of the duration of increase in pressure from zero (at the initial moment of time) to nominal value (at the moment of a stop) on the temperature for a friction pair metal–ceramic pad/cast iron disc is studied. Fluctuations of pressure are taken into account, too. The analytical solution to a thermal problem of friction during braking is obtained for a plane-parallel strip/semi-space tribosystem with a time-dependence friction power and the heat transfer through a contact surface.

1. Introduction: evolution of the contact pressure and sliding speed during braking

The nature of change in time of the specific load on the nominal contact depends on a loading system (pneumatic, hydraulic, mechanical, and electromagnetic), and a change of loading during braking (pulse braking, anti-lock braking system, automatic stability control system, etc.). Generally, the evolution of the pressure and movement during braking can be described by the equations [1–3]

$$p(\tau) = p_0 p^*(\tau), \quad p^*(\tau) = (1 - e^{-\tau/\tau_m}) \times [1 + a\sin(\omega\tau)], \quad 0 \le \tau \le \tau_s, \quad a \ge 0, \quad \omega > 0, \tag{1}$$

$$\frac{2W_0}{V_0^2}\frac{dV(\tau)}{d\tau} = -fp(\tau)A_k, \quad 0 \le \tau \le \tau_s, \quad V(0) = V_0. \tag{2}$$

Substituting the pressure of Eq. (1) to the right side of the Eq. (2), after integration we obtain

$$V^*(\tau) = V_1^*(\tau) - \frac{a}{\tau_s^0} V_2^*(\tau), \; 0 \le \tau \le \tau_s, \tag{3}$$

where

$$V_1^*(\tau) = 1 - \frac{\tau}{\tau_s^0} + \frac{\tau_m}{\tau_s^0}\left(1 - e^{-\tau/\tau_m}\right), \tag{4}$$

$$V_2^*(\tau) = \frac{1}{\omega}[1 - \cos(\omega\tau)] + \frac{1}{\tau_m^{-2} + \omega^2}\{[\tau_m^{-1}\sin(\omega\tau) + \omega\cos(\omega\tau)]e^{-\tau/\tau_m} - \omega\}, \tag{5}$$

$$\tau_s^0 = \frac{2W_0}{fV_0 p_0 A_k}. \tag{6}$$

At the stop time moment $\tau = \tau_s$ from Eqs. (3)–(6) we find the nonlinear equation of the dimensionless time of braking τ_s in the form

$$\tau_s^0 V_1^*(\tau_s) = aV_2^*(\tau_s). \tag{7}$$

If the increase in pressure is monotonically without oscillations ($a = 0$), then the Eqs. (1), (3) and (7) take the form

$$p^*(\tau) = 1 - e^{-\tau/\tau_m}, \quad V^*(\tau) = 1 - \frac{\tau}{\tau_s^0} + \frac{\tau_m}{\tau_s^0}\left(1 - e^{-\tau/\tau_m}\right), \quad 0 \le \tau \le \tau_s. \tag{8}$$

If pressure reaches its maximal value p_0 immediately ($\tau_m \to 0$), then from Eq. (8) it follows that

$$p^*(\tau) = 1, \quad V^*(\tau) = 1 - \frac{\tau}{\tau_s^0}, \quad 0 \le \tau \le \tau_s = \tau_s^0, \tag{9}$$

i.e. parameter τ_s^0 (6) may be treated as the dimensionless duration of braking at the constant deceleration.

The thermal behavior of a brake system, that consists of a shoe and a drum, for three specified braking actions: the impulse, unit step and trigonometric stopping actions was investigated in article [4]. Most often for an analytical determination of average temperature in the pad/disc system three calculation schemes are used: two semi-spaces, a plane-parallel strip/the semi-space (the foundation), and two plane-parallel strips. The corresponding thermal problems of friction can be formulated as one-dimensional boundary-value problems of heat conductivity of parabolic type. The temperature analysis for two homogeneous semi-spaces with the pressure increasing monotonically

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Nomenclature

d	strip thickness
f	coefficient of friction
h	coefficient of thermal conductivity of contact
K	thermal conductivity
k	thermal diffusivity
p	pressure
p_0	nominal pressure
$q_0 = fV_0p_0$	specific power of friction
T	temperature
$T_{\max}$	maximal temperature
$T_0 = q_0d/K_s$	temperature scaling factor
t	time
$t_{\max}$	time, when maximal temperature is reached
t_m	duration of the increase of the loading from zero to maximum value p_0
t_s^0	duration of braking in the case of constant pressure
t_s	braking time
V	sliding speed
V_0	initial sliding speed
W_0	the initial kinetic energy
z	spatial coordinate

Dimensionless parameters

α	amplitude of pressure oscillations
$Bi = hd/K_s$	Biot number
$K^* = K_f/K_s$	relative conductivity
$k^* = k_f/k_s$	relative diffusivity
$T^* = T/T_0$	relative temperature
$\tau = k_st/d^2$	time (Fourier number)
$\tau_m = k_st_m/d^2$	duration of pressure increase
$\tau_s^0 = k_st_s^0/d^2$	duration of braking with constant deceleration
$\tau_s = k_st_s/d^2$	stop time
ω	frequency of pressure oscillations
$\zeta = z/d$	spatial coordinate

Indexes

f	foundation (disc)
s	strip (pad)

during braking, in accordance with Eq. (8), has been performed in the articles [5,6]. The corresponding solution for two plane-parallel strips has been obtained in article [7].

The evolution and distribution of temperature in a strip/foundation tribosystem at sliding with a constant deceleration (Eq. (9)) have been investigated in articles [8,9]. In this article the corresponding solution with time-dependent contact pressure in the most general form (Eq. (1)), is obtained.

2. Statement of the problem

The problem of contact interaction of a plane-parallel strip (the pad) and a semi-infinite foundation (the disc) is under consideration. The time-dependent normal pressure $p(\tau)$, $0 \le \tau \le \tau_s$ (1) in the direction of the z-axis of the Cartesian system of coordinates $Oxyz$ is applied to the upper surface of the strip and to the infinity in semi-space (Fig. 1). In addition, the strip slides with the speed $V(\tau)$, $0 \le \tau \le \tau_s$ (3)–(6) in the direction of the y-axis on the surface of the semi-space. Due to friction, the heat is

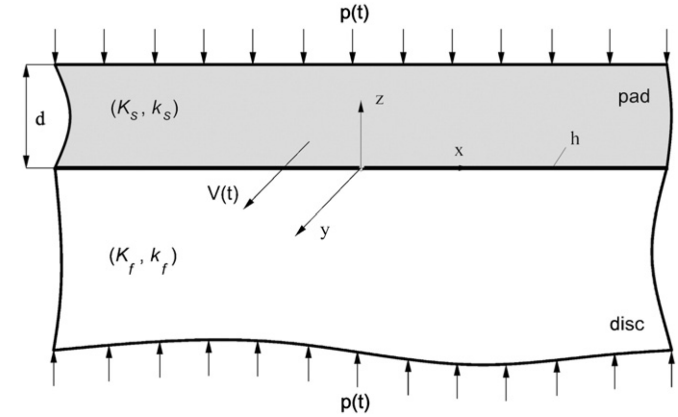

Fig. 1. Scheme of the problem.

generated on a surface of contact $z = 0$, and the elements are heated. It is assumed, that:

1) the sum of heat fluxes, directed from a surface of contact inside each bodies, is equal to a specific friction power [10]

$$q(\tau) = q_0 q^*(\tau), \quad q^*(\tau) = p^*(\tau)V^*(\tau), \tag{10}$$

where the functions $p^*(\tau)$ and $V^*(\tau)$ have the form (1) and (3), respectively;
2) between contact surfaces of the strip and the foundation the heat transfer takes place with a coefficient of thermal conductivity of contact h; and
3) the temperature on the upper surface of the strip is equal to zero.

Let us find the distribution of temperature fields in the strip and foundation. Further, all values and the parameters concerning the strip and foundation will have bottom indexes "s" and "f", respectively.

In accordance with the above-mentioned assumptions, the heat conductivity problem at friction takes form:

$$\frac{\partial^2 T^*(\zeta,\tau)}{\partial \zeta^2} = \frac{\partial T^*(\zeta,\tau)}{\partial \tau}, \quad 0 < \zeta < 1, \quad 0 \le \tau \le \tau_s, \tag{11}$$

$$\frac{\partial^2 T^*(\zeta,\tau)}{\partial \zeta^2} = \frac{1}{k^*}\frac{\partial T^*(\zeta,\tau)}{\partial \tau}, -\infty < \zeta < 0, \quad 0 \le \tau \le \tau_s, \tag{12}$$

$$K^*\frac{\partial T^*}{\partial \zeta}\bigg|_{\zeta = 0-} - \frac{\partial T^*}{\partial \zeta}\bigg|_{\zeta = 0+} = q^*(\tau), \quad 0 \le \tau \le \tau_s, \tag{13}$$

$$K^*\frac{\partial T^*}{\partial \zeta}\bigg|_{\zeta = 0-} + \frac{\partial T^*}{\partial \zeta}\bigg|_{\zeta = 0+} = Bi[T^*(0+,\tau) - T^*(0-,\tau)], \quad 0 \le \tau \le \tau_s, \tag{14}$$

$$T^*(1,\tau) = 0, \quad 0 \le \tau \le \tau_s, \tag{15}$$

$$T^*(\zeta,\tau) \to 0, \quad \zeta \to -\infty, \quad 0 \le \tau \le \tau_s, \tag{16}$$

$$T^*(\zeta,0) = 0, \quad -\infty < \zeta \le 1, \tag{17}$$

where the function $q^*(\tau)$ is given by formula (10).

3. Solution to the problem

The solution $T^*(\zeta,\tau)$ to a boundary-value problem of heat conductivity (11)–(17) in the case when the bodies are compressed