Machine Dynamics Research
2012, Vol. 36, No 3, 23–28

Modeling of Thermal Phenomena in a Mechanical Friction Clutch

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Abstract

In this work mathematical model describing the heat generation and its propagation in the mechanical friction clutch is presented and used. The proposed model takes into account the thermal conductivity of friction linings materials, the heat transfer between the friction linings of clutch and its surrounding environments, as well as the unequal distribution of flux density of generated heat in the clutch. The analyzed system is described by a set of algebraic linear equations, and it is derived using a computer numerical method. Both examples of numerical and experimental results are obtained and discussed. Work carried out in experimental studies were designed to confirm the presented mathematical model. Simple qualitative experimental verification of the model indicates a relatively good qualitative agreement with numerical results to the experimental ones. Relatively simple experiments carried out revealed that the proposed mathematical model describes the phenomenon well enough heat present in the real friction clutches.

Acknowledgements

The work has been partially supported by the National Science Foundation of Poland under the grant MAESTRO2 No. 2012/04/A/ST8/00738 for years 2012–2016.

1. Introduction

Heat generation and thermal phenomena in a mechanical clutch system have a big influence on its dynamics as well as on strength of its elements. Thermal phenomena associated with the generation, conduction and heat transfer through a direct contact between various solid bodies can be found in many mechanical systems. In general these dynamical processes depend on many system parameters,

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and it attracted attention of many researches focused on analysis of the mentioned phenomena in different kinds of mechanical systems like clutches, brakes, and others. Heat generated in a friction clutch is yielded by friction during sliding of friction linings, and propagates within the linings' materials. The heat transfer also occurs between lining materials and a surrounding environment. In many studies related to thermal phenomena in clutches (or brakes) various simplified mathematical models for their description have been used and applied (Evtushenko et al., 2000; Olesiak et al., 1997; Osiński, 1996). Namely, heat simple models describing processes of the generation and propagation of heat have been used assuming a uniform temperature distribution on the contact surfaces and ignoring the unequal temperature distribution on the surface. In this work we are aimed on a more accurate mathematical description of the considered thermal processes. Namely, numerical model allowing determination of non-uniform temperature distribution on the contact surface of friction linings for any instant of time has been used in computer simulations. It is expected that the obtained results allow a better forecast of the friction clutch systems real behavior. An extensive literature review on scientific papers devoted to heat various types can be traced in review papers by Goldstein et al. (2001, 2005 and 2006). In the review work by Evtushenko et al., 2000 papers published in recent years devoted to the analysis and calculations of thermal phenomena occurred in different kinds of friction brakes are also presented, illustrated and discussed.

2. Model of the considered system

Fig. 1 shows a cross section of the friction linings of the clutch with computing grid, deposited on the clutch cross section divided into m equal sections of length ΔR along the radius R with the nodes, where the appropriate temperatures are calculated.

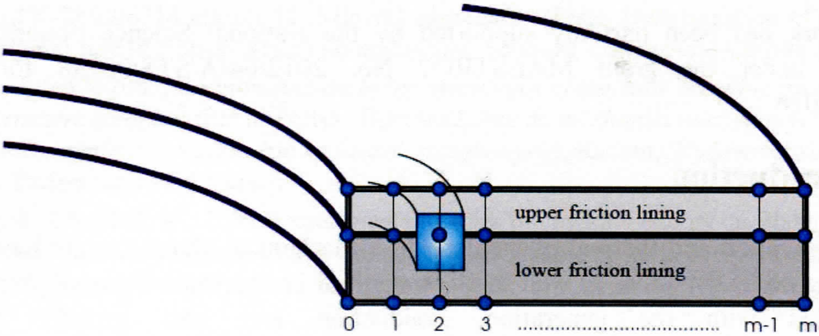

Fig. 1. Mechanical friction clutch linings cross section and the computing grid with nodes

The friction linings are fixed to both claddings of the clutch. The friction contact between linings occurs in the ring shape area $R \in [R_1, R_2]$. Thicknesses of the upper and lower linings are H_1 and H_2, and thermal conductivities of respective linings are $k_1^{(p)}$ and $k_2^{(p)}$, respectively. Heat transfer coefficients between the upper (lower) friction lining and the upper (lower) clutch cladding are λ_1 and λ_2, respectively. Moreover, heat transfer coefficients between the upper/lower lining and environment in turn are λ_3 and λ_4, respectively. Specific heats of materials of which the linings are made are c_{w1} and c_{w2}, respectively, while densities of material of which these linings are made are ρ_1 and ρ_2. The heat flux density $q(t)$ generated on the clutch working surfaces can be determined as a part of the work of friction force generated per unit time, and penetrated through the unit area. The heat flux density has the form (Alexandrov and Annakulova, 1990)

$$q(t) = (1-\chi)\mu |V_r(t)| P(t) \tag{1}$$

where χ is a part of the work of friction force not converted into heat (for instance, this part of the work is associated with wear), μ is the coefficient of friction, $V_r(t)$ is the relative sliding velocity, and $P(t)$ is the contact pressure distribution at the interface of bodies. Heat conduction in the cladding material is governed by the Fourier's law of the form

$$q(t) = -k^{(p)} \operatorname{grad} T \tag{2}$$

where $k^{(p)}$ is the thermal conductivity coefficient (thermal conductivity) of the material, and $\operatorname{grad} T$ is the gradient of temperature T perpendicular to the isothermal surface. The heat flux density exchanged at the border between the body and its surroundings environment is

$$q(t) = \lambda(T - T_{amb}) \tag{3}$$

where λ is the coefficient of heat transfer between the body and its surroundings environment, T is the temperature of the body at the border of its surroundings, and T_{amb} is the ambient temperature. Formula (6) describes the mechanism of heat exchange between body and environment known as the second type boundary condition. The detailed mathematical description of process of heat generation and propagation in the mechanical friction clutch is presented in the work (Grzelczyk, 2010). In this work the results of numerical simulations of obtained relationships are presented and compared to our own experimental investigations.

3. Numerical and experimental results

Numerical calculations are carried out using method for solving the set of algebraic linear equations and own numerical algorithms written in C++. Appropriate linear equations were solved using the Gauss-Jordan elimination method. Moreover, presented numerical simulations are verified experimentally using infrared camera for determining the temperature distribution on the surface of the frictional linings. In this work we consider two cases: uniform contact pressure distribution on the entire working surface $P(R,t) = \text{const.}$, and non-uniform contact pressure distribution on the entire working surface $P(R,t) = A/R, A = \text{const.}$ Fig. 2 shows examples of the obtained temperature distributions.

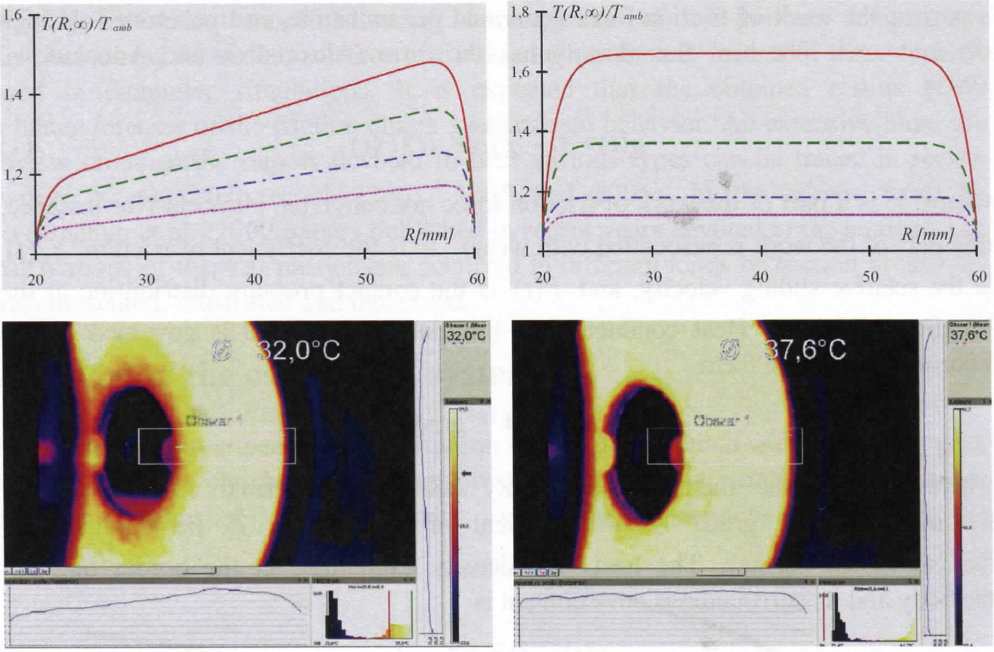

Fig. 2. Steady state contact friction materials surface temperature distributions obtained numerically (at the top) and experimentally (at the bottom) for $P(R,t) = \text{const.}$ (on the left) and $P(R,t) = A/R, A = \text{const.}$ (on the right)

Fig. 2 (on the left) shows examples of the temperature distributions on the working surface of the clutch in its steady state regime for $P(R,t) = \text{const.}$ In this case the temperature distribution reaches a steady state due to the setting up of thermal equilibrium between the heat generated in the friction material of the clutch and the heat transmitted to the surrounding environment. Inside the friction contact surface the temperature increases linearly with radius R, while at the borders of this surface the temperature is much lower. This decrease in temperature within the borders of contact materials is a result of the heat exchange between the friction materials and the surrounding environment (air). Besides, Fig. 2 (on the left) shows real temperature distribution and temperature profile along the radius of the frictional linings for uniform contact pressure distribution. Deviations from the linear relationship appear mainly due to the fact that in reality the exchange of heat between the lining and its surroundings on the borders of the contact, hence the less is the temperature at these sites lining.

Fig. 2 (on the right) shows examples of temperature distributions in the steady state regime for $P(R,t) = A/R, A = \text{const}$. Temperature distribution reaches a steady state due to the setting up of thermal equilibrium between the heat generated in the friction material of the clutch and the heat transmitted to the surrounding environment. Inside the friction contact surface the temperature is constant, while at the borders of this surface it is much lower. Besides, Fig. 2 (on the right) shows real temperature distribution and temperature profile along the radius of linings. However, it has been run for the linings, which reached (approximately) fixed contact pressure distribution. In this case it can be seen that the temperature distribution is approximately uniform over the entire surface. According to the presented mathematical model of the temperature distribution the obtained results are also would be helpful. In a real system one deals with slightly lower temperatures both on the inside and outside due to heat exchange between the lining and its surroundings. Even for this case one may confirm that that experimental results are roughly consistent with those obtained numerically.

4. Conclusions

The paper has been devoted to modeling of the heat generation and thermal phenomena occurring at the interface between the surface lining of the mechanical friction clutch. The used model takes into account thermal conductivity of materials of linings, the heat transfer between the linings of clutch claddings and its environments, and the unequal distribution of flux density of generated heat at the interface between linings rubbing themselves. Work carried out in experimental studies were designed to confirm the proposed mathematical model. A simple qualitative experimental verification of the model indicates a relatively good qualitative agreement with numerical solutions to the experimental results. Relatively simple experimental verifications carried out revealed that the proposed mathematical model describes the phenomenon well enough heat present in the real friction clutches.

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