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The temperatures distributions of a single-disc clutches using heat partitioning and total heat generated approaches

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ABSTRACT

An accurate estimation of temperature distribution is considered necessary to avoid the premature failure of friction clutches. In this work, different approaches were used to compute the surface temperatures of the friction clutch disc. The results presented the maximum surface temperature when the contact occurs between the rubbing surfaces during a single engagement and repeated engagements. Two approaches were used to simulate the thermal models of the automotive clutches to obtain the temperature field are heat partitioning approach and total heat generated approach. The analysis was conducted using developed axisymmetric finite element models to study the thermal behavior of the friction clutches during multi-engagements. The comparison was made between the temperature distributions based on the proposed approaches to show the accuracy of each approach. It was found that the heat partitioning approach was not accurate to investigate the thermal problem of the friction clutch during the multi-engagements.

1. Introduction

Friction clutches are repeatedly subjected to a considerable amount of frictional heat generation on the contact surfaces. This kind of heat generation happened due to the existing slipping between contacting parts of the friction clutch (in a single-disc clutch e.g. pressure plate, clutch disc and flywheel). High surface temperatures appeared as a result of the frictional heat generated when the friction clutch started to work. In some case the maximum temperatures exceed the allowable working temperature; consequently, many drawbacks appear on the surfaces of contacting parts such as plastic deformations, fast wear and surface cracks. When the friction clutch works under these circumstances, the early failure may occur in the contacting area of friction clutch elements.

Abdullah et al. [1–12] developed different numerical approaches to investigate the distribution of the temperature and the dissipated heat of the dry friction clutches which appeared due to the relative motion between the contacting elements. The thermo-elastic behaviors of the single and multi friction plates under varies operational conditions were studied intensively. The new mathematical model of a clutch disc to determine the quantities of storied energies at any time of the engagement period was presented. Furthermore, the surface roughness of the friction surfaces was measured experimentally and then used to simulate the numerical model of clutch disc to solve the thermoelastic problem.

Senatore et al. [13–15] investigated experimentally the effect of the slipping and contact pressure on the response of automotive clutches and brakes using different types of friction materials. The results presented the surface temperature field and the amount of

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the energy dissipation during the sipping time. It was assumed that the heat generated was a function of the wall temperature. The analysis was built based on Dirichlet and Neumann boundary conditions. The results proved that the contact pressure and the slipping speed are considered the most effective factors on the life time of the automotive clutches and brakes.

Ayala et al. [16] carried out the stability of a transient thermoelastic of the sliding systems. The effect of the intermittent contact on the thermoelastic problem of the sliding systems was studied. They showed that the frictional heat input is important at lower Fourier numbers. Under this condition, the critical speed is an inverse linear function of the duration of the contact time. In this case, the higher Fourier numbers was used to obtain the lower critical speeds.

Cho and Ahn [17] studied theoretically and experimentally the effect of the operating boundary conditions on the chattering of the automotive disc brakes. It was used a brake dynamometer to determine the disc's temperature during chattering. Fast Fourier Transformation with finite element methods was used to examine the thermoelastic behavior of three-dimensional brake system. The results showed that the phenomenon of the transient thermoelastic instability and the chattering in the brake discs have a significant affect on bulk temperature.

Al-Shabibi and Barber [18,19] investigated the thermomechanical behavior of the sliding systems using a reduced order model approximation which is described by one or more dominant perturbation or eigenfunctions. The mathematical model was built of the sliding system with a modest degree of freedom to obtain the contact pressure and the temperature distributions. The results were proved that a reduced order models have very good approximations in the early period of the automotive brake or clutch engagement when the sliding speed is above the critical sliding speed of the system.

This work highlights a fundamental point to adopt the accurate mathematical model in the design of the dry friction clutches. Two mathematical models have been developed based on the heat partitioning and the total heat generated approaches to computing the surface temperatures of the friction clutch during the sliding and full engagement phases. The finite element method was applied to conduct the thermal analysis of a friction clutch during multiple engagements in this research paper. The selected friction clutch consists of a single plate with two active frictional faces.

The short overview of the approaches which used in this work to simulate the thermal models of the automotive clutches to obtain the temperature field is:

- Heat partitioning approach: modeling the clutch system parts individually based on the heat partition factor to determine the amount of heat which enters into to each part of the clutch system.
- Total heat generated approach: modeling the clutch system parts together (whole model of the clutch system) and apply the total heat generated at the interface between the contact parts.

In this analysis, the effect of convection is considered for both approaches.

2. History of heat partition factor

The slipping between contacting surfaces will occur at the beginning of the clutch engagement until the driven shaft have the same speed as the driving shaft. The heat will generate from the rubbing surfaces due to the power dissipation by the frictional slip between the pressure plate and flywheel from one side and the friction clutch disc from the other side. The heat generated which appeared at the boundary between the contacting surfaces will be divided unequally into the contact elements of the clutch system. The amounts of these energies (heats) are depending on the material properties of each contacting element. The heat partition ratio (γ) represented the factor that specifies the amount of heat which enters into each body of two bodies system.

In the case when there are two bodies were in contact, when the first body (1) slides over the second body (2). The heat was generated due to friction, and the amount of the total heat generated at any time is q_T (Fig. 1). The amount of the heat flux which enters into the body (1) is

$$q_1 = q_T \gamma \tag{1}$$

where q_T is the sum of heat fluxes ($q_T = q_1 + q_2$). The amount of the heat flux which enters into the body (2) is

$$q_2 = q_T (1 - \gamma) \tag{2}$$

In the clutch system the amount of heat generated is,

$$q = \mu\, p\, V_s \tag{3}$$

where μ, p and V_s are the friction coefficient, the contact pressure and the sliding speed, respectively.

Blok [20] presented the heat partition term of two bodies system in contact. Two models were selected to achieve sliding problem between two bodies this study. The first one was roughness surface with a square cross section ($a \times a$) and the second one is a circular (radius $= a$) contact with a semi-space surface. It was concluded that the contact area ratio (actual contact area divide by nominal contact area) was very significant. It was assumed that the heat was generated at the contact surfaces; the development of the heat expansion was just in the perpendicular direction to the contacting surfaces. Constant heat flux intensity at any time was applied. It was applied a heat flux (q_1) to heat up the rough semi-space surface, and the heat flux (q_2) was applied for heating the small zone of the semi-space surface. The heat partition factor expression when the sliding speed range was low ($V_s \le 8\, k_2/25a$ or $P_e \le 0.32$) is