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THERMO ELASTIC INSTABILITY WITHIN A CLASS IV FRICITON JOINT

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Abstract
With a class IV couple of friction joint there are conditions when the disturbances of the pressures on the interface increase, decrease or remain unchanged. When the two materials of the joint are identical a relative stability is formed regarding this phenomenon, while a good heat-conducting material coupled with a heat insulator, depending on certain characteristics of sliding speed, creates instability. Equation of this paper specifies the threshold for instability.

Keywords:
Thermo elastic instability; Solutions; Temperature wave

1. INTRODUCTION

With a class IV friction joint (annular joint), which is the primary sealing of a frontal sealing, may appear situations in which pressure disturbances within the interface decrease, increase, or remain constant. These in turn are influenced by the properties of the materials in contact, coefficient of friction and relative sliding velocity.

The increase of the pressure disturbances in the interface leads to an increase in contact pressure and the local temperature. Adjacent to the zones with low pressure the surfaces can detach leading to important losses by leakage.

Materials of the same type making the joint tend to a relative stability when speaking of this phenomenon, while a joint composed of a good heat conductor material and a insulator will always show characteristics of relative sliding speed, from which instability appears.

The sliding contact at relatively high speeds is associated with a macroscopic instability, so that on a flat and uniform contact area will appear disturbances of local pressure.

This leads to negative effects upon the contact area from the point of view of heating and wear.

The simplified configuration of the primary sealing (class IV friction joint) is presented in Fig. 1. For such geometry, if the pressure is uniform in the interface, the temperature slowly rises until it hits a nominal value determined by the operating parameters.

If instead the uniform distribution of the pressure is disturbed even sparsely (which can be expressed as a Fourier series or waves along the contact surface) the disturbance may diminish, may remain unchanged or may rise. Thus, the stability of the pressure distribution can be investigated according to the behavior of waves of initial disturbance.

The problem is assumed to be ideal linear, with a linear heat transfer, thermal expansion and elastic displacement so that:

- the solution found is for the pressure wave produced at the surface of the semi-infinite ring extremity when there is a temperature wave of constant amplitude moving with constant speed;
- there is a relationship between the pressure wave and the heat produced by friction, generated at the limiting value, where it is assumed that another plate slides over and takes over the pressure distribution.

As an additional restriction of harmful waves it is assumed that there is no disruption at the extremities of the distance corresponding to the circumference of the tube (fig 1).

This implies that the harmonic components of the disturbance, complete one or more numbers of cycles over the specified length.

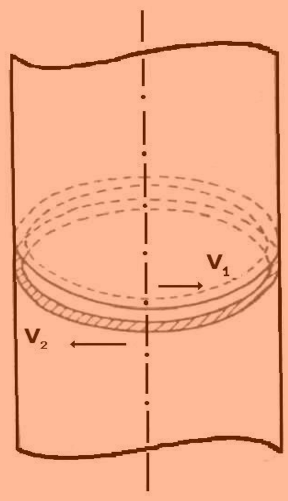

Figure 1

The combination of properties of materials in contact and operating conditions which satisfy the entire set of conditions will be considered to define the circumstances of a specified wavelength disturbance, without diminution or amplification.

2. SOLUTIONS FOR A TEMPERATURE WAVE WITH CONSTANT MOVEMENT

If referred to one of the plates marked with 1, the edge temperature perturbation can be expressed:

$$T = T_0 * \sin \omega(x-vt) \tag{1}$$

where:

- T_0 is the constant for temperature
- $\omega = 2n\pi/L$ the measure of wave number
- x – is measured along the contact surface
- v - Instantaneous transverse velocity of the wave along the contact surface

Heat transfer equation:

$$\delta^2T/ \delta x^2+ \delta^2T/ \delta y^2-(\delta T/ \delta t)/k=0 \tag{2}$$

$$-\infty \le x \le \infty$$

$$0 \le y \le \infty$$

with T=0 when $y \to \infty$; y is measured perpendicular to the contact surface

Solution for body number 1:

$$T_1= T_0e^{-b_1y_1} \sin (\omega x - \omega v_1t + a_1y) \tag{3}$$

where:

$$b_1= \{\omega^2/2 + \omega/2 [\omega 2 + (v_1/k_1)^2]^{1/2} \}^{1/2} \tag{4}$$

$$a_1 = \{- (\omega^2/2) + \omega/2 [\omega^2+ (v_1/k_1)^2]^{1/2} \}^{1/2} \tag{5}$$

where:

- k – material diffusion capability
- K - material conductivity
- p - pressure
- c_p – specific heat

The heat flow (q_1) is given by the equation:

$$q = - K(\delta T/ \delta y)_{y1=0} = -KT [a_1\cos(\omega x - \omega v_1t) - b_1\sin(\omega x - \omega v_1t)] \tag{6}$$

Surface temperature will be:

$$T=T_0 \sin \omega t \tag{7}$$

and

$$q_1 = K_1 T_0 (b_1\sin \omega x - a_1 \cos \omega x) \tag{8}$$

For the second body (which moves in the opposite direction relatively to the temperature wave with the speed v_2):

$$T_2 = T_0e^{-b_1y_1} \sin(\omega x - \omega v_2t - a_2t) \tag{9}$$

Where a_2 and b_2 correspond to the (4) and (5) equations with the correct changes for indices. Thus:

$$q_2 = - K_2 (\delta T_2/ \delta y_2)_{y2->0} = K_2 T_0[a_2\cos(\omega x - \omega v_2t) – b_2\sin(\omega x + \omega v_2t)] \tag{10}$$

If the wave is stationary and plate is moving relative to it:

$$q_2 = K_2 T_0 (b_2\sin \omega x + a_2\cos \omega x) \tag{11}$$

and

$$q = q_1+ q_2=T_0 [(K_1b_1+ K_2b_2) \sin \omega x +(K_2a_2- K_1a_1) \cos \omega x] \tag{12}$$

3. STATE OF THERMO ELASTIC STRESS IN A PLATE SUBJECTED TO A WAVE OF TEMPERATURE THAT MOVES UNIFORMLY

The thermo elastic equation of a plate depending on the potential of displacement Ψ is:

$$\delta^2 \Psi / \delta x^2+ \delta^2 \Psi / \delta y^2 = (1+ v_0)\alpha T_0e^{-by} \sin (\omega x + ay- \omega vt) \tag{13}$$

where: α - coefficient of thermal expansion

ν_0 – Poisson's coefficient

The speed **v** of the surface on the direction of y is zero ($v_{y->0}$) and $\Psi \to 0$ when $y \to \infty$, $\delta \Psi / \delta y \equiv v$, resulting in:

$$\Psi_1= (Ae^{-\omega y})(C \cos\omega x+D \sin\omega x)+(k_1/v\omega)(1+v_1) \alpha_1T_0e^{-b_1y} \cos(\omega x+ a_1y) \tag{14}$$

Coefficients C and D are evaluated to meet the condition on the limit. Results that the surface pressure p_1' will be:

$$p_1' = E_1 \alpha_1 T_0 k_1 [-(\omega - b_1)\cos\omega x + a_1 \sin\omega x]/v_1 \quad (15)$$

A similar equation can be written for the body numbered 2. At the moment of contact between the two bodies each surface will suffer a displacement equal and contrary till the equalization of tensions:

$p_1'' = E\omega\delta/2$ with $\delta = \delta_0 \sin\omega x \leftarrow$ thermal layer thickness

As a result:

$$p = -E_1\omega\delta/2 = p_1' + p'' \quad (16)$$

$$p = E_1\omega\delta/2 = p_2' + p'' \quad (17)$$

Given the fact that *p* must be identical for the two bodies (according to the law of balance) δ can be eliminated

$$p = E_1E_2T_0\{[\alpha_2k_2(\omega-b_2)/v_2 - \alpha_1k_1(\omega-b_1)/v_1]\cos\omega x + [\alpha_2k_2a_2/v_2 + \alpha_1k_1a_1/v_1]\sin\omega x\}/(E_1+E_2) \quad (18)$$

According to the principles of equilibrium, the heat generated by friction must be equal to the heat from the interface if:

$$mp(v_1 + v_2) = q \quad (19)$$

$$(K_1b_1+K_2b_2)\sin\omega x + (K_2b_2-K_1b_1)\cos\omega x = (v_1+v_2)\mu E_1E_2\{[\alpha_2k_2(\omega-b_2)/v_2 - \alpha_1k_1(\omega-b_1)/v_1]\cos\omega x + [\alpha_2k_2a_2/v_2+\alpha_1k_1a_1/v_1]\sin\omega x\}/(E_1+E_2) \quad (20)$$

To satisfy the equation (2):

$$K_1b_1+K_2b_2 = (v_1+v_2)\mu E_1E_2[\alpha_2k_2a_2/v_2+\alpha_1k_1a_1/v_1]/(E_1+E_2) \quad (21)$$

$$K_2b_2-K_1b_1 = (v_1+v_2)\mu E_1E_2[\alpha_2k_2a_2(\omega-b_2)/v_2 - \alpha_1k_1a_1(\omega-b_1)/v_1]/(E_1+E_2) \quad (22)$$

So for bodies of the same material: $v_1=v_2=v/2$, and equation (21) reduces to:

$$\mu E\alpha ka/bK = 1 = \mu E\alpha ka\{[1+[1+(v/k\omega)^2]^{1/2}]/[1+[1+(v/k\omega)^2]^{1/2}]\}^{1/2}/K \quad (23)$$

and for two bodies of which, one is good conduit for heat and other heat isolated:

$k_1 \to 0$, $K \to 0$, $v_2 \to 0$, and $v_1 \to v$. If $v>1$, $a_1 \to \omega(v_1/2k_1\omega)^{1/2}$

$a_2 \to v_2 2k_2$; $b1 \to \omega(v_1/2k_1\omega)^{1/2}$; $b_2 \to \omega[1+(c_2/k_2\,\omega)^2/8]$

and equation (21) reduces to:

$$v_1 = v = 2K_2\,\omega(E_1+E_2)/\mu E_1E_2\alpha_2 \quad (24)$$

4. CONCLUSIONS

The equations from above serve to provide the terms depending on which the pressure disturbance in a frontal sealing interface increases. In this case load concentrations occur in small portions of the contact surfaces, resulting in damage or separation of the rings.

For materials of the same type, instability occurs only at a high coefficient of friction. Initial size of the uniform load has little influence on the general temperature which may alter the properties of the materials. Role of slip velocity is also small.

In case the material has different properties from the point of view of transfer of heat produced by friction will be taken from the heat-conducting body and the limit between stability and instability depends on the relative sliding velocity.

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