TRANSITION IN THE FRETTING PHENOMENON BASED ON THE VARIABILE COEFFICIENT OF FRICTION

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Abstract: Fretting is now fully identified as a small amplitude oscillatory motion which induces a harmonic tangential force between two surfaces in contact. It is related to three main loadings, i.e. fretting-wear, fretting-fatigue and fretting corrosion. Fretting regimes were first mapped by Vingsbo. In a similar way, three fretting regimes will be considered: stick regime, slip regime and mixed regime. The mixed regime was made up of initial gross slip followed by partial slip condition after a few hundred cycles. Obviously the partial slip transition develops the highest stress levels which can induce fatigue crack nucleation depending on the fatigue properties of the two contacting first bodies. Therefore prediction of the frontier between partial slip and gross slip is required.

1.INTRODUCTION

More recently fretting has been discussed using the third-body concept and using the means of the velocity accommodation mechanisms introduced by Godet et al.[1,2]
Fretting regimes were first mapped by Vingsbo [3]. In a similar way, three fretting regimes will be considered: stick regime, slip regime and mixed regime. The mixed regime was made up of initial gross slip followed by partial slip condition after a few hundred cycles. Obviously the partial slip transition develops the highest stress levels which can induce fatigue crack nucleation depending on the fatigue properties of the two contacting first bodies. Therefore prediction of the frontier between partial slip and gross slip is required.

This papers proposes several criteria to determine the transition between partial slip and gross slip. A theoretical expression of the transition depending on the applied normal force and the tangential displacement will be introduced in order to plot fretting maps. All the relations exposed in the present paper obey the restrictive conditions exposed by Mindlin[4]. A ball on flat contact will be considered with a constant normal force P and a varying tangential force Q. All the relations were written using Johnson’s notation [5]

2. TRANSITION CRITERIA

From this rapid description of the sliding behavior, several criteria have been introduced that allow for a quantitative determination of the transition between a partial and gross slip behavior for alternated loadings.

2.1.The energy ratio

The energy ratio A between dissipated energy Wd and the total energy Wt was introduced to normalizes the energy evolution as a function of the loading conditions.
In this case we analyzed the transition criterions for the case of one variable friction coefficient between surfaces.In this case the energy ratio is calculate with the relation:

$$A_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{\Delta E_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)}{4k_{as}\delta_{fr}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)} \quad (1)$$

The condition of the partial sliding can be written: $A_{ad} \langle A_{adcr}$

Where : A_{adcr} represent the critical energy ratio in the case of one variable friction coefficient, being dependent by the contact conditions and by the material characteristics.

A_{adcr} -has values corresponding with the parameters who satisfied the existence conditions previous specified ($C_e = 0)$) and ratio $\frac{r_a}{\sqrt[3]{C_e}} \langle 1$

Thus, solving the equation (2) results the first existence solutions for the fretting contact :

$$C_e(\tau_0, \beta, k_{ad}, k_{ass}) = 1 - \frac{k_{ass}}{\beta k_{af}(\tau_0, \beta, k_{ad})} = 0 \qquad (2)$$

The solutions presented in the Fig.1 and Fig.2 depend on contact conditions and materials characteristics.

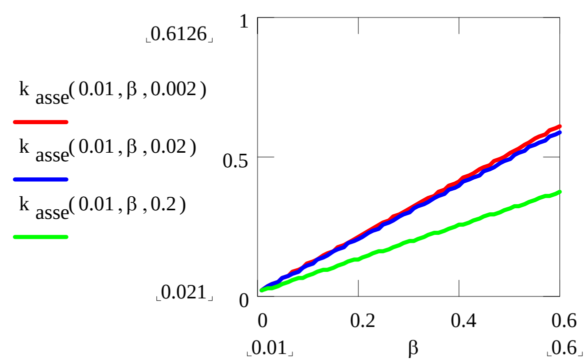

Fig.1.Solutions of the existence condition, $k_{asse}(\tau_0, \beta, k_{ad})$

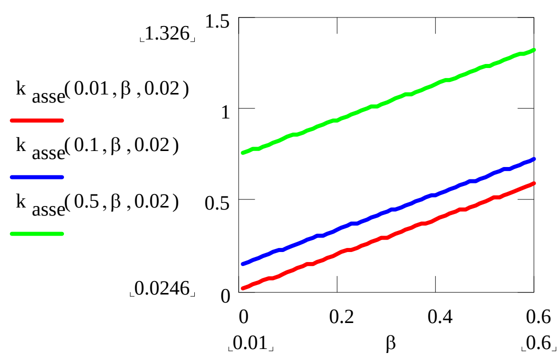

Fig.2.Solutions of the existence condition, $k_{asse}(\tau_0, \beta, k_{ad})$

The second condition $\frac{r_a}{\sqrt[3]{C_e}} \langle 1$ can be written:

$$\frac{r_a}{\sqrt[3]{C_e}} - 1 = \frac{r_a - \sqrt[3]{C_e}}{\sqrt[3]{C_e}} = \frac{C_{et}}{\sqrt[3]{C_e}} \langle 0 \qquad (3)$$

Solving the equation :

$$C_{et} = r_a - \sqrt[3]{C_e} \qquad (4)$$

results the maximum radius of the adhesion circler.

In fig.3 and fig.4 we represented the dependence of the equation solutions (4) by the materials properties materials (β şi τ_0)

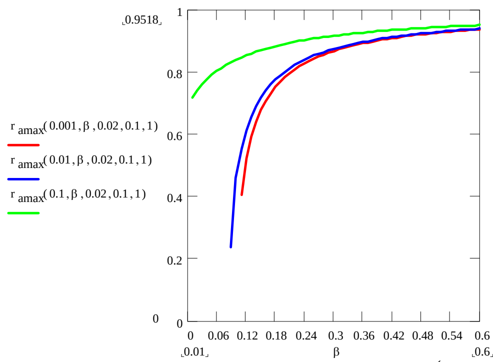

Fig.3 Solutions of the existence condition $r_{a\max}(\tau_0, \beta, k_{ad}, k_{as}, \alpha)$

The graphic representation of the energy ratio in the case of variable friction coefficient is in fig.5.

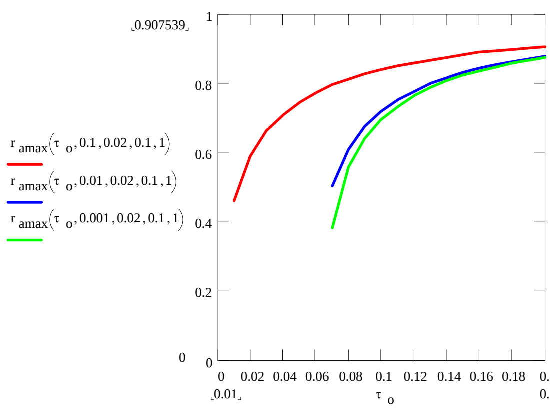

Fig.4 Solutions of the existence condition , $r_{a\max}(\tau_0, \beta, k_{ad}, k_{as}, \alpha)$

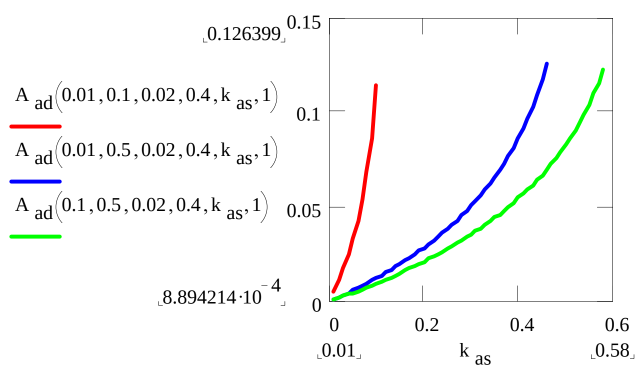

Fig.5 The dependence of the energetical ratio A $A_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

The critical values for A_{ad} is determined by graphic method or numerical calculation for the existence conditions previous specified.

2.2. The sliding ratio

The evolution of the aperture of fretting cycles was also used as a transition criterion. The sliding ratio was defined as:

$$D = \frac{\delta_0}{\delta} \tag{5}$$

In this case we analyzed the transition criterions for the case of one variable friction coefficient between surfaces.

If we consider the friction coefficient being variable, the sliding ratio will be:

$$D_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) = \frac{\delta_{fr0}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)}{\delta_{frs}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)} \tag{6}$$

The critical values of the sliding ratio is determined by graphic method or by numerical calculus.

In fig.6 we represented the dependence of the sliding ratio $D_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$ by the materials characteristics and by the loadings of the contact, respectively.

2.3. The deferential criteria

The transitions between partial slip and gross slip can also obtained using a derivation of the function Q=f(δ) and $W_d = f(\delta)$ with regard to the displacement amplitude δ.

Two different expressions are introduced for each of these functions depending on the sliding condition. Demonstration will only be given in the case of partial slip and for the force approach.

2.3.1. The case of the partial sliding

In this case we analyzed the transition criterions both friction with constant coefficient and for the case of one variable friction coefficient between surfaces.

a)Constant friction coefficient

In this case the relative displace will be:

$$\delta_{ars}(\mu, k_{as}) = \delta_{ar}(\mu, k_{as}) \tag{7}$$

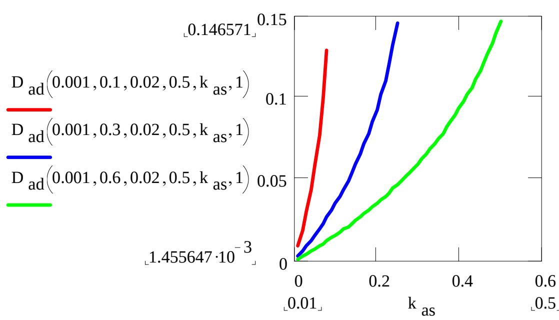

Fig.6.The dependence of the sliding ratio, $D_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

The first derivative is:

$$D_{er}(\mu, k_{as}) = \frac{d}{dk_{as}} \delta_{ars}(\mu, k_{as})$$

Respectively the second:

$$D_{er2}(\mu, k_{as}) = \frac{d^2}{dk_{as}^2} \delta_{ars}(\mu, k_{as}) \tag{8}$$

The graphic representation of the two derivatives in relation with the contact loading is in fig.7

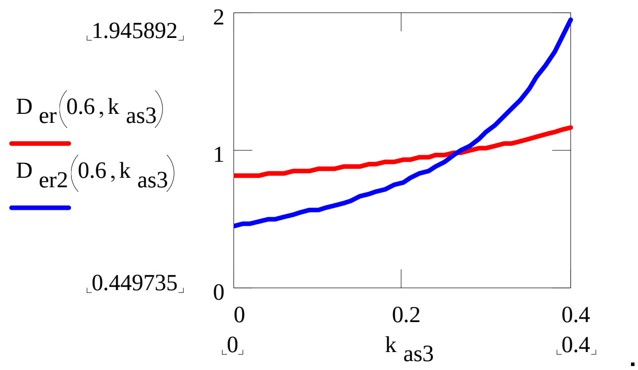

Fig.7.The dependence of the differential criterion $D_{er2}(\mu, k_{as})$

b) Variable friction coefficient

In this case the two derivatives of the sliding will be:

$$D_{era}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d}{dk_{as}}\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \quad (9)$$

$$D_{er2a}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d^2}{dk_{as}^2}\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \quad (10)$$

The graphic representation of the two derivatives in relation with the contact loading is in fig.8.

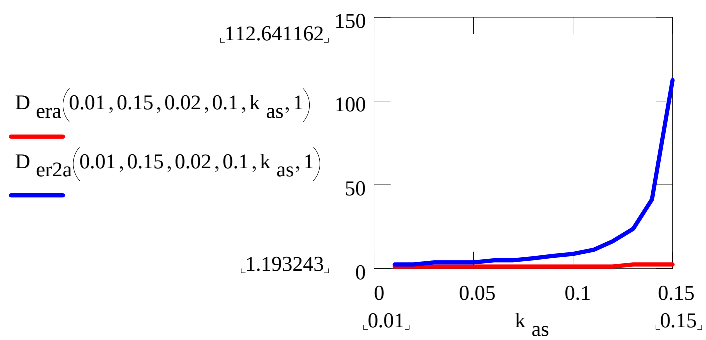

Fig.8.The dependence of the differential criterion $D_{er2a}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

2.3.2. The energetically case

a)constant friction coefficient

The first derivative of the energy in relation with the load is:

$$D_{ee1}(k_{as},\mu)=\frac{d}{dk_{as}}\Delta E_a(k_{as},\mu) \quad (11)$$

Respectively the second:

$$D_{ee2}(k_{as},\mu)=\frac{d^2}{dk_{as}^2}\Delta E_a(k_{as},\mu) \quad (12)$$

The graphic representation of this criterion in relation with the load is in fig.9.

b) variable friction coefficient

In this case the two derivatives will be:

$$D_{eea1}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d}{dk_{as}}\Delta E_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \quad (13)$$

$$D_{eea2}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d^2}{dk_{as}^2}\Delta E_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \quad (14)$$

The graphic representation of the two derivatives is in fig.10

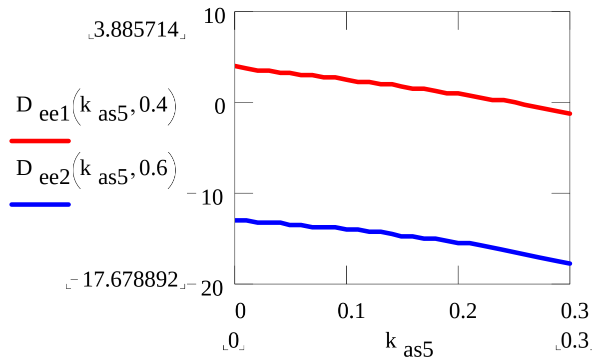

Fig.9 The dependence of the differential energetically criterion $D_{ee2}(k_{as},\mu)$

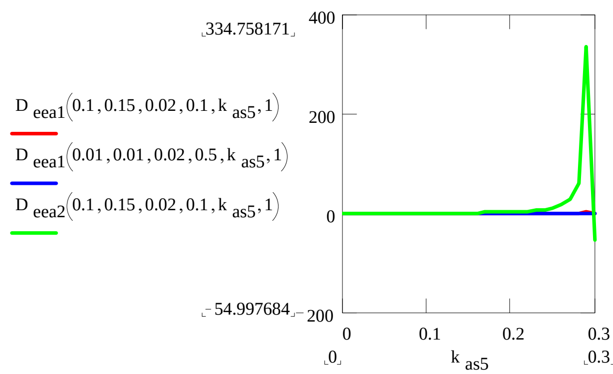

Fig.10 The dependence of the differential energetically criterion $D_{eea1}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

The transition can be seen like a discord observed for the second derivative. For the presented case the discord is observed for k_{as} =0.28.

3. CONCLUSION

The analytical development for both the energy and the sliding ratio permitted better identification of the fretting conditions and an expression of the theoretical expressions for the boundary between fretting partial and gross slip conditions.

The calculations were complemented by experiments for two different tribosystems which present different coefficients of friction. Comparison between the theoretical and the experimental computations appears to be possible if the tangential compliance of the system is taken into account.

REFERENCES

[1] D.W.Hoeppner, Mechanisms of fretting fatigue and their impact on test method development, ASTM-STP 1159(1992) 23-32
[2]P.Blanchard, Ch.Colombier,V. Pellerin,S. Fayeulle and L.Vincent, Material effects in fretting wear: application to iron, titanium and aluminum alloys, Met. Trans. A,22(1991) 1535-1544
[3] O.Vingsbo and M.Soderberg, On fretting maps, Wear, 126 (1988) 131-147
[4]R.D.Mindlin and H.Deresiewicz, Elastic spheres in contact under varying oblique forces, ASME Trans J. Appl. Mech. E.,20(1953) 327-344
[5]K.L.Johnson, Contact Mechanics, Cambridge University Press, Cambridge,1985, pp.202-233