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THE TRANSITION IN THE FRETTING PHENOMENON

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Keywords: Fretting, transition, variable friction coefficient.

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. 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

Fretting damage is often the origin catastrophic failures or loss of functionality in many industrial applications.

Considered as a plague for modern industry, fretting is encountered in all quasi-static loadings submitted to vibration and thus concerns many industrial branches. Specifically, fretting-fatigue damage was reported by Hoeppner [4] to occur in parts found in helicopters, fixed-wing aircraft, trains, ships, automotives, trucks and buses ,farm machinery, engines, construction equipment, orthopedic implants, artificial hearts, rocket motor cases, wire ropes, etc.

During a fretting test, it is important to record the tangential force variation vs. the instantaneous displacement for every cycle. The evolution of the tangential force vs. the displacement during the test is given by friction logs or Ft-D-N curves [1], each cycle is characterized by a specific shape. Three shapes have been identified: closed, elliptic or quasi-rectangular. They are related to the three fretting conditions, i.e. respectively the so-called stick, partial sliding gross slip conditions.

Fretting regimes were first mapped by Vingsbo [7]. 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[6]. 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]

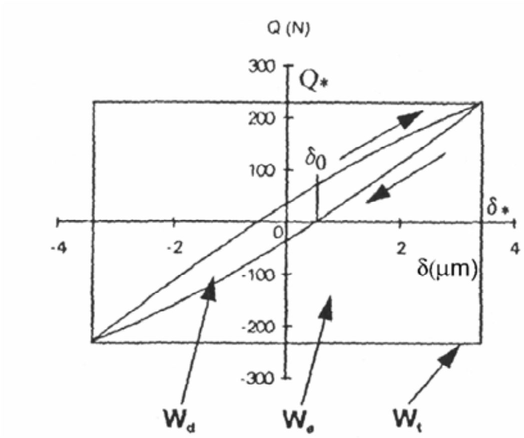
2. ALTERNATED TANGENTIAL FORCE LOADING.

For these loading conditions, the applied tangential force Q will be constricted in the interval [-Q,+Q].

Thus the sliding behavior will depend on the level Q referring to the limit value μP.

2.1.PARTIAL SLIP

In this case, the tangential force amplitude Q is inferior to μP. The evolution of Q=f(δ) describes an elliptic shape i.e an hysteresis loop(Fig1)



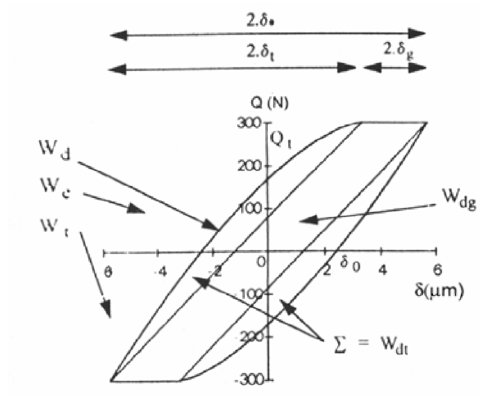


Fig.1.Representation of the various parameters characterizing the fretting cycle under partial slip condition cycle

Fig.2.Representation of the various parameters characterizing the fretting under gross conditions

The displacement amplitude δ and the tangential force amplitude Q can be connected by the relation:

$$\delta_x = \frac{K_1 \mu P}{a}\left[1-\left(1-\frac{Q}{\mu P}\right)^{2/3}\right] \quad (1)$$

The area of the curve corresponds to the mechanical energy dissipated during the cycle Wd. Mindlin expressed this energy using an elliptic distribution of stress:

$$W_d = \frac{24K_1(\mu P)^2}{5a}\left[1-\left(1-\frac{Q}{\mu P}\right)^{5/3} - \frac{5Q}{6P\mu}\left(1+\left(1-\frac{Q}{\mu P}\right)^{2/3}\right)\right] \quad (2)$$

The expression can be simplified by introducing the following variable:

$$Y = \left(1-\frac{Q}{\mu P}\right) \quad (3)$$

Several other variables can be introduced: the „total energy” Wt defined as the energy input by the system

$$W_t = 4\delta \cdot Q \quad (4)$$

and the elastic energy We restored by the contact accommodation. This elastic energy is determined by the difference between the total energy and the dissipated energy,

$$W_e = W_t - W_d \quad (5)$$

For a purely elastic behavior, the elastic energy We will be equal to the total energy Wt. For a purley dispersing system, i.e. no elastic accommodation, the dissipated energy Wd will be equal to the total energy Wt. This latter case can be illustrated by pin on disk loading conditions.

2.2.GROSS SLIP

To extend the above results to gross slip conditions, an energetic description of the fretting cycle was developed (Fig.2)

With regard to the description of the gross slip cycle the total displacement (2δ*) can be expressed as the sum of partial slip displacement (2δt) and of the total sliding component (δg),i.e.

$$\delta^* = \delta_t + \delta_g \tag{6}$$

The dissipated energy Wd corresponds to the sum of the energy dissipated during the partial slip accommodation and the energy dissipated during the total sliding component Wdg. The relation [3]:

$$W_d = W_{dt} + W_{dg} \tag{7}$$

is deduced with

$$W_{dg} = 4\delta_g Q_t \tag{8}$$

and determined

$$W_d = W_{dt} + 4\delta_g Q_t \tag{9}$$

3.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.

3.1.THE ENERGY RATIO

The energy ratio A between dissipated energy Wd and the total energy Wt was introduced to normalize the energy evolution as a function of the loading conditions.
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 energy ratio is calculated with the relation [2] :

$$A(\mu, k_{as}) = \frac{6}{5}\frac{1-Y^{5/3}}{(1-Y)(1-Y^{2/3})} - \frac{1+Y^{2/3}}{1-Y^{2/3}} \tag{10}$$

with:

$$Y(\mu, k_{as}) = 1 - \frac{k_{as}}{\mu} \tag{11}$$

Considering the transition from partial slip to gross slip, the tangential force amplitude will be at least equal to μP. Referring to Amonton's principle, the coefficient of friction being constant, Y=0 and a constant value for the energy ratio is obtained :At=0.2. For A<At,partial slip prevails.
The experimental studies confirmed a transition value for the energy ratio At=0.2.
The same approach was applied to detect transition in the case of a gross slip condition, where:

$$A = \frac{Wd}{Wt} = \frac{Wdt + Wdg}{Wt} \tag{12}$$

Introducing We as the restored elastic energy during the cycle, We is shown to be identical to restored energy during the partial slip accommodation.
Then

$$\text{Wet} = \text{Wtt} - \text{Wdt} \tag{13}$$

And

$$A = 1 - \frac{\text{Wet}}{4\text{Qt}\,\delta^*} \tag{14}$$

If $\delta \to \delta_t (\delta_g \to 0)$, $4\text{Qt}\,\delta^* \to \text{Wtt}$

and $A = 1 - \frac{Wdt}{Wtt} = At = 0.2$ (15)

Therefore, At=0.2 was demonstrated to be the transition between partial slip and gross slip conditions whatever the initial slip condition was. This constant is independent of the material properties (ν_1,ν_2,G_1,G_2),of the contact geometry (R*) and of the coefficient of friction (μ).

In fig.3 we represented the variation of the energy ratio depending on loading contact k_{as}

b) variable friction coefficient

In this case the energy ratio is calculed with the relation:

$$A_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) = \frac{\Delta E_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)}{4k_{as}\delta_{fr}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)} \quad (16)$$

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 (17) results the first existence solutions for the fretting contact:

$$C_e(\tau_0,\beta,k_{ad},k_{ass}) = 1 - \frac{k_{ass}}{\beta k_{af}(\tau_0,\beta,k_{ad})} = 0 \quad (17)$$

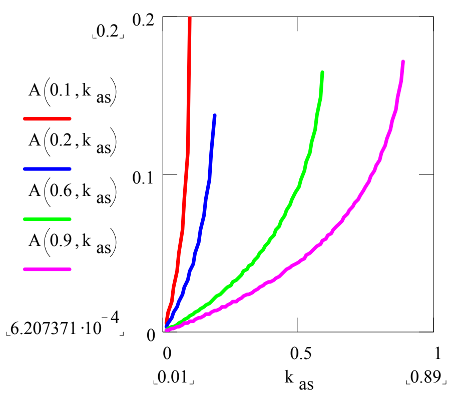


Fig.3.The variation by the energy ratio A

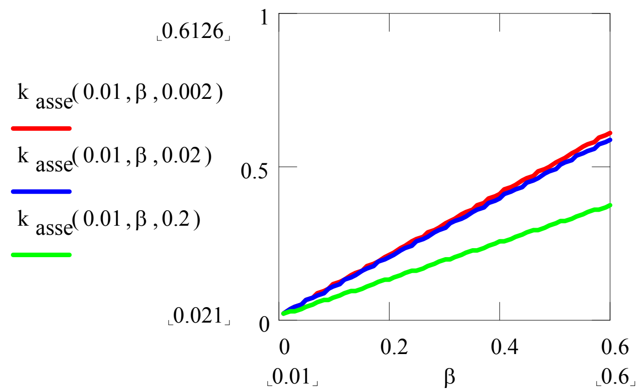


Fig.4.Solutions of the existence condition $k_{asse}(\tau_0,\beta,k_{ad})$

The solutions presented in the Fig.4 and Fig.5 depends on contact conditions and materials characteristics.

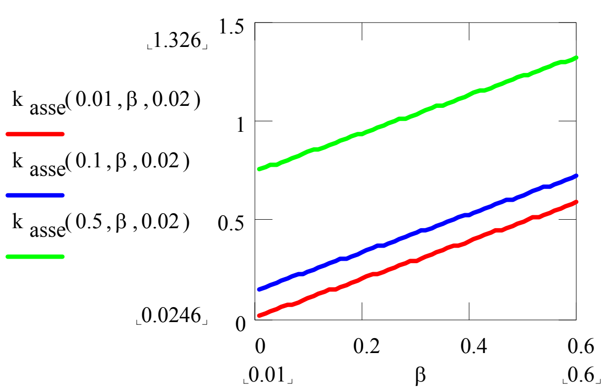


Fig.5.Solutions of the existence condition

$k_{asse}(\tau_0,\beta,k_{ad})$

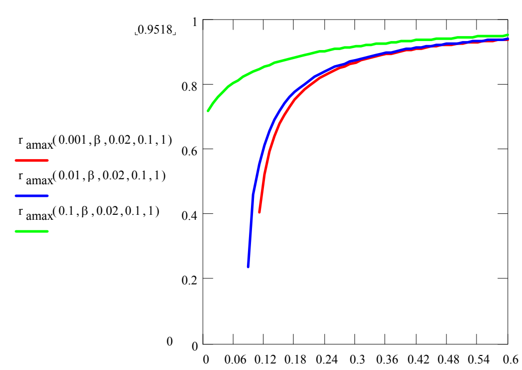


Fig.6 Solutions of the existence condition

$r_{a\max}(\tau_0,\beta,k_{ad},k_{as},\alpha)$

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

$$\frac{r_a}{\sqrt[3]{C_e}}-1=\frac{r_a-\sqrt[3]{C_e}}{\sqrt[3]{C_e}}=\frac{C_{et}}{\sqrt[3]{C_e}}\langle 0 \tag{18}$$

Solving the equation :

$$C_{et}=r_a-\sqrt[3]{C_e} \tag{19}$$

results the maximum radius of the adhesion circler.

In fig.6.and fig.7 we represented the dependence of the equation solutions (19) by the materials properties materialelor (β şi τ_0)

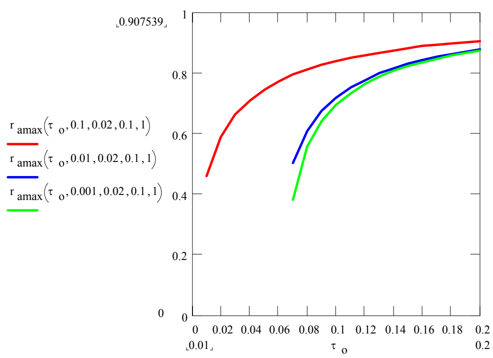


Fig.7 Solutions of the existence condition $r_{a\,\max}(\tau_0,\beta,k_{ad},k_{as},\alpha)$

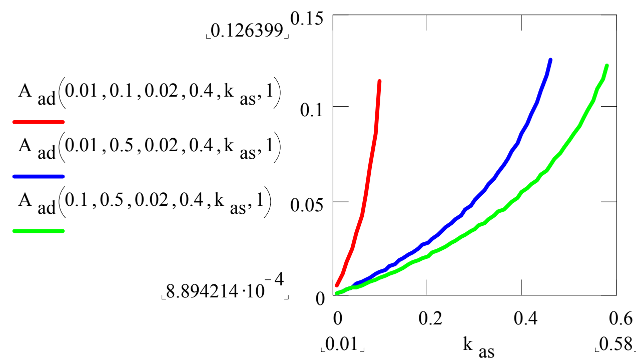


Fig.8 The dependence of the energetical ratio A $A_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

The graphic representation of the energy ratio in the case of variable friction coefficient is in fig.8.

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

3.2.THE SLIDING RATIO

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

$$D=\frac{\delta_0}{\delta} \tag{20}$$

This variable was first introduced to analyze the sliding behavior under fretting conditions.

In this case, too, 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

As is the case for the energy ratio, it is possible to give an analytical expression of this parameter and for partial slip conditions:

$$D(\mu,k_{as})=1-2\left[\frac{1-\left(\frac{1+Y}{2}\right)^{2/3}}{1-Y^{2/3}}\right] \tag{21}$$

As can be seen with the energy ratio, this parameter appears to be independent of the contact dimension and of the mechanical properties of the tribopair. Considering the transition between the sliding conditions (i.e.Y=0),Dt reaches a constant value:

$$\mathrm{Dt}=\frac{\delta_0 t}{\delta t}=2\left(\frac{1}{2}\right)^{2/3}-1\approx 0{,}26 \tag{22}$$

In the same way, in the case of the gross slip condition Dt is shown to reach Dt=0.26 at the transition to partial slip and to reach 1 when δ tends to infinity
The graphic representation of this ratio is in fig.9

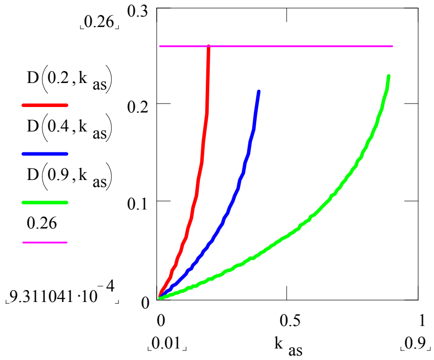


Fig.9 The dependence of the sliding ratio $D(\mu,k_{as})$

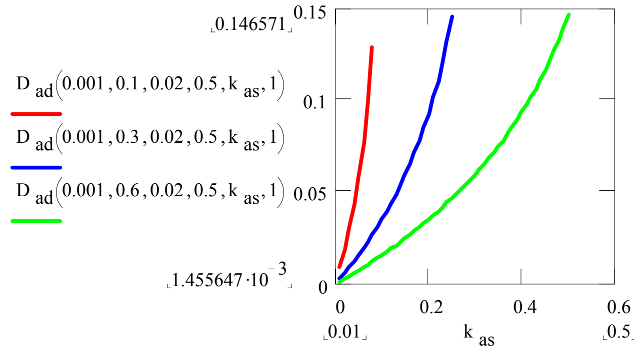


Fig.10.The dependence of the sliding ratio $D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

b)variable friction coefficient

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

$$D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{\delta_{fr0}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)}{\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)} \quad (23)$$

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

In fig.10 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.

4. 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] Blanchard,P.,Colombier, Ch.,Pellerin, V., Fayeulle, S. and Vincent L., Material effects in fretting wear: application to iron ,titanium and aluminium alloys, Met. Trans. A,22(1991) 1535-1544
[2] Fouvry S., Kapsa Ph, Vincent, L. Analysis of sliding behaviour for fretting loadings: determination of transition criteria,Wear,185 (1995) 35-46
[3] Ghimisi, S. An elastic-plastic adhesion model for fretting,15 Th.Symposium “Danubia Adria”, Bertinoro, Italia, 181-183
[4] Hoeppner, D.W., Mechanisms of fretting fatigue and their impact on test methoda development,ASTM-STP 1159(1992) 23-32
[5] Johnson, K.L., Contact Mechanics,Cambridge University Press, Cambridge, 1985, pp.202-233
[6] Mindlin, R.D.and Deresiewicz, H., Elastic spheres in contact under varying oblique forces,ASME Trans J. Appl. Mech. E.,20(1953) 327-344
[7] Vingsbo, O. and Soderberg, M., On fretting maps,Wear, 126 (1988) 131-147