TRANSITION IN THE FRETTING PHENOMENON

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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.*

Keywords: Fretting, transition, variable friction coefficient.

1.Introduction

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 [1] to occur in parts found in helicopters, fixed-wing aircraft, trains, ships, automotives, trucks and buses, engines, construction equipment, orthopaedic implants, artificial hearts, 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 [2], 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 slip and gross slip conditions. Fretting regimes were first mapped by Vingsbo [3]. 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 paper 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. Alternated tangential force loading.

For these loading conditions, the applied tangential force Q will be constricted in the interval [-Q,+Q]. Thus the sliding behaviours 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 $Q=f(\delta)$ describes an elliptic shape i.e an hysteresis loop (Figure 1)

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

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

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:

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

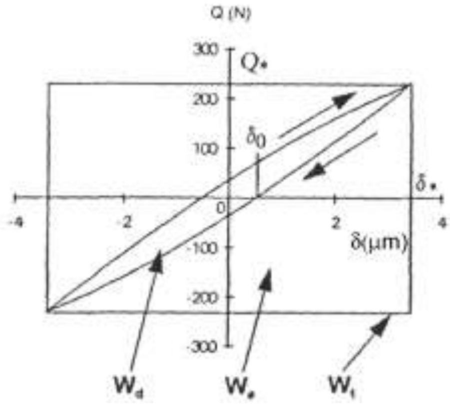

Fig. 1. Representation of the various parameters characterising the fretting cycle under partial slip condition [6]

The expression can be simplified by introducing the following variable:

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

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

$$W_t = 4\delta \cdot Q \tag{4}$$

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,

$$W_e = W_t - W_d \tag{5}$$

For a purely elastic behaviour, the elastic energy We will be equal to the total energy Wt. For a purely 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 (Figure 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 ($2\delta_t$) and of the total sliding component (δ_g), i.e.

$$\delta^* = \delta_t + \delta_g \quad (6)$$

The dissipated energy W_d 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 [8], [17]:

$$W_d = W_{dt} + W_{dg} \quad (7)$$

is deduced with:

$$W_{dg} = 4\delta_g Q_t \quad (8)$$

and determined

$$W_d = W_{dt} + 4\delta_g Q_t \quad (9)$$

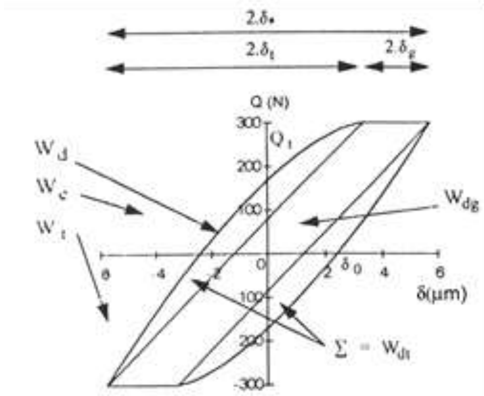

Fig. 2. Representation of the various parameters characterising the fretting cycle under gross conditions. [7]

The load of the cycle may be given depending on the size δ_0t and magnitude of transition slip δg.

$\delta_0 = \delta_0$t + δg (10)

Based on studies on partial and total slippage we can draw the following conclusions:

- Partial sliding corresponds to the elliptical loop (Q=f (δ)) which indicates that the area of bonding is maintained in the center of the contact;

- The total slippage begins with a partial slip at the charging start point, followed by a full sliding contact over the entire area.

The relation Q=f(δ) is described by a quadratic form loop.

The values for δ*, Wd and Wt obtained in transition δt, Wdt and Wtt may be expressed by:

$$\delta t = \frac{K_1 \mu P}{a} \quad (11)$$

$$Wdt = \frac{4(\mu P)^2 K_1}{5a} \quad (12)$$

$$Wtt = \frac{4(\mu P)^2 K_1}{a} \quad (13)$$

and:

$$Wtt = \frac{16(\mu P)^2 K_1}{5a} \quad (14)$$

3. Transition criteria

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

3.1. The energy ratio

The energy ratio A between dissipated energy Wd and the total energy Wt was introduced to normalise the energy evolution as a function of the loading conditions.

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

a) constant friction coefficient

This variable was first introduced by Mohrbacher and others [9] in experimental work.

Under a partial slides, for $Q^* < \mu P_0$ we can say:

$$A = \frac{Wd}{Wt} = 1 - \frac{We}{Wt} \quad (15)$$

The energy ratio is calculated with the relation [8]:

$$A(\mu, k_{as}) = \frac{6}{5} \frac{1 - Y^{5/3}}{(1-Y)\left(1-Y^{2/3}\right)} - \frac{1+Y^{2/3}}{1-Y^{2/3}} \quad (16)$$

with:

$$Y(\mu, k_{as}) = 1 - \frac{k_{as}}{\mu} \quad (17)$$

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:

$$A = \frac{Wd}{Wt} = \frac{Wdt + Wdg}{Wt} \quad (18)$$

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:

$$Wet = Wtt - Wdt \tag{19}$$

And:

$$A = 1 - \frac{Wet}{4Qt\,\delta^*} \tag{20}$$

If $\delta \to \delta_t \left(\delta_g \to 0\right), 4Qt\,\delta^* \to Wtt$

and

$$A = 1 - \frac{Wet}{Wtt} = At = 0.2 \tag{21}$$

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

a) variable friction coefficient

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

$$A_{ad}\left(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha\right) = \frac{\Delta E_{ad}\left(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha\right)}{4k_{as}\delta_{fr}\left(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha\right)} \tag{22}$$

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 $\frac{r_a}{\sqrt[3]{C_e}} \langle 1$

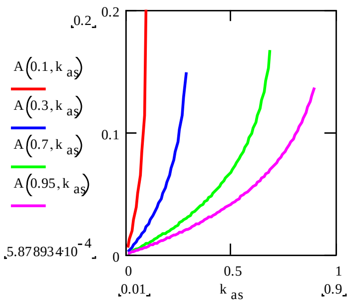

Fig. 3. The variation by the energy ratio A

Thus, solving the equation (23) results the first existence solutions for the fretting contact:

$$C_e(\tau_0, \beta, k_{ad}, k_{ass}) = 1 - \frac{k_{ass}}{\beta k_{af}(\tau_0, \beta, k_{ad})} = 0 \qquad (23)$$

The solutions presented in the Figure 4 and Figure 5 depend on contact conditions and materials characteristics.

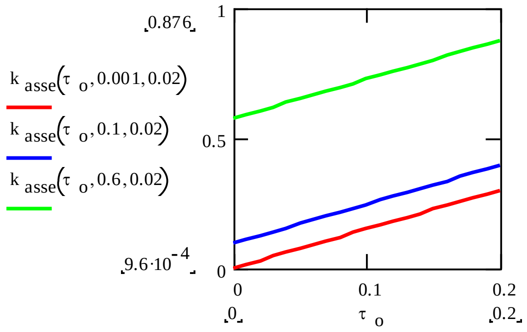

Fig. 4. Solutions of the existence condition $k_{asse}(\tau_0, \beta, k_{ad})$

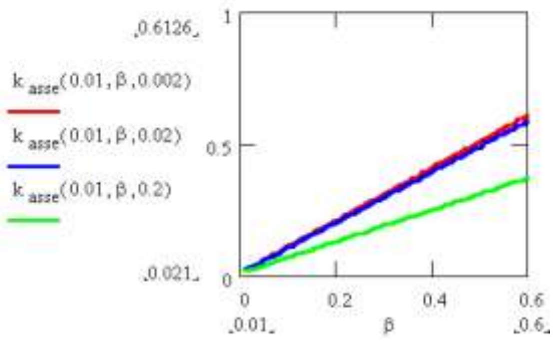

Fig. 5. Solutions of the existence condition $k_{asse}(\tau_0, \beta, k_{ad})$

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

$$\frac{r_a}{\sqrt[3]{C_e}} - 1 = \frac{r_a - \sqrt[3]{C_e}}{\sqrt[3]{C_e}} = \frac{C_{et}}{\sqrt[3]{C_e}} \langle 0 \qquad (24)$$

Solving the equation:

$$C_{et} = r_a - \sqrt[3]{C_e} \qquad (25)$$

Results the maximum radius of the adhesion circler.

In Figure 6 and Figure 7 we represented the dependence of the equation solutions (25) by the materials properties (β şi τ_0)

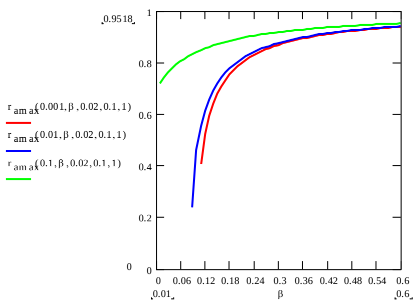

Fig. 6 Solutions of the existence condition $r_{a\,\max}(\tau_0, \beta, k_{ad}, k_{as}, \alpha)$

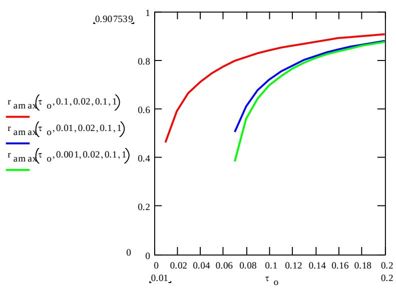

Fig. 7 Solutions of the existence condition $r_{a\,\max}(\tau_0, \beta, k_{ad}, k_{as}, \alpha)$

The graphic representation of the energy ratio in the case of variable friction coefficient is in Figure 8, Figure 9 and Figure 10.

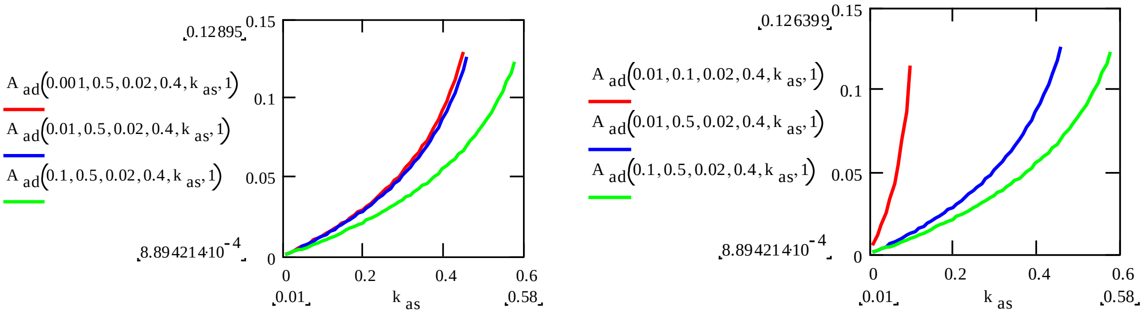

Fig. 8 The dependence of the energetical ratio A $A_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

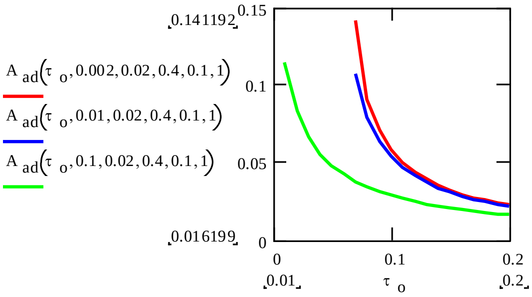

Fig. 9 The dependence of the energetical ratio A $A_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

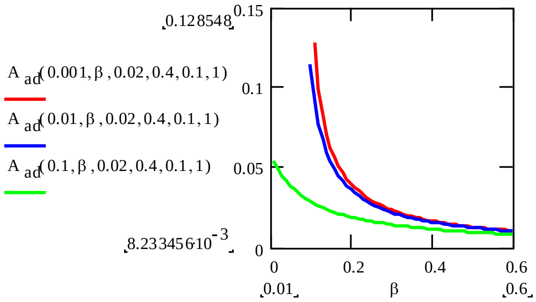

Fig. 10 The dependence of the energetical ratio A, $A_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

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

3.2. The sliding ratio

The evolution of the aperture of fretting cycles was also used as a transition criterion [11], [15], [16].

The sliding ratio was defined as:

$$D = \frac{\delta_0}{\delta} \tag{26}$$

This variable was first introduced to analyze the sliding behaviour under fretting conditions. In this case, too, we analysed 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:

$$D(\mu, k_{as}) = 1 - 2\left[\frac{1-\left(\frac{1+Y}{2}\right)^{2/3}}{1-Y^{2/3}}\right] \tag{27}$$

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 tribo-pair. Considering the transition between the sliding conditions (i.e.Y=0), Dt reaches a constant value:

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

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 Figure 11.

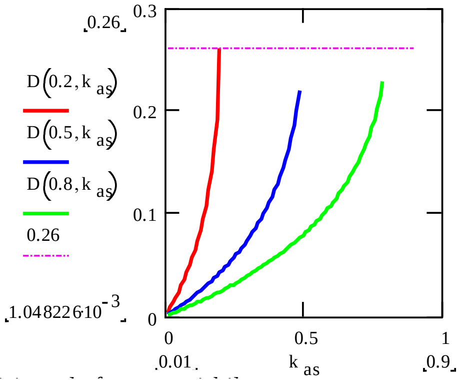

Fig. 11 The dependence of the sliding ratio. $D(\mu, k_{as})$

Confirmation of the theoretical values for partial slipping and full sliding transition was based on the experimental studies of Fouvry and others. [10] They, considering a sphere-plan and contact conducted fretting attempts for a normal load of 300 N e 12.7 mm radius of the sphere.

Tracing the evolution of criteria A and D while increasing amplitude (Figure 12 and Figure 13) it is observed that the curve shows a discontinuity point between the values 0.19 and 0.23 (closer to A_t = 0.2) and D point of discontinuity will be found between 0.25 and 0.29 (close to D_t = 0.26), the transition was confirmed experimentally by observing the shape of

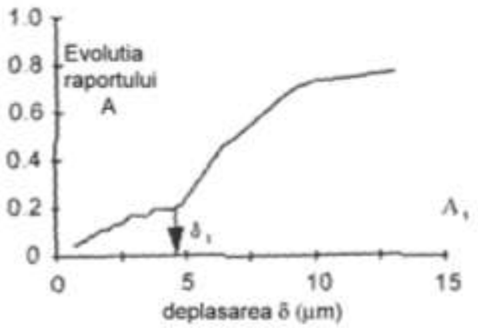

Fig. 12. The evolution of ratio energy A considering the amplitude displacement, for a normal force of 300N [10]

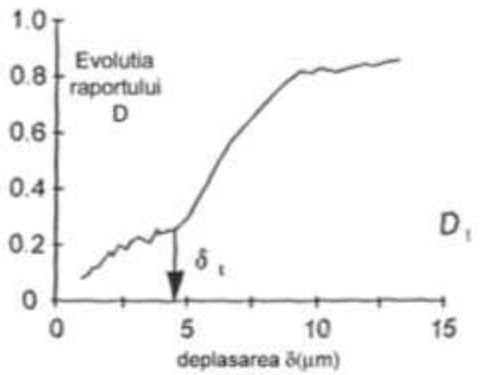

Fig. 13. The evolution of ratio energy D considering the amplitude displacement, for a normal force of 300N [10]

b) variable friction coefficient

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

$$D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{\delta_{fr0}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)}{\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)} \tag{29}$$

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

In Figure 14, Figure 15 and Figure 16 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.

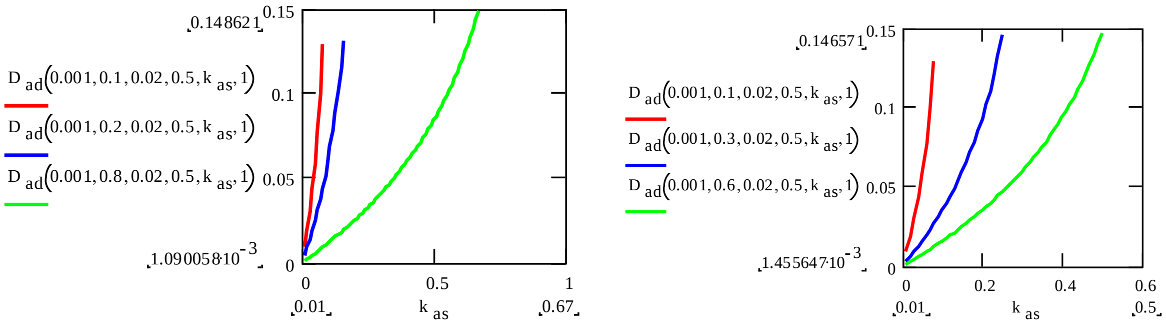

Fig. 14. The dependence of the sliding ratio $D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

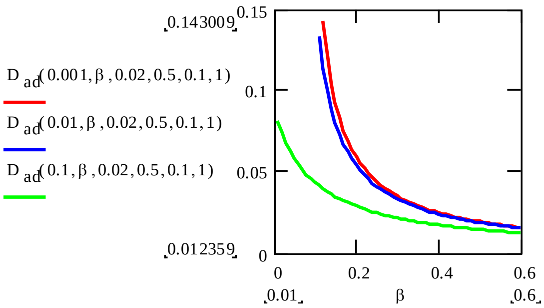

Fig 15. The dependence of the sliding ratio. $D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

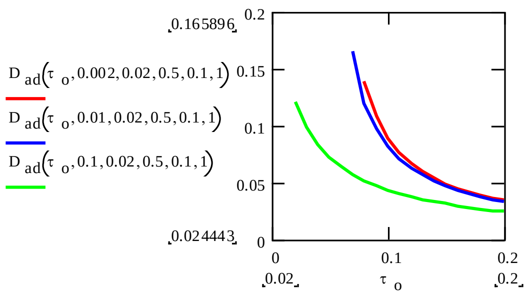

Fig 16. The dependence of the sliding ratio $D_{ad}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

3.3. The diferential 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 [12], [13]. [14], [18].

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.

3.3.1. 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

The dependency Q = f(δ) is given by:

$$Q = Qt\left[1-\left(1-\frac{\delta}{\delta t}\right)^{3/2}\right] \tag{30}$$

So :

$$\frac{dQ}{d\delta} = \frac{3Qt}{2\delta t}\left(1-\frac{\delta}{\delta t}\right)^{1/2} \tag{31}$$

And :

$$\frac{d^2Q}{d\delta^2} = -\frac{3Qt}{2\delta t^2}\cdot\frac{1}{\left(1-\frac{\delta}{\delta t}\right)^{1/2}} \tag{32}$$

Transition conditions (δ → δt), give: $\frac{dQ}{d\delta} \rightarrow 0$ and $\frac{d^2Q}{d\delta^2} \rightarrow -\infty$

In case of complete slipping (δ ≥ δt), $\frac{dQ}{d\delta} = 0$ and $\frac{d^2Q}{d\delta^2} = 0$

The transition can be seen as a discontinuity, observed for the second derivative of Q. This is of infinite value (negative) for δ = δt under partial slip (δ ≤ δt) and is zero for the total sliding conditions (δ ≥ δt).

The criteria of the transition can be expressed by:

$$\max \frac{d^2Q}{d\delta^2} \tag{33}$$

This criteria can be used when the graph Q = f(δ) is drawn on the basis of the variation amplitude displacement (δ). An example of the use of this criterion is the experimental study for sphere plan contact shown in Figure 17. In this case the normal force was kept constant throughout the test (300 N).

The transition between the sliding part and total slippage is indicated by the discontinuity which has a maximum for the second derivative.

Determination of the curve Q / P = f (δ) was made based on the mean square approximation, a similar methodology being used for the first and second derivatives.

This procedure is demanding but allows a quasi-linear dynamics analysis and further development of the contact testing system.

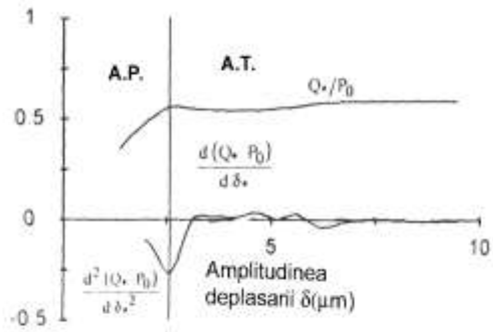

Fig. 17. The evolution of Q/P ratio depending on the displacement amplitude for a normal force of 300 N [10]

For complete slip conditions:

$$\frac{d\,Wd}{d\delta} = 4Qt = C_{st} \quad \text{şi:} \quad \frac{d^2\,Wd}{d\delta^2} = 0$$

The transition can also be recounted by determining:

$$\max \frac{d^2\,Wd}{d\delta^2} \tag{34}$$

The transition criterion may be expressed in relative slipping, as follows:

$$\delta_{ars}(\mu, k_{as}) = \delta_{ar}(\mu, k_{as}) \tag{35}$$

The first derivative is:

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

Respectively the second:

$$D_{er2}(\mu, k_{as}) = \frac{d^2}{dk_{as}^2} \delta_{ars}(\mu, k_{as}) \tag{36}$$

The graphic representation of the two derivatives in relation with the contact loading is in Figure 18.

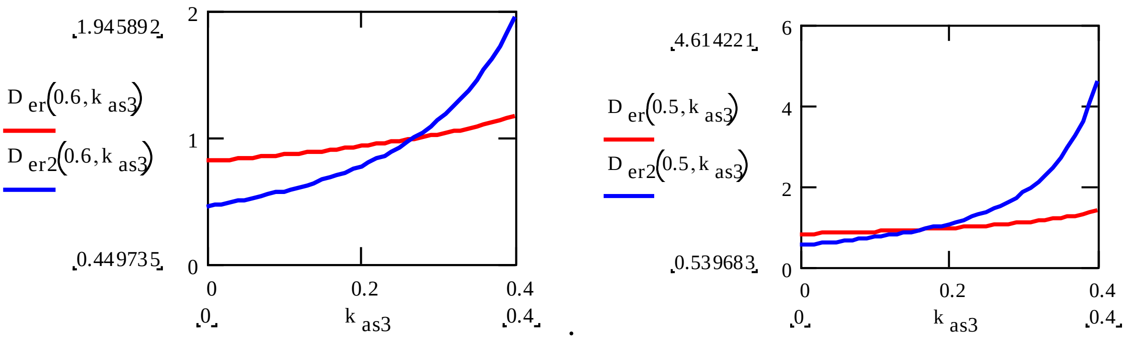

Fig. 18. The dependence of the differential criterion $D_{er2}(\mu, k_{as})$

b) Variable friction coefficient

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

$$D_{era}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d}{dk_{as}}\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \tag{37}$$

$$D_{er2a}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)=\frac{d^2}{dk_{as}^2}\delta_{frs}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha) \tag{38}$$

The graphic representation of the two derivatives in relation with the contact loading is in Figure 19.

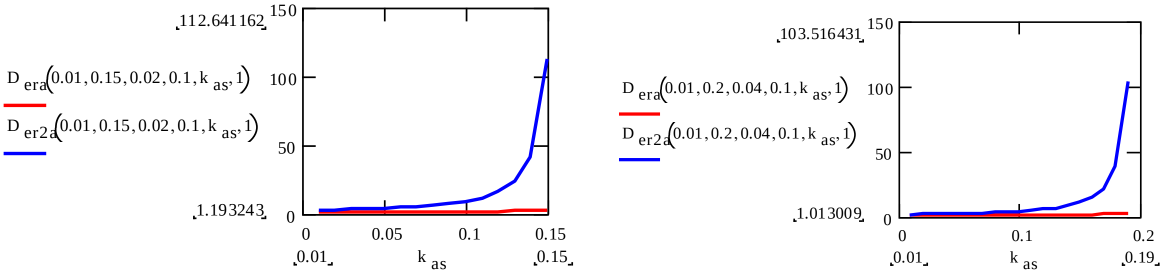

Fig. 19. The dependence of the differential criterion $D_{er2a}(\tau_0,\beta,k_{ad},r_a,k_{as},\alpha)$

3.3.2. The energetically case

a) constant friction coefficient

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

$$D_{ee1}(k_{as},\mu)=\frac{d}{dk_{as}}\Delta E_a(k_{as},\mu) \tag{39}$$

Respectively the second:

$$D_{ee2}(k_{as},\mu)=\frac{d^2}{dk_{as}^2}\Delta E_a(k_{as},\mu) \tag{40}$$

The graphic representation of this criterion in relation with the load is in Figure 20.

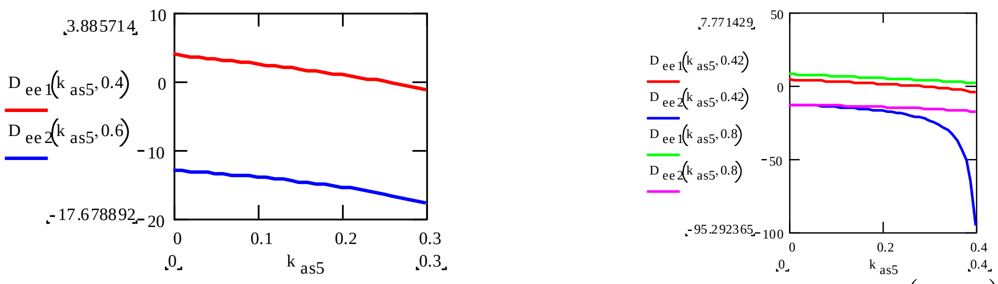

Fig. 20. The dependence of the differential energetical criterion $D_{ee2}(k_{as}, \mu)$

b) variable friction coefficient

In this case the two derivatives will be:

$$D_{eea1}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) = \frac{d}{dk_{as}} \Delta E_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) \tag{41}$$

$$D_{eea2}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) = \frac{d^2}{dk_{as}^2} \Delta E_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) \tag{42}$$

The graphic representation of the two derivatives is in Figure 21

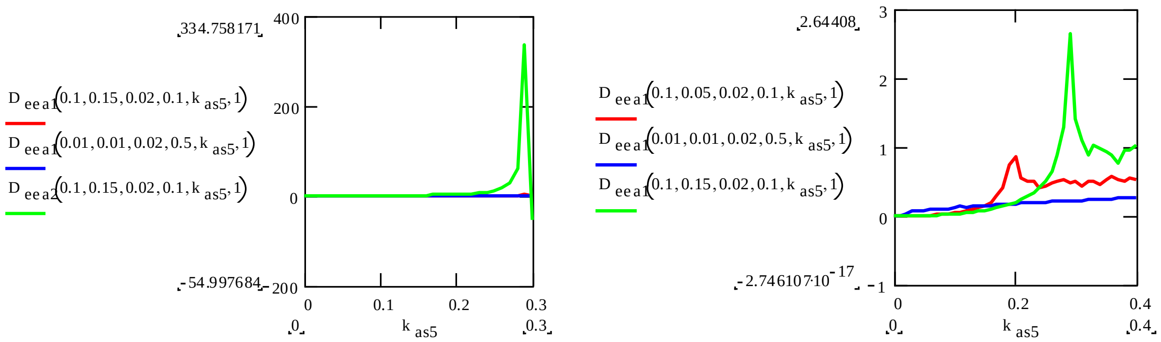

Fig. 21. The dependence of the differential energetical criterion

$$D_{eea2}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$$

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.

3.4. Criteria - independent of transition

Although determining the criteria A and D can specify transitions between partial and total slipping, however working with these criteria is cumbersome because it requires experimental confirmation for determining the compliance of the testing system. By using an advanced system, errors are small, but it would be easier if we establish a transition criteria that does not depend very much on the testing system.

a) **constant friction coefficient**

By engaging two criteria: the criterion for energy and sliding, a transition criterion can be obtained irrespective of the mechanism of the test.

So:

$$B = \frac{Wd}{4Q^{*}\delta_0} \qquad (43)$$

For partial slipping:

$$B(\mu, k_{as}) = \frac{6}{5(1-Y)} \frac{\left[1 - Y^{5/3} - \frac{5}{6}(1-Y)\left(1+Y^{2/3}\right)\right]}{2\left[\frac{1+Y}{2}\right]^{2/3} - Y^{2/3} - 1} \qquad (44)$$

B has a constant value (Qt = μp and Y = 0) : Bt ≈ 0.77 (45)

With : $\left(Bt = {}^{At}/_{Dt}\right)$.

For total slipping, B reaches ≈ 0.77, although for $\delta_g \to \infty$, B will equal 1.

Graphical representation of this criterion according to system loading is given in Figure 22.

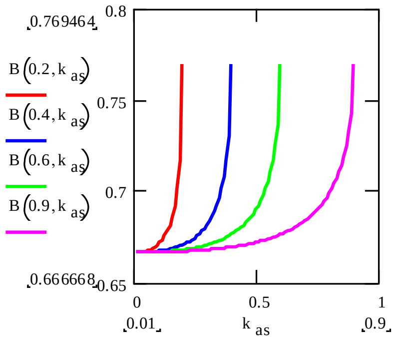

Fig. 22. The dependence of a free system criteria $B(\mu, k_{as})$

Experimental studies have confirmed this transition criteria (Fouvry, Figure 23); the point of transition between the sliding part and total slippage occurring based on the "hub friction". Considering Mindlin assumptions, the energy dissipated can be expressed in terms of the amount of movement and constant Bt.

From Wd = WDT + Wg follows:

$$Wd = 4P\mu\left(d_g + Bt\,\delta_0 t\right) \qquad (46)$$

Which for large amplitudes can be simplified:

$$Wd = 4P\mu\delta_0 \qquad (47)$$

Differences between relations (2.33) and (2.34) can be expressed by the ratio:

$$\left|\frac{\Delta Wd}{Wd}\right| = \frac{1-Bt}{\delta_g/\delta_0 t + Bt} = \frac{1-Bt}{\delta_0/\delta_0 t + Bt - 1} \quad (48)$$

Developments in this report is given in Figure 24, looking for errors that are less than 2.5%.

The dissipated energy is given directly by the normal force, it can be also formulated by Hertzian pressure p_0 and q_0 voltage.

From the Hertz relationship:

$$q_0 = \mu p_0 = \frac{3\mu p}{2\pi a^2} = \frac{3}{2}\mu P_m = \frac{3}{2} q_m \quad (49)$$

We get:

$$Wd = Wdt + \frac{8}{3}\pi q_0 a^2 \delta_g \quad (50)$$

and then:

$$Wd = \frac{8}{3}\pi q_0 a^2 \delta_g \quad (51)$$

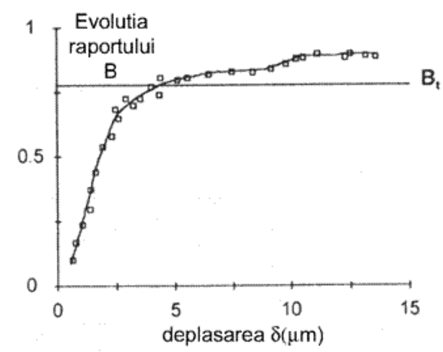

Fig. 23. Evolution of the ratio by displacement amplitude B.[10]

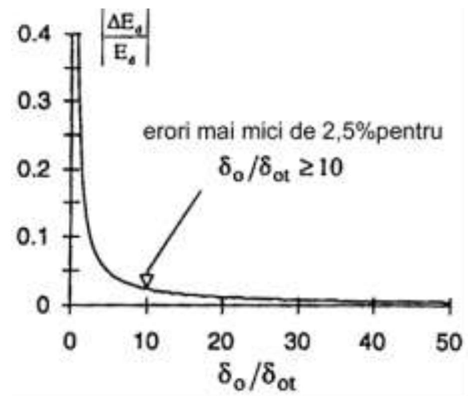

Fig.24. Evolution of the induced errors in the calculation of total dissipated energy $\delta_0 = \delta_g B_t \delta_{0t}$ [10]

a) **variable friction coefficient**

In this case the transition criterion independent of the test system will be defined by:

$$B_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha) = \frac{\Delta E_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)}{\delta_{fr0}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)} \quad (51)$$

In this case the graphical representation is given in Figure 25 depending on the contact loading parameters and characteristics of the material.

The transition between the partial and total sliding may be determined by deriving the function Q=f(δ) and E=f(δ). In this case the transitional criteria being obtained by differential calculus.

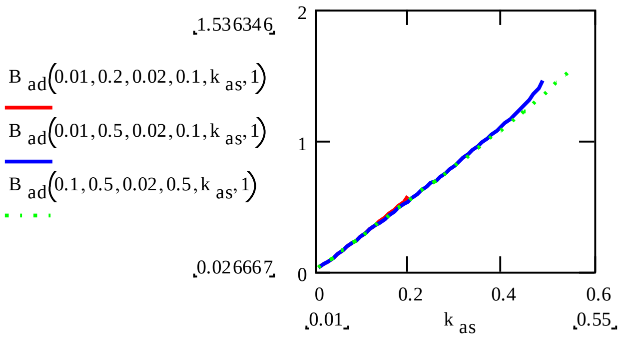

Fig. 25. The dependence of free system criterion $B_{ad}(\tau_0, \beta, k_{ad}, r_a, k_{as}, \alpha)$

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 tribo systems 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.

Defining these transition criteria is useful knowledge of the phenomenon of fretting giving the possibility of establishing a border between partial and total slipping.

Choosing one of the criteria, however, present difficulties related to the possibility of their experimental verification.

Energy report is most easily determined experimentally, however, depends on test equipment. Criterion "open system" is dependent upon the variation of movement and is not easily determined experimentally. Differential criterion allows dynamic evolution quantification of different parameters.

Introducing transition criteria considering adhesion phenomena existing in contact, and considering the coefficient of friction between the surfaces in contact as variable, represents a step forward in the knowledge of the phenomenon of fretting.

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