Vibrations induced by friction forces in dynamic systems

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Abstract: - Vibrations induced by friction generated a series of major problems in functioning of mechanisms of industrial equipment. Dynamic systems, with parts in motion, function with friction due to direct contact between surfaces of its various components. The present paper shows a synthesis of negative effects caused by different types of friction that can be identified analyzing the vibration signal, thus avoiding the appearance of faults and shortcomings that can compromise the ongoing of an industrial process.

Keywords: - Non-Smooth Dynamics, Unilateral Contacts, Coulomb Friction, Dry Friction.

1. INTRODUCTION

Friction phenomenon forms an important aspect in functioning of high precision industrial machines. Their performance is implicitly affected by the friction between his constitutive parts in contact. Friction is present in any mechanism with moving components or in contact ones, causing undesirable behaviour of the system, in time leading to physical faults of mechanism's composing parts.

Fluctuant friction forces can be considered internal excitation sources (perturbations) of the system and can be identified by analysing vibrations transmitted during mechanism's operation. Thus, at industrial machines, of great interest is transitory phase considered from the starting point of the machine until reaching processing speed.

Vibrations due to frictions can appear at parts that perform a rotational motion: spindles and sliding or roller bearings; train of gears; gear transmissions; belts; shanks; impellers; electrical drive motors; etc.; or vibration caused by frictions during the ongoing technological process, between the work piece and the processed part.

Geometrical, kinematics and dynamics parameters, as well as material properties of the surfaces in contact, influence the type of friction phenomenon. Friction phenomenon can be emphasized in various forms. Internal friction, for example, is often constant over a wide range of frequencies of vibration, proportional to the squared amplitude of vibration, and formulated as a structural damping, while external friction is usually denoted by the damping ratio (loss coefficient), a non - dimensional number proportional to the energy loss per cycle of work [2].

2. FRICTION CONDITIONS

Friction is a complex, mechanical and energetic process that occurs with energy dissipation during contact of two surfaces of parts in motion, often leading to attrition and abasement of system components.

Energetically, friction is expressed by friction mechanical work estimated as subtraction between energy at system entry and energy at system output, energetic losses being thermal and of deformation and is expressed by friction loss:

$$\mu_L = \frac{L_f}{L} \tag{1}$$

where L_f is mechanical work consumed by friction and L is absolute mechanical work of all forces acting on the system.

Friction conditions of system's components in motion are actuated by sundry factors as the type of contact between surfaces, plastic direct contact, resilient or lubricated one.

2.1. DRY FRICTION

Dry friction is seldom seen and can be defined as friction between two components with dry surfaces, as in parts of linear joints or rotating coupling. For parts in motion this type of friction is called sliding friction or dynamic friction expressed using Coulomb's Laws sustainable in resilient deformation area. In this case kinetically friction force is proportional to normal force and is not reliant on sliding speed but only on material properties of surfaces in contact. Friction phenomenon is defined by the kinetic friction coefficient, μ_k, non-dimensional, determined as ratio between kinetic friction force, F_f , and normal force acting on the contact area of the surfaces, F_n :

$$\mu_k = \frac{F_f}{F_n} \tag{2}$$

as well as sliding friction angle, φ, rated as the angle between normal force direction, F_n , and the direction of the resultant forces F_n and F_f:

$$\varphi = \text{arctg}\ \mu_k \tag{3}$$

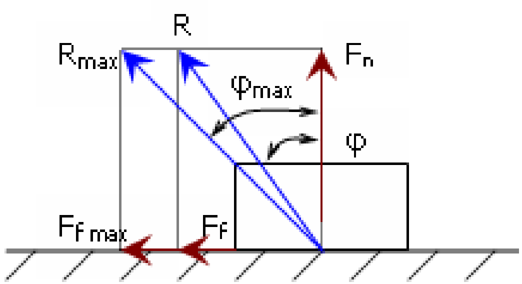
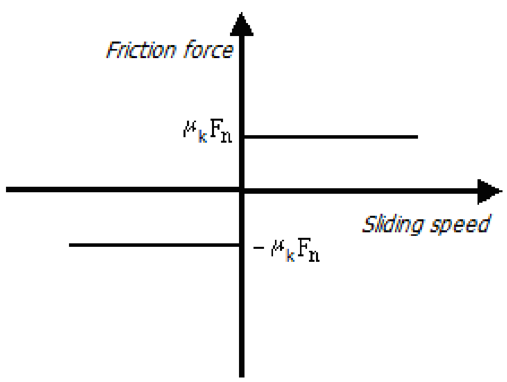
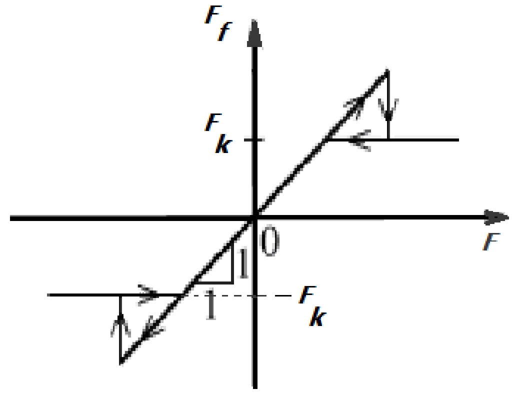


Figure1. Dry friction model

In dry friction case vibrations due to this phenomenon can't be slighted, it's negative impact can cause the stick-slip effect that manifest itself through noise at deceleration and jars of system's equipments. Sliding friction characteristic is shown in figure 2 (a, b) and points to friction force's dependency on normal force (fig.2.a), tangent force (fig.2.b) acting on the contact area of the components.



a)



b)

Figure2.a),b). Dry friction characteristics

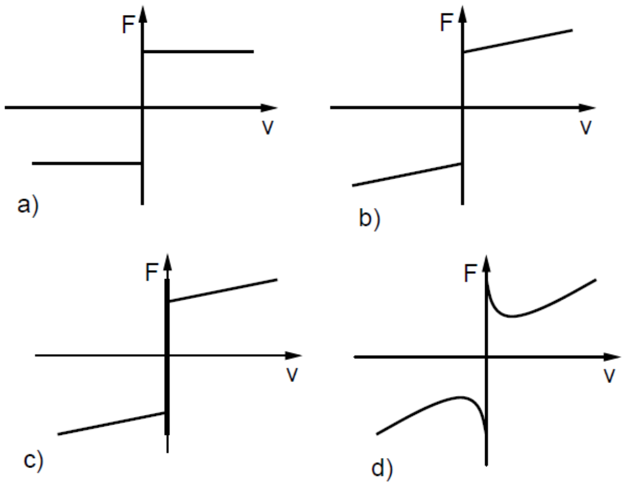


Figure3. Static friction models:
a) Coulomb friction; b) Coulomb + lubricated friction;
c) Coulomb + lubricated + stick slip friction; d) Stribeck curve

The classical friction models (fig. 3) consist of different components, each taking care of certain aspects of the friction force. The main idea is that friction opposes motion and that its magnitude is independent of velocity and contact area.

2.2. LUBRICATED FRICTION

Starting with the modernisation of high precision machines and the increase of work speed it has been define a new type of friction that depends on velocity and on lubricating fluid's nature. The concept of lubricated friction was associated with the viscosity of lubricating fluid, which becomes stiffer at higher pressures produced by higher speed [2].

At lubricated friction, represented in figure 4, the nature of surfaces has a low influence upon friction phenomenon, although it must be taken into consideration the adherence component and the thermal transfer.

In case of lubricated friction the parts surfaces are not involved in a direct contact, the friction appears between surfaces and lubricating fluid. From a certain value of work speed a minimum clearance follows up, which advantages obtaining lubricated friction condition.

Establishment of the lubricated friction areas, of lubricated conditions in general, it can be accomplished using the Stribeck curves which indicates the variation of the lubricated fluid's thickness and the variation of friction coefficient, μ_k, with the normal force, F_n , velocity, v, and fluid's viscosity, η [2]:

$$\mu_k = \frac{\eta \cdot v}{F_n} \tag{4}$$

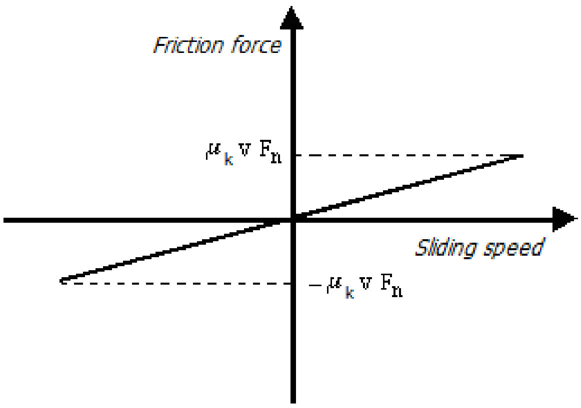


Figure4. Lubricated friction characteristic

2.3. MIXED FRICTION

Mixed friction appears at the limit between the two friction conditions described earlier and it's brought on by the instability of lubricant film. This type of friction follows system starting or stopping or a direction changing of the motion. Mixed friction coefficient's value is lower than dry friction coefficient but the attrition yield after mixed friction is higher than the one caused by lubricated friction.

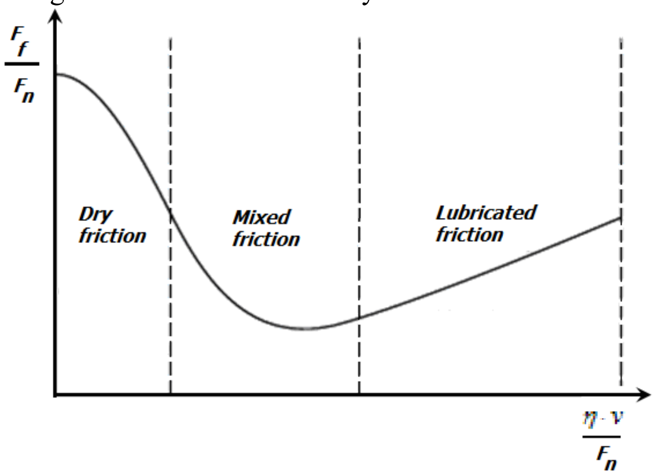


Figure5. Simplified Stribeck curve

In the case of this friction condition is often met the stick-slip phenomenon distinguished by short term periodic oscillations between adhesion friction and sliding friction, phenomenon which generates strong vibrations. This is due to increasing and decreasing of the elastic force – friction force ratio on short time periods.

Simplified Stribeck curve from figure 5 shows a global feature of lubricated surfaces motion. It can be noticed that the friction coefficient is proportional to velocity and to lubricant viscosity.

3. VIBRATIONS CAUSED BY FRICTION FORCES AT INDUSTRIAL MACHINES COMPONENTS IN MOTION

The most common vibration situations caused by friction phenomenon can be seen either at sliding bearings or at roller bearings.

In case of sliding bearings vibrations occur due to frictions between journal and backing. There is no direct contact among the surfaces of the two parts, the space being replete with lubricant. Hereby, during rotary motion occur vibrations due to all three friction conditions: dry; mixed; lubricated.

Non-linear viscous friction can be identified in vibratory signal using Hilbert transform or Wavelet transform which allows an analysis in time or frequency domain of non-linear oscillations with a FFT transform.

At the transition from dry friction to mixed friction in vibration spectrum can be observed self-excited oscillations.

In case of roller bearings sliding frictions is substituted by the rolling friction which determines vibrations that evidences changes of vibration spectrum in the domain of excitation frequencies.

At occurrence of friction among components in rotary motion the radial vibrations spectrums are similar to vibrations spectrums caused by faults as insufficient tightening or weakening of mechanical joints. If the time signal includes impulses, amplitudes or modulation frequencies then in the vibration spectrum will appear side bands [4].

The friction that occurs between a fast component and a component in rotary motion (radial compressor) reverberates in frequency spectrum as a series of spectral lines, the subtraction of frequency of two spectral adjacent lines being equal to rotation frequency of the component engaged in motion. If the spectrum shows two series of lines mean that two of the eigenfrequencies have been excited.

Following a frequency analysis of the vibratory signal, frictions in the seals can be determined which, if are not observed in due time, lead to deterioration of the seals and therefore to major system faults.

Frictions at the level of coupling teeth lead to excitation of first inflexion eigenfrequency of impeller. At toothed gear transmissions it is of great interest the spectral analysis of frequencies, showing crests in gear frequency harmonics, side bands or lower harmonics of rotational frequency.

Damping system can be recognized with modal analysis, using measures as structure's eigenfrequency or forms of vibrations eigenmodes. Eigenfrequencies values are determined by using peak amplitude method and are identified with frequencies for which picks can be noticed in the amplitude-frequency diagram. For force signals is usually applied frequency analysis (FFT) and Cepstrum analysis.

At electric motors frictions between brushes and collector shims lead to faults that appear in the vibrations spectrum as lower harmonics of the main commutation frequency as well as side bands on both sides of the commutation frequency with increased amplitudes.

4. CONCLUSIONS

Is obvious the fact that dynamic systems can't function without producing friction phenomenon. Friction among system's parts in motion can induce vibrations that lead to faults as attrition, corrosions, etc, that generate errors in the functioning of industrial machines and in the progress of their ongoing processes.

Therefore, it is of great importance to identify friction by analysing vibrations signals, having at hand a wide domain of methods and analysis procedures as well as high technology that smoothens the process.

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