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Utility of a fretting device working under free displacement

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ABSTRACT

Relative movements of low amplitudes between two materials in contact are generally reproduced on fretting devices with imposed displacement or imposed tangential force. The damage kinetics observed (cracking, wear) is established under such conditions. In this article, a fretting device working under free displacement is used to characterize the damages generated by seizure and wear. The conditions of seizure are analyzed from the total sliding distance and the discussion is focused on a correlation established with Dupre's work of adhesion. The wear behavior of materials has been characterized from an energetic wear coefficient taking into account the wear volume of contact, the total sliding distance and the dissipated energy.

1. Introduction

Many mechanical assemblies are subjected to vibratory loading stress, resulting from very low amplitude displacements between parts in contact. The micro-sliding generated between surfaces causes well-known damages: cracking and rupture, corrosion or structure transformations, wear with debris formation and seizure [1–5]. These damages are usually studied by imposing either tangential force, or displacement.

- When *tangential force is imposed* (Fig. 1a), the contact adapts by responding in terms of displacement. However, a force controlled test is stable only if it works under partial slip conditions. In full slip conditions, the tangential stiffness is zero when tangential force is proportional to normal force. In this configuration, only cracking is usually studied.
- When *displacement is imposed* (Fig. 1b), the contact adaptation responds in terms of tangential force. In this situation, cracking (nucleation and propagation) and wear (kinetic···) depend on displacement amplitude, oscillation frequency and normal load.

In these two approaches, cracking is studied using efficient fatigue criteria [6,7], whereas wear is studied using the "dissipated energy" [8] and "third body" [9] concepts. However, in certain industrial applications, for example blade and disk contact in aircraft turbine engines, recent studies have shown that vibratory instabilities involve great variability in the displacement amplitude [10]. In addition, the authors highlight the free variation of displacement amplitudes during the three flying conditions (take off, hovering and landing). By controlling variable periods of amplitude, a machine working under imposed displacement can generate the free evolution of the displacement.

This article analyzes the damage induced by a contact, which adapts in terms of both tangential force and displacement (Fig. 2). Initially, we describe the function of an experimental device, developed in order to apprehend the complex industrial fretting conditions where effort and displacement amplitudes generally follow uncontrolled variations. Then, we propose to perform a mechanical analysis of this device. In previous articles, we showed that this machine can display seizure conditions [5] and allows the determination of the boundary between seizure and sliding conditions [11]. Seizure is usually defined as the arrest of the relative motion as a result of the adhesive interactions of the rubbing surfaces as well as the debris trapped [12]. In this study, we show that this phenomenon can be carried out by the thermodynamic theory of adhesion [13]. Then, we propose to compare the evolution of wear parameters, such as energetic wear coefficient [11], with thermodynamical parameters, such as work of adhesion. Finally, a physical meaning is proposed for this energetic wear coefficient.

2. Fretting device

2.1. Description

The fretting device used to simulate the fretting phenomena occurring on quasi-static assemblies allows the free evolution of the displacement amplitude (Fig. 3). This machine presents a hemispherical pin-on-disc configuration. Its load capacity ranges

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Nomenclature

Device and fretting parameters

P	normal force (N)
P_c	critical normal force (N)
Q	tangential force (N)
δ	real displacement amplitude (μm)
δ_r	referred displacement (μm)
δ_m	measured displacement (m)
δ_o	aperture of the fretting cycle (μm)
δ_{oi}	aperture of the *i*th fretting cycle (μm)
δ_1, δ_2	deformation due to the bending, respectively, of pin holder and slider (m)
δ_3	relative displacements of the whole assembly surfaces (m)
L	length of the pin holder or of the pin (m)
l	pin radius (m)
S	cross section of the pin holder (m^2)
I	moment of inertia (m^4)
C	measured compliance ($\mu m\,N^{-1}$)
K	stiffness ($N\,\mu m^{-1}$)
C_c	contact compliance ($\mu m\,N^{-1}$)
C_t	tangential compliance ($\mu m\,N^{-1}$)

Materials and coatings properties

t	thickness of coatings (μm)
E	Young's modulus (GPa)
H	hardness (GPa)
Ra	average roughness parameter (μm)
γ	surface free energy ($J\,m^{-2}$)
γ^{LW}	dispersive component of the surface free energy ($J\,m^{-2}$)
γ^{AB}	Lewis acid–base component of the surface free energy ($J\,m^{-2}$)
γ_{12}	interfacial surface free energy ($J\,m^{-2}$)
W_{12}	Dupre's work of adhesion between two substrates in contact ($J\,m^{-2}$)
W_{12}^{LW}	Dupre's work of adhesion due to dispersive Van der Waals interactions ($J\,m^{-2}$)
W_{12}^{AB}	Dupre's work of adhesion due to Lewis acid–base interactions ($J\,m^{-2}$)

Analysis of slip, seizure and damage

D_o	total sliding distance (m)
E_d	dissipated energy (J)
E_{di}	dissipated energy of *i*th fretting cycle (J)
E_{dt}	total dissipated energy (J)
r	radius of a fretting scar on the slider (m)
R	radius of hemispherical slider (m)
V_c	global wear volume of contact (m^3)
V_d	wear volume of disc (m^3)
V_p	wear volume of slider (m^3)
V^+	wear volume of transfer of matter (m^3)
V^-	wear volume of removal of matter (m^3)
U_c	wear rate of contact ($m^3\,N^{-1}\,m^{-1}$)
GY	energetic wear coefficient ($m^2\,J^{-1}$)

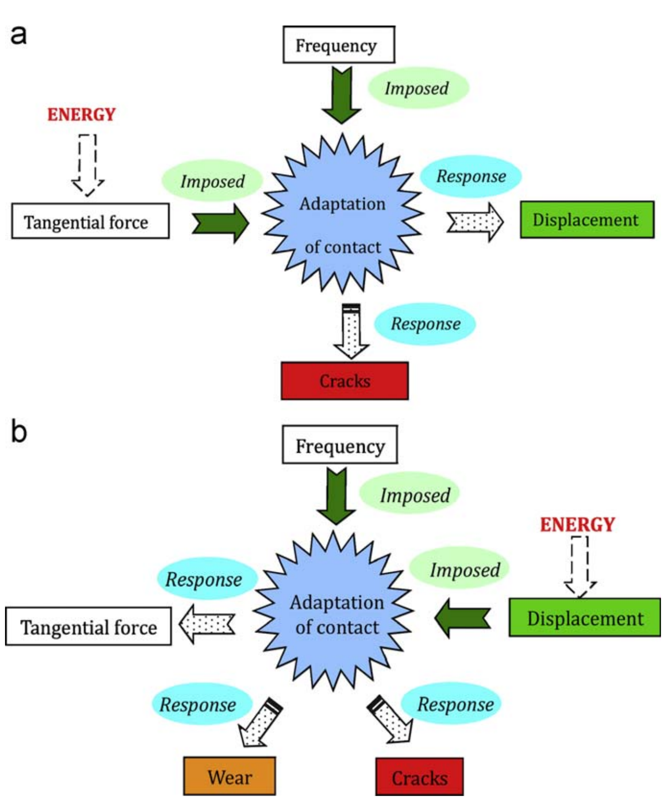

Fig. 1. Approach used for the damage analysis in fretting with a device which: (a) imposed tangential force and (b) imposed displacement.

from 2 to 30 N with initial displacement amplitude ranging from ±10 to ±600 μm and oscillation frequencies of up to 160 Hz.

The rigidity of the device frame is sufficient to prevent the creation of parasitic vibrations of the samples during the test. These dimensions are about 40 cm × 150 cm × 80 cm. The frame supports a platform (reference) provided with four units: an actuator unit, a moving unit, a positioning unit and a loading unit (Fig. 3a).

- The *actuator unit* ① constitutes the vibration generator (exciter). This exciter works on the principle of an electromagnet that generates alternative movements where displacement and frequency are controlled. The maximum tangential force delivered by the exciter reaches approximately 100 N.

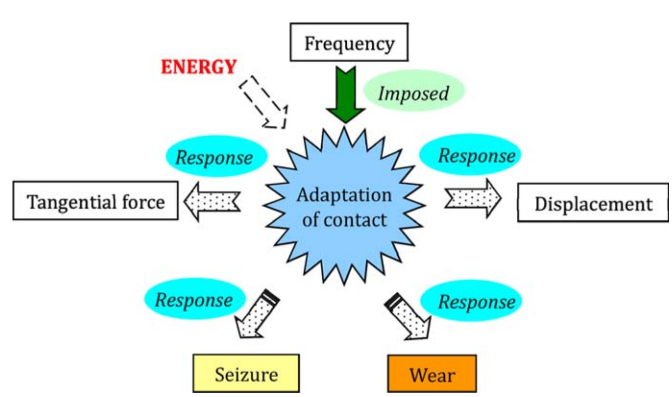

Fig. 2. Approach for the damage analysis in fretting with a device working under free displacement.