Dependence of dry friction on atomic bond type

Yuhim Lerner

Abstract: *An equation is proposed for the forced oscillation of surface electrons in bodies with ionic bonds under dry friction. The friction–velocity ratio is obtained. It is also shown that friction is weaker for bodies with a covalent bond than for their ionic bond counterparts.*
Keywords: dry friction; electrons; forced oscillation; ionic, metallic, and covalent bonds.

I.   INTRODUCTION

Study [1] contemplates the friction between a silicon crystal and niobium film at different temperatures. It was found that at levels below the critical one (8.2K for Nb), the friction is weaker by a factor of 2-3 than at levels above it. In the first case, the phononic component is operative, and in the second, both the phononic and the electronic (electrostatic and van der Waals') components are involved. The model is shown in the article: electrostatic friction showed in [1] is induced by variable ES field.

The present paper proposes an equation for the above-mentioned forced oscillation under dry friction conditions between bodies with ionic bonds. It is shown that the friction is weaker for covalent bonds.

On the surface of the element in motion, electric charges generate a variable electrostatic field which is thus displaced along the surface of the stationary element. The oscillation in the surface layer of an ionic bond stationary body reads as follows:

$$m(d^2x/dt^2) + F = q\, E\cos \square\, t \qquad\qquad (1)$$

where **m, x, F, q** and $\square$ denote respectively the mass, displacement, motion resistance, change and oscillation frequency of the electron while **E** is the intensity amplitude of the field.

The model adopted in oscillation theory assumes the motion resistance force to be proportional to the velocity, namely, zero at rest and increasing linearly in motion. It is known, however, that the friction at rest is approximately the same as in motion, and in the latter case not proportional to the velocity. In other words, the above model is inapplicable to dry friction.
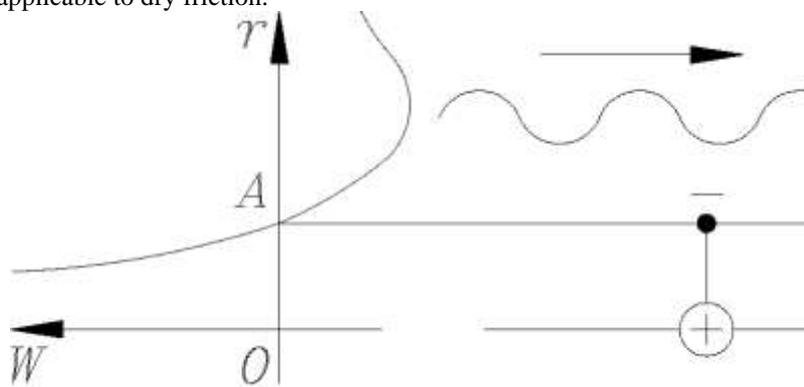
Fig.1

Fig. 1 shows in its left-hand part the run energy vs. distance for ionic bond atoms, and in its right-hand part – an electron in the surface layer of a stationary body. Point A in the curve corresponds to the position of the electron when external forces are absent. When the mobile body is in motion, the field generated as described above induces forced oscillation of the surface layer electrons in the stationary body. Assume that as a result, point A undergoes a short displacement along a tangent mentally drawn through it. In line with this assumption, we have the following approximation for the MR force:

$$F = m\, C^2\, \square_0{}^2 x, \qquad\qquad (2)$$

---

where C is a non-dimensional coefficient and w_0 is the natural oscillation frequency. With (1) and (2) in mind, the oscillation equation for the centre of the electronic charge reads as follows:

$$m(d^2x/dt^2)\ m\ C^2\ \square_0\ ^2x = qEcos\square\ t \qquad (3)$$

And its particular solution is

$$x = q\ Ecos\ \square\ t\ /\ mC^2\square_0\ ^2[1 - (\square\ /\ C\ \square_0)\ ^2] \qquad (4)$$

Substituting the value of x in (2) we have:

$$F = N\ q\ E\ cos\ \square\ t, \qquad (5)$$

where

$$N = 1/[1 - (\square\ /\ C\ \square_0)^2] \qquad (6)$$
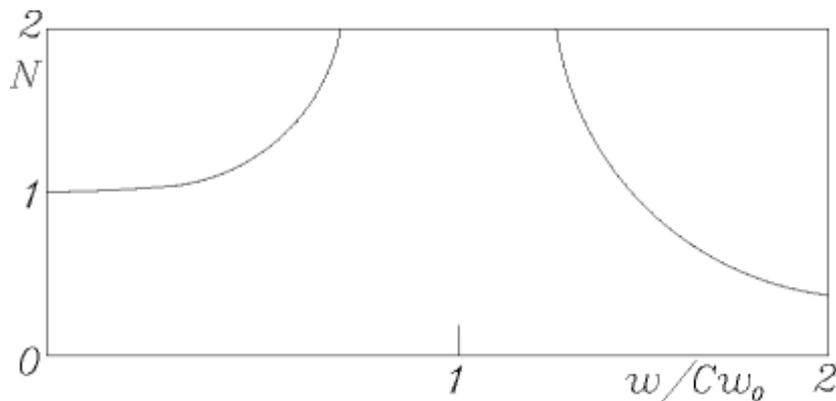
Fig.2

Fig. 2 shows this relationship for C = 1, the values of N being taken as positive. It is seen that N increases moderately in the low frequency range, then more steeply with a discontinuity at the resonance level, and finally decreases asymptotically.
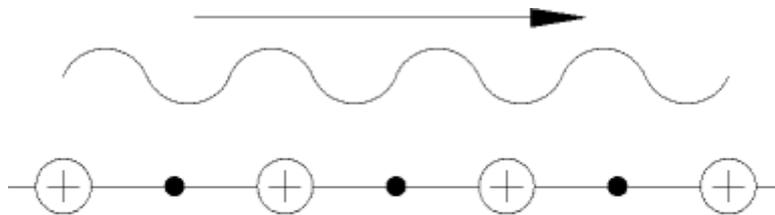
Fig.3

Fig. 3 shows schemes of covalent bond atoms such as those of carbon chains.

The oscillation patterns in Fig. 1 and 3 differ substantially. While in the first case the oscillation proceeds along the electron–nucleus axis, in the second it is normal to it. In those geometrical circumstances, the oscillation amplitude in the first case is necessarily much larger than in the second – in other words, the friction of covalent bond materials must be weaker than that of their ionic bond counterparts.

Let us now match the proposed theory against experimental data [2]. Graphite and diamond (covalent bonds) were tested under deep vacuum, after degassing for complete removal of surface oxygen. Under these conditions the friction coefficient of graphite is 0.45, of diamond −0.3, while under normal conditions it is only a fraction of the above. The friction of the rock salt NaCl (ionic bond) is substantially stronger: f = 0.7-0.8, and that of gold (metallic bond, oxygen chemisorptions are impossible), even stronger, namely f = 0.8-1.5.

The left-hand branch of the diagram in Fig.2 disagrees with the finding of [2] that the increase in friction with increasing velocity is insignificant. This conflict between theory and experiment can be explained by the findings of the author's experimental study of the electronic resistance R (comprising the closure and tunnelling resistance) of a pair of crosswise-coupled [90^0] and mutually-skewed [$\ddagger 90^0$] cylinders under $0.1 - 1$ Newton loads [3, 4]. For rhodium (Rh–coated cylinders) and for a palladium–iridium alloy oxygen chemisorptions are impossible and the tunneling resistance is zero. In the experiments, R remained unchanged once contact was established.

In the cases of a gold-copper alloy and of beryllium bronze, oxygen chemisorptions are possible. In the above experiments, asymptotic decrease of R was observed after contact – 5%–10% in 2–5 sec in the first case, 20%–30% in 30–60 sec in the second one. This decrease evidences the weakening of the tunneling resistance. It is known [5] that the latter depends exponentially on the clearance between the bodies. The gap, filled with a non-conducting film, is not constant in the case of oxygen chemisorptions, but increases as the velocity increases – in turn making for some weakening of the friction.

The tool used in the metal friction study at very high velocities in [2] was a small steel ball boosted by a rotating magnetic field. The initial velocity of the ball was 600 m/sec, decreasing in the course of the rest. A copper-tungsten pair showed the lowest result at the maximum velocity, namely f = 0.15, increasing as the velocity decreased and becoming infinite at about 200 m/sec. The friction–velocity relationship for a metallic bond corresponds to the right-hand branch in Fig. 2. For chromium-diamond and copper-diamond pairs the pattern was different – for the first pair f = 0.4 at 500 to 250 m/sec, f = 0.05 – 0.1 at 250 to zero; for the second pair – f = 0.03 – 0.04 throughout the whole range 500 m/sec to zero. It is seen that the friction is significantly weaker when one element has a covalent bond.

The results in [3] partially corroborate the proposed theory, for the covalent bond the friction is weaker than for its counterpart.

LITERATURE

[1].   Kisel M., Gnecco T., Gusin U., Marot L., Kast S., Meyer E. Suppression of electronic friction on Nb films in the superconducting state// Nature Materials. 2011. V. 10 pp. 119-122.
[2].   Bowden F. P., Tablor D. The Friction and Lubrication of Solids. Part 2. Oxford. University Press. 2001.
[3].   Lerner Y. Strength of adhesive non-conducting films on metallic surfaces in friction// Trenie I Iznos. Gomel (Belarus). Vol. 25. No. 3. pp. 271-275.
[4].   Lerner Y. About some regularities of dry friction// Vestnik Mashinostroenia. Moscow. 2005. No. 8. pp. 87-90.
[5].   Holm R. Electrical Contacts. Springer. 2000.