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# INFLUENCE OF AN EXTERNAL NORMAL HARMONIC FORCE ON REDUCTION OF FRICTION FORCE

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***Abstract***

*The paper shows; the results of studies on the influence of an external normal harmonic force upon reduction of a friction force, in the system of two bodies in a planar contact. It has been pointed out that, the main reason for the friction force reduction is due to dynamical effect; kind of stick – slip monition. Nature of the phenomenon has been described and explained in the article. The computational studies have been validated with experimental results available in literature. Moreover a nondimensional relation, between forces acting on a slider and average velocity of the slider, has been found.*

***Keywords:*** *stick-slip, friction, reduction, contact, nonlinear vibration*

## 1. Introduction

Interaction between the friction force and the normal forces takes place in many dynamical systems, e.g. in. vibrating plate compactors or vibrating feeders. The phenomenon was described in many publications [1-16], in context of friction reduction due to normal vibrations or forces. The reduction of the friction force, under normal vibrations and a variable normal force, is usually explained in the literature thorough:

- decreased value of friction coefficient [15];
- decreased average value of contact deflection [8, 16];
- decreased "efective" value of the reaction force [16];
- decreased average value of the real area of contact [3, 5, 7, 14]; and
- stick-slip motion caused by a variable normal reaction [4, 9, 10, 12, 13].

Although the matter has been known for a long time, there is not one widely accepted opinion for the reason of friction force reduction. The main goal of this paper is to prove that, the main reason of the friction force reduction due to an external normal harmonic force, is the stick-slip motion.

In the considered work; the friction coefficient has a constant value, contact deflection has been neglected, and the mean value of the reaction equals the earthpull (equilibrium of momentum and impulse). Moreover according to Bowden and Tabor [1]; the value of the true contact area is directly proportional to the value of the normal reaction, and of the friction force is directly proportional to value of true contact area. Therefore the factors are not considered as a reason of the friction force reduction.

## 2. Model

The aforementioned system of the two bodies in a planar contact, shown in Fig. 1, is investigated in the section. The system consists of a slider and a slideway. The rough surfaces undergoing friction create an elastoplastic interface. Nevertheless in this model, the contact flexibility is neglected, because the force of inertia is very slight, during vibrations excited by low frequency external force [9]. Thus the reaction force is the sum of earthpull and external force,

$$R = Q - P_a \sin(2\pi f t) \,, \tag{1}$$

where:
$R$- denotes reaction force,
$Q$- earthpull,
$P_a$- amplitude external force,
$f$- frequency,
$t$- time.
As evident from Eq. (1) the average value of reaction equals earthpull ( $\overline{R} = Q$ ).

A constant driving force $F_d$ is applied to the slider (Fig.1), and tends to introduce a sliding motion. While the friction force $F_f$ acting in the contact region, tends to stop the motion. The friction force is expressed by the Coulomb's formula

$$\text{If } \dot{x} = 0 \text{ then } F_f = -F_d \text{ else } F_f = -\mu R \operatorname{sgn} \dot{x} \,, \tag{2}$$

where:
$\mu$- is a constant friction coefficient,
$x$- displacement,
$F_f$ - friction force,
$F_d$ - driving force.
The directly proportional relation between the reaction force and the friction force, during slip (Eq, (2)) means, that the decrease of the coeficient of friction is not considered at all. Moreover while smooth sliding takes place, the average friction force is equal to the product friction coefficient and the earthpull ( $\overline{F_t} = \mu\overline{R} = \mu Q$ ).

The sliding motion of the slider of mass $m$, which is assumed to be a rigid block, is described by the ordinary differential equation:

$$\ddot{x} = m^{-1}(F_d - F_f) \,, \tag{3}$$

where:
$m$- denotes mass of the slider.

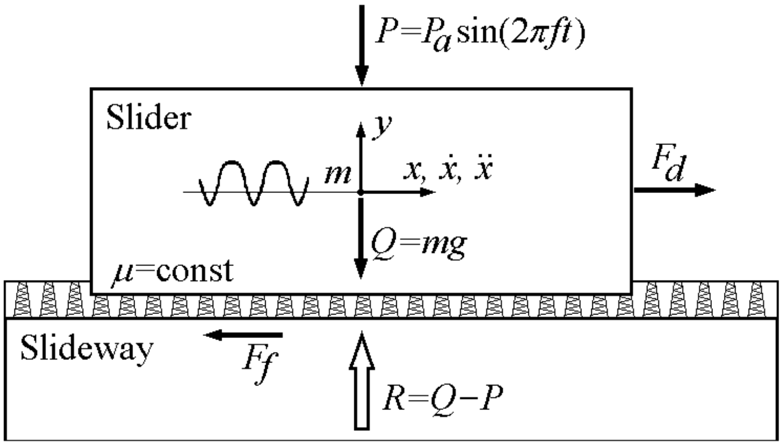


*Fig. 1. Model of a simple dynamical system with external force P and Coulomb's friction*

## 3. Investigation of friction force and sliding motion

In the case, when amplitude of external force equals zero $P_a$=0; then driving force must be higher or equal to friction force, to cause or maintain sliding motion in the considered system;

$$F_d \geq F_{fN} = \mu Q = \mu mg \ , \tag{4}$$

where:
$F_{fN}$- denotes the nominal static force in the absence of contact vibrations, and
g- is gravitation acceleration.

The sliding motion of the slider may occur at lower values of the driving force then shown previously (Eq. (4)), when the normal external force is present. The conditions for motion to occur may be written down as follows

$$F_d > \mu(Q-P_a) = F_{f\,min} \, , \tag{5}$$

where:
$F_{f\,min}$ - denotes the minimum of the friction force.
The formula delimits areas of motion and stillness (Fig. 3.). The equation of slider motion was studied in detail. Firstly the time history was simulated. Diagrams (Fig. 2.) show clearly the time histories of the motion and the mechanism of reduction friction force. The slider begins a short-time slip, at the point (*A*), in which the potential friction force $\mu R$ begins to be lower than the tangential force $F_d$,. The reduction of the friction force is coupled with unloading of the contact by the external force. The slider accelerates to the time instance (*B*), in which the friction force $F_f$ begins to be higher than that of the tangential force $F_d$. At he point (*B*) the velocity of the slider is the highest. Next the friction force $F_f$ is higher than that tangential force $F_d$, in turn the velocity drops to zero at point (*C*), because the slider's kinetic energy has been dissipated. Finally is the period of stick (immobility of the slider). The period last to the time instance, when the potential friction force $\mu R$ is again lower than that of the tangential force $F_d$. Therefore the stick-slip motion is periodical and interrupted.

In short; temporary and periodical drops of the friction force are used for slider displacement. The slider moves when conditions are the best and "waits" when conditions are not good enough to move. The periodical motion can be seen as continuos one, when frequency of the motion is high. The feature may leads sometimes to misinterpretation of the phenomena.

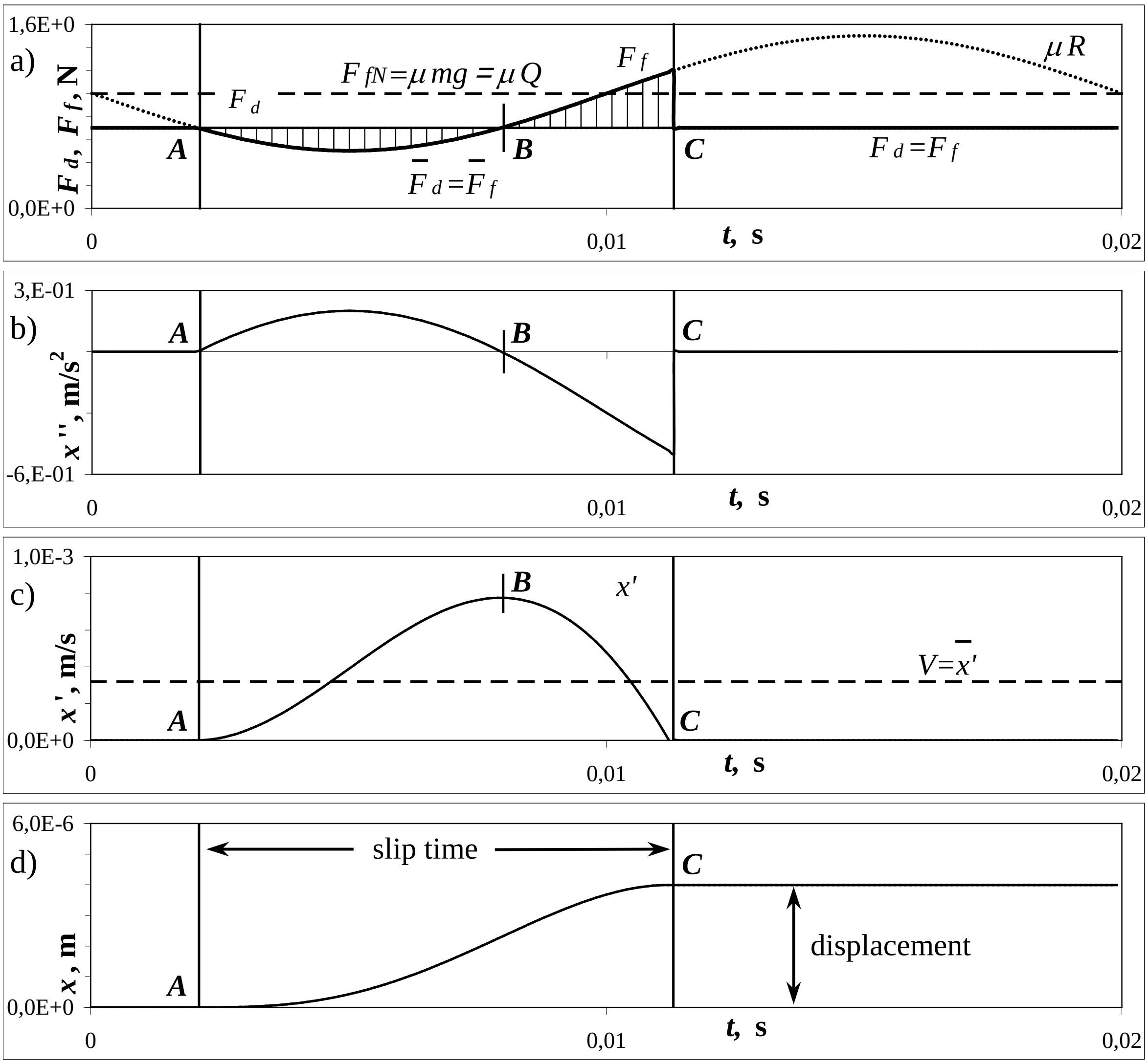


*Fig. 2. Results of computer simulations illustrating time histories of forces and their influence on kinetic values* $\ddot{x}, \dot{x}, x$ *characterising motion of the slider (adopted data:* $P_a$=5*N*, $F_d$=0,7*N*, *f*=50*Hz*, $\mu$=0,1, *g*=10*m/s*$^2$, *m*=1*kg*)

In general, the occurrence of sliding motion of the slider, and its behaviour depend on: the value of the tangential force $F_d$ (which is lower than $F_{fN}=\mu mg$); amplitude $P_a$ of the external force (which is lower than $Q=mg$) and the frequency $f$ of the external force. Velocity of the slider depends on time histories of the tangential force $F_d$ and the friction force $F_f$, in other words on impulse of the forces (lined areas in Fig. 2a). Thus by integration of the areas velocity is calculated. Velocity of the slider is increasing, when the lined area is rising. An analysis of factors, which influence on impulse of the forces, and consequently on velocity of the slider, leads to conclusion that; a general nondimensional solution can be received (Fig. 3). Nondimensional velocity of the slider $U$ may be written down as follows

$$U = \frac{Vf}{g\mu} \ , \qquad (6)$$

where:

$V$ [m/s] - denotes average velocity of the slider.

Influence of $P_a/Q$ and $F_d/F_{fN}$ , on the nondimensional velocity $U$ of the sliding motion, has been presented on Fig. 3. In the figure, the area of variations of controllable data ($F_d/F_{fN}$ and $P_a/Q$) is noticeable, in which the sliding motion does not occur ($U$=0). This takes place for, appropriately small amplitudes of external force and values of the tangential force. The area, in which the sliding motion occurs, is noticeable too. Nondimensional velocity $U$ increases with the rise of the amplitude of the external force $P_a$ and the tangential force $F_d$. These forces can be used to steer the slider.

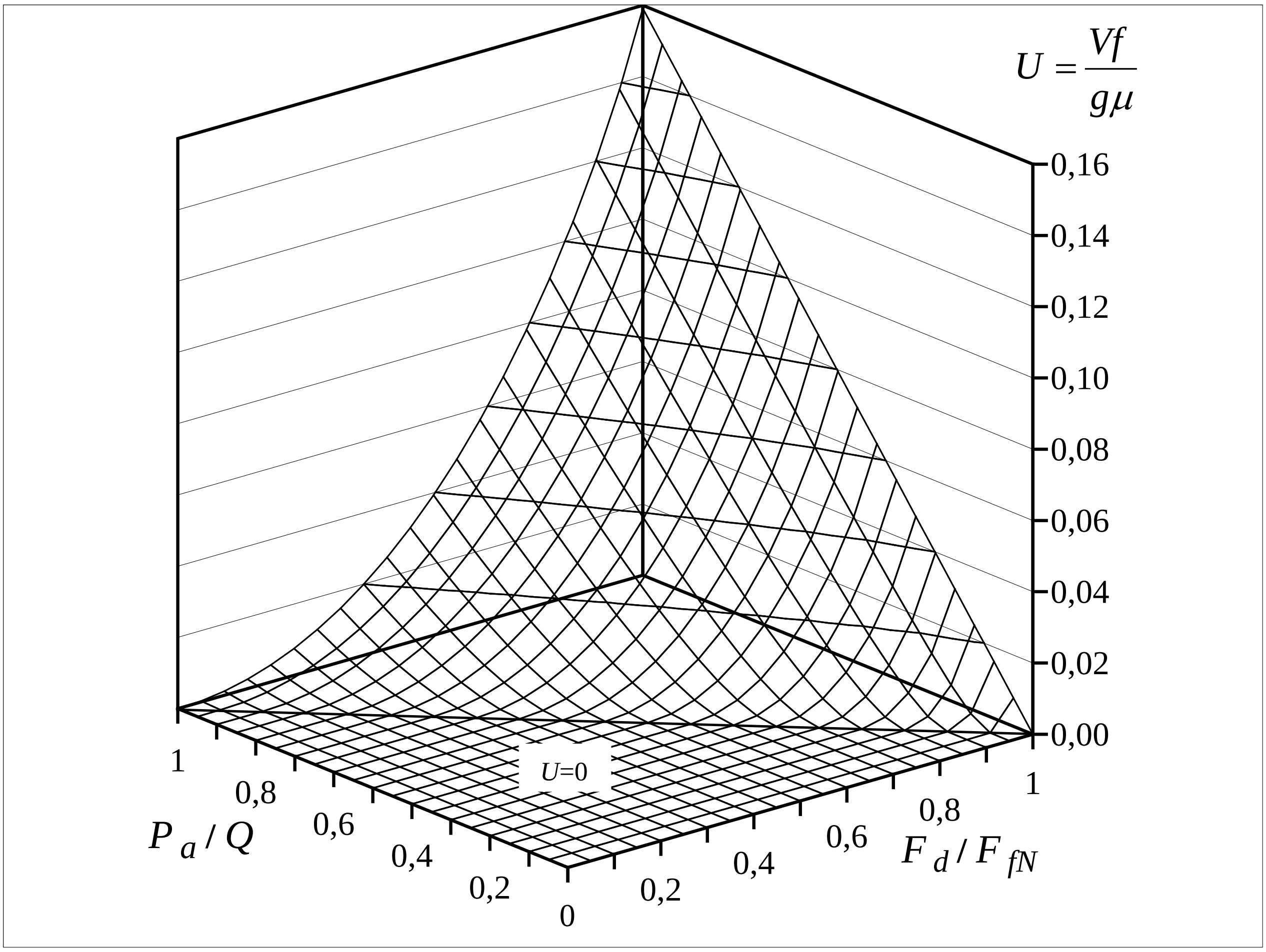


*Fig. 3. Influence of $P_a/Q$ and $F_d/F_{fN}$ on the nondimensional velocity U of the slider*

The model of the reduction friction force is verified. The results of simulation were validated with the experimental results (Fig. 4) presented by Lomakin [12]. The differences between the results are slight, which gives the opportunity to suppose, that the main reason of the friction force reduction has been presented in the article.

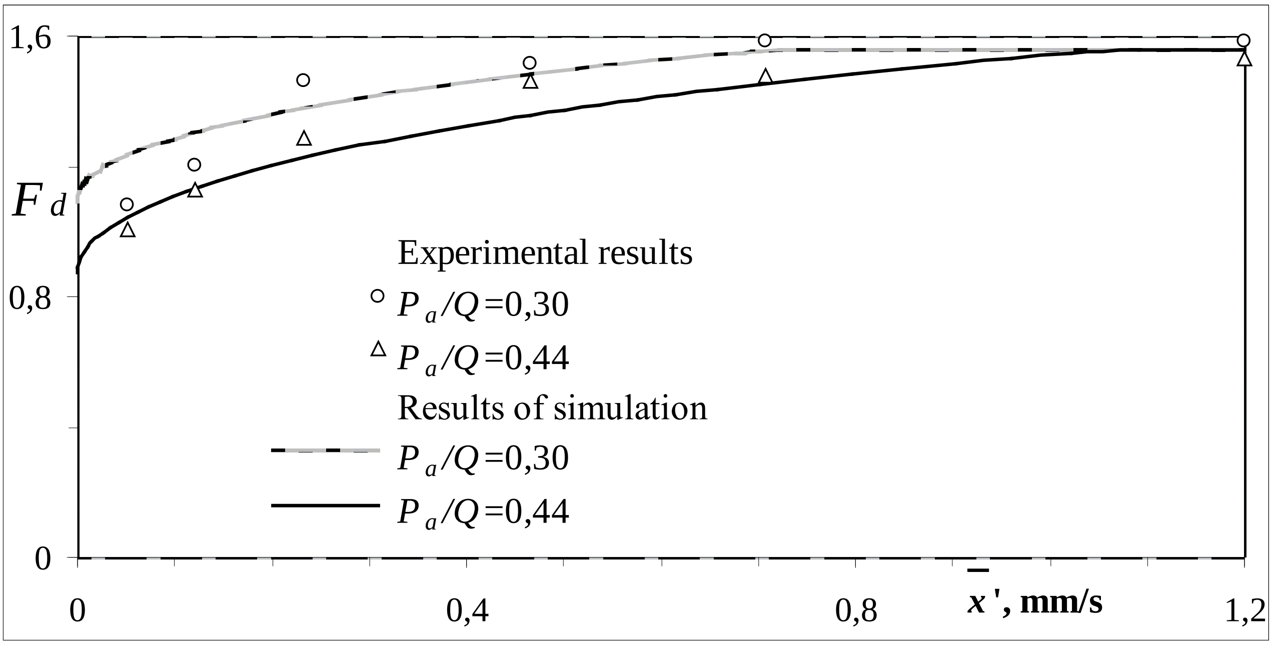


*Fig. 4. Comparison of the results of simulations against the experimental results presented by Lomakin (1955) (adopted data:* $\mu$=0,156, $m$=1$kg$, $g$=10$m/s^2$ , $f$=100$Hz$)

## 4. Conclusions

The adopted model as well as the simulations and experimental results indicate, the mechanism of the reduction of the friction force, for planar contact of solids under the normal external force. It has been shown: the influence of a normal external force on the reduction of the friction force, and that reduction of:

- mean value of the friction coefficient,
- mean value of the normal reaction,
- mean value of the real contact area,

are not necessary in order to reduce the friction force in a sliding system. The reduction can be explained, on the ground of nonlinear dynamics, as a result of stick-slip motion. Moreover the nondimensional relation, between the forces acting on the slider and the average velocity of the slider, has been found as well.

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