

STUDY REGARDING THE SLOW SPEED MOTION STABILITY IN SLEDGE-SLIDE KINEMATICAL COUPLES

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ABSTRACT

The dynamical phenomena associated to machine tools' functioning are determined by the interaction between the equipment's elastic system and the cutting process. Vibration occurrence is inherent, especially due to transitory processes (start/stop, motion sense reversal, etc.). In this paper, we analysed the feed kinematical chain running with slow sliding speeds, in the context of the frictional process complexity. The speed minimum value enabling the sledge continuous motion and, at the same time, avoiding the appearance of the self-excited vibrations (in connection to the well-known "stick-slip" phenomenon) was studied.

KEYWORDS: static/dynamic frictional force, critical sliding speed, self-excited vibrations, stick-slip phenomenon

1. INTRODUCTION

Vibration occurrence during the manufacturing process performed on machine tools is inherent. These vibrations amplitude is in close connection to both dimensional and shape precision of the machined surface. The dynamical behaviour of a machine tool is determined, during its exploitation, by the cutting regime parameters (cutting speed v , feed rate s , and cutting depth t), characterizing the cutting process (CP) intensity, and by the machining system (MS) stiffness, fig.1. During the occasional presence of a vibration process, an unwanted relative displacement (y) between the cutting tool and the worked piece takes place, depending on the values of the above-mentioned parameters.

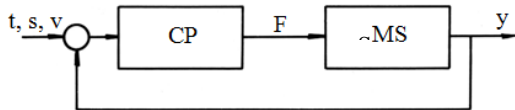


Fig. 1. Flowchart illustrating the dynamical behaviour of the CP - MS couple

By identifying the transfer functions of both cutting process and machining system (machine tool / fixtures / worked piece / cutting tool) structure, the dynamical stability can be analyzed, if the friction forces have a negligible influence. However, in the case of slow speed feed motion, the relative sliding between surfaces in contact is characterized by a

significant variation of the friction forces. If the machining system has low rigidity, the relative motion inside the sledge / slide couple is intermittent; in the dedicated literature, this is called the "stick-slip" phenomenon. Due to feed speed variation, unfavourable effects concerning the machined surface quality and cutting tool durability do appear.

2. MANUFACTURING SYSTEM STRUCTURE

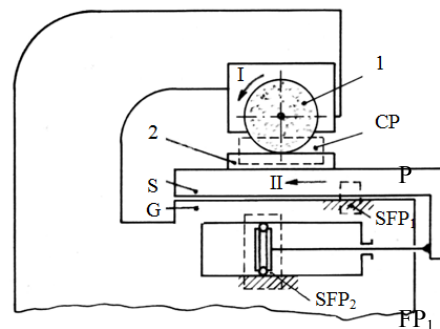


Fig. 2. The mechanical structure of a plain grinding machine

In the case of machine tools with feed kinematical chains hydraulically driven, the dynamical stability is depends on the magnitude of friction forces which characterize the cylinder-piston

couple, from the hydraulic motor, and also on the low stiffness of the sealing elements (fig. 2).

The description of the system running in a dynamical regime is depicted as a flowchart in fig. 3, where the cutting process (CP) together with the

sliding friction processes (SFP) are represented. These processes are considered inside the elastic structure of the machining system (ESMS), composed of the sledge / slide (S/G) kinematical couple and of the stem/cylinder components (fig. 3).

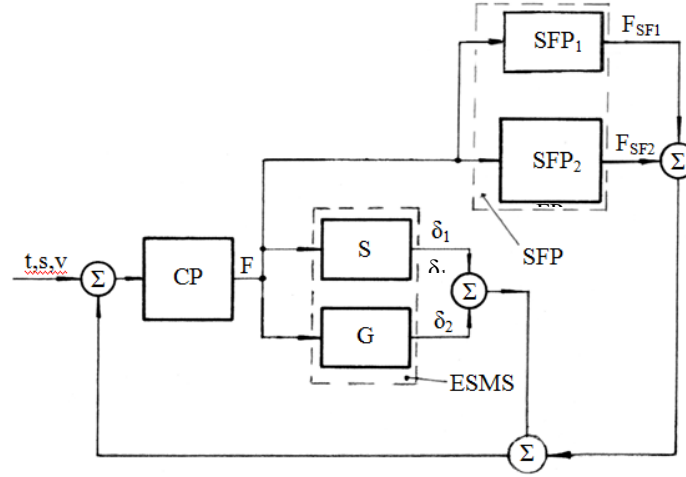


Fig. 3. Flowchart illustrating the machining system running in dynamical regime

3. THEORETICAL ASPECTS

The sliding friction, depending on lubricant presence, can be dry, mixed or liquid. In the specific case of sliding couples sledge/slide, when the cutting regime is characterized by a slow feed speed, the contact between the surfaces in relative motion is defined by phenomena characteristic to the mixed friction regime.

Therefore, the lubricant layer has a thickness which is time-varying, between the extreme states corresponding to direct contact or to complete fluid flow, leading to the stick-slip phenomenon (fig.4).

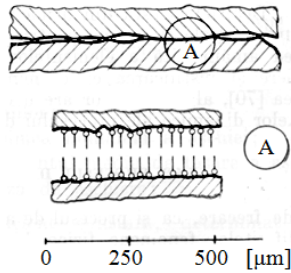


Fig. 4. The contact between two surfaces in mixed friction regime

The lubrication has, generally speaking, a double effect: it generates a viscous resistance and it creates an elastic that behaves like a component of the machining system’s elastic structure.

In most of the cases, the feed speed magnitude has an impact on vibration amplitude, as a damping element, namely at feed speed increase, the vibration amplitude diminishes. In the case of low feed speeds, due to the dependence existing between the friction force magnitude and the velocity in the relative

motion between the surfaces of the sledge/slide sliding couple, the study of the self-excited vibration generated by the friction process requires an elastic system model with a single degree of freedom, 1-DOF (fig. 5a).

The motion equation of the sledge having the m mass, after the moment when the system’s elastic force overpasses the limit of the static friction state, has the expression:

$$\ddot{x} + 2n\dot{x} + p^2x = 0, \quad (1)$$

where: $2n = \frac{\nu}{m}$ is the viscous damping coefficient, ν – the lubricant viscosity; m – the system mass; $p^2 = \frac{k}{m}$ – the elastic damping coefficient; k – the elastic constant.

The general solution of equation (1) is:

$$x = e^{-nt} a \cdot \sin(p_1t + \varphi). \quad (2)$$

We can notice that the motion is damped oscillating (fig. 5b) or aperiodic (fig. 5c), depending on the value of the damping coefficient. At low speeds, the friction force is reduced concomitantly with the speed. By considering, at a first level approximation, the dependence $F_f = f(\dot{x})$ as linear:

$$F_f = F_0 = \nu x, \quad (3)$$

we obtain, from (1)

$$\ddot{x} - 2n\dot{x} + p^2x = -F_0, \quad (4)$$

with the general solution:

$$x = e^{nt} a \cdot \sin(p_1 t + \varphi) - \frac{F_0}{p^2} \quad (5)$$

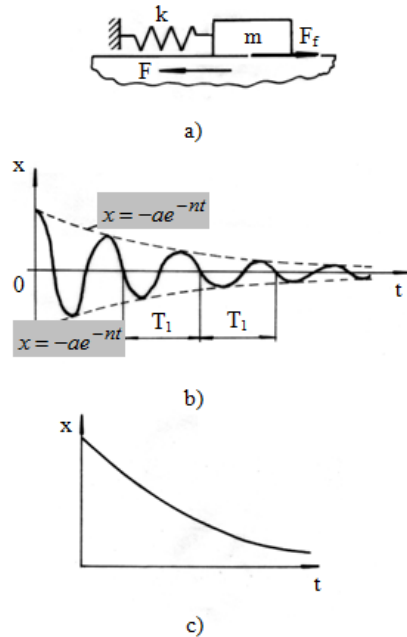


Fig. 5. Elastic system of 1-DOF type

In reality, the friction force is varying, depending on the speed, according to the graphical representation from Fig.6. The system motion can be expressed by a differential equation of the shape:

$$x + f(\dot{x}) + \varphi(x) = 0, \quad (6)$$

where $f(\dot{x})$ has to satisfy, during a period, successively the conditions:

$$f(\dot{x}) < 0 \text{ and } f(\dot{x}) > 0. \quad (7)$$

In relation (5), the presence of the exponential factor, increasing with the time factor, shows that the motion is unstable. This is a feature specific for the self-excited linear systems only. In the case of non-linear systems, it is also possible to have a stable, periodic motion, or a motion with limited amplitudes, which is no more harmonic.

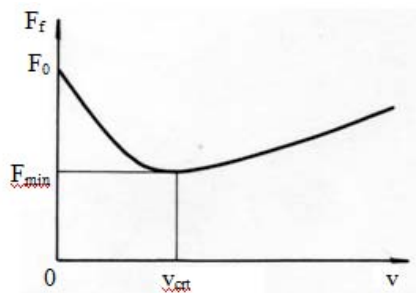


Fig. 6. The dependence between the friction force and the sliding speed

4. EXPERIMENTAL RESEARCH

From the above presented facts, the necessity of knowing the friction forces' variation curves, depending on their influent parameters, and, especially, the $F = f(x)$ function expression, in the different situations met in practice is obvious.

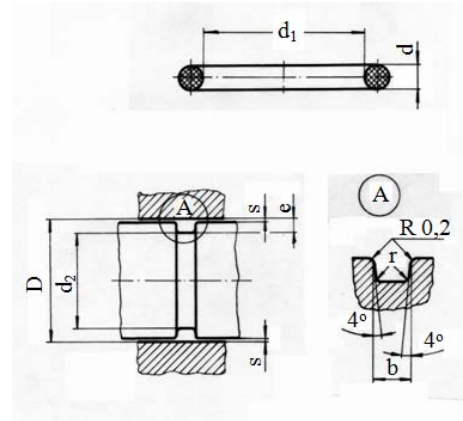


Fig. 7. Shape and dimensions of the "O-ring" sealing system components

In the research here presented, the friction force variation was studied in the specific case of sealing systems which are used by the hydraulic motors of cylinder-piston type. In this case, the contact between the conjugated surfaces is one between a rigid element and an elastic element.

From the sealing systems mostly encountered in practice, the largest part is formed by "O-ring" category, because they have the following advantages: easiness in manufacturing the sealing element and its packing space, small size of the zone with sealing function, easy and quick assembling / disassembling.

The dimensional and shape characteristics of this sealing system components and of the whole system ensemble are represented in fig. 7 and 8 (according to SR ISO 3601).

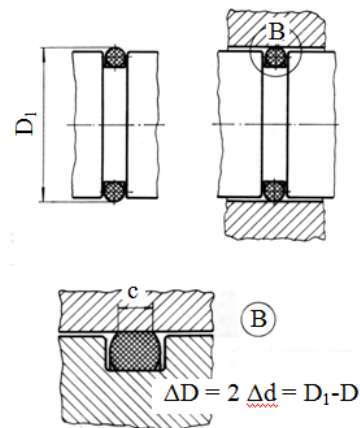


Fig. 8. The "O-ring" sealing system ensemble

The experimental research target was to establish the variation law for the friction force after the piston velocity during its displacement, and after the gasket initial interference ($\Delta d = d_i - d_j$). The experimental measurements were done in the following working conditions:

- Sealing element: “O-ring” gasket with, $d = 5.7$ mm;
- Hydraulic cylinder diameter: $D = 54$ mm;
- Hydraulic installation running regime: idle running (no hydraulic pressure);
- Lubrication with turbine oil Tb 5004, having the viscosity $\nu = 1.11$ cm²/s at a temperature of 25°C;
- All measurements were executed in the same cylinder region, of 50 mm length, in order to keep the same influence of the cylinder shape deviations.

The notations from the experimental setting picture (fig. 9) have the following meanings: 1 – dynamometric ring (previously gauged); 2 – test indicator (1 μ m resolution); 3 – hydraulic cylinder; 4 – “O-ring” gasket; 5 – piston; 6 – machine tool table.

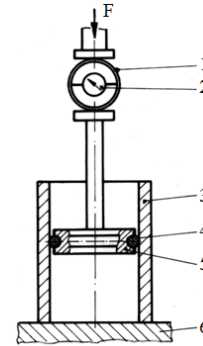


Fig. 9. The experimental setting

5. RESULTS AND CONCLUSIONS

After the performed experiments, we noticed that the $F = f(x)$ curves' profile is similar to the ones presented in the dedicated technical literature for the friction couple of sledge / slide type. From the gathered results (fig.10) regarding the interference domain with practical interest, ($\Delta d > 0.3 \dots 0.4$ mm), the friction force variation is more important at slow sliding speeds and it becomes, gradually, negligible when the sliding speed increases. Hereby, for the 0...50 mm/min speeds, the curves' medium inclination is between 0.23 and 0.12, while inside the 100...150 mm/min speed interval the inclination is below 0.03.

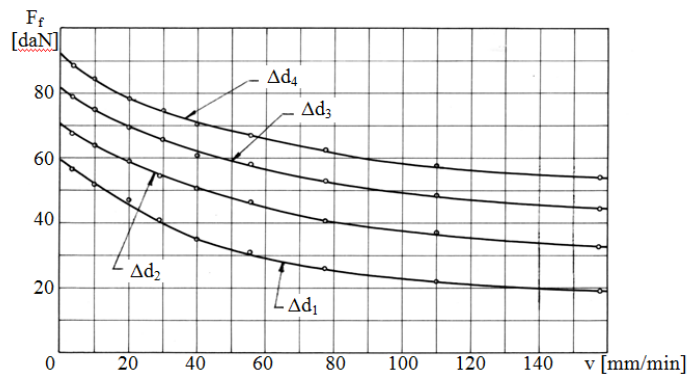


Fig. 10. The friction force variation depending on the sliding speed magnitude and on gasket interference: $\Delta d_1 - 0.30$ mm; $\Delta d_2 - 0.50$ mm; $\Delta d_3 - 0.65$ mm; $\Delta d_4 - 0.75$ mm

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