U.P.B. Sci. Bull., Series, D, Vol. 71, Iss. 1, 2009 ISSN 1454-2358

DYNAMIC RESEARCH AND PROCEDURE TO OBTAIN A USEFUL DOMAIN OF DYNAMOMETERS FOR MACHINE TOOLS

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Analiza dinamică pe baza de vibraţii este utilizată cu prioritate pentru identificarea stării de funcţionare a maşinilor-unelte. În lucrare sunt detaliate caracteristicile specifice pentru funcţia de transfer a dinamometrelor utilizate în special în domeniul de cercetare a maşinilor-unelte. Principalul obiectiv al lucrării a fost acela de a identifica o procedură de a obţine frecvenţele proprii pentru dinamometrele utilizate în scopul de a îmbunătăţi condiţiile procesului de aşchiere.

Vibration analysis has long been used for the detection and identification of machine tool condition. The specific characteristics of the transfer function of the dynamometers used in machine tool research aria are detailed in the papers. The main focus is on identifying a procedure to obtain eigen frequencies for dynamometers used to improve the cutting process on the machine tool.

Keywords: dynamometers**,** vibration, transfer function.

1. Introduction in the dynamic analysis

Analysis of dynamic behaviour of machines and equipments is an important method to redesign the product or the manufacturing process and to assure the proper quality, maintenance and service. When we study machines or only part of them, the dynamic behaviour is analysed for the following situations: constant operating speed (e.g. the angular speed of a rotor); a variable speed into a limited operating domain; an imposed speed inside the operational domain (e.g. rotational frequency 1...1000 Hz); In all of the mentioned cases, the behaviour of the system under the effect of external excitation is evaluated (fig. 1).

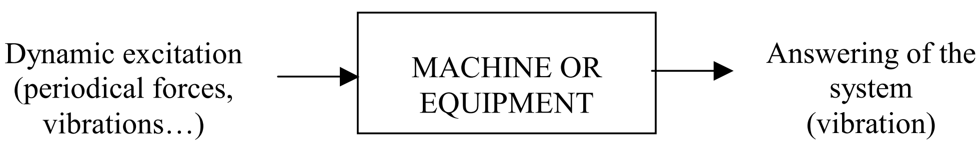

Fig. 1. Transfer function

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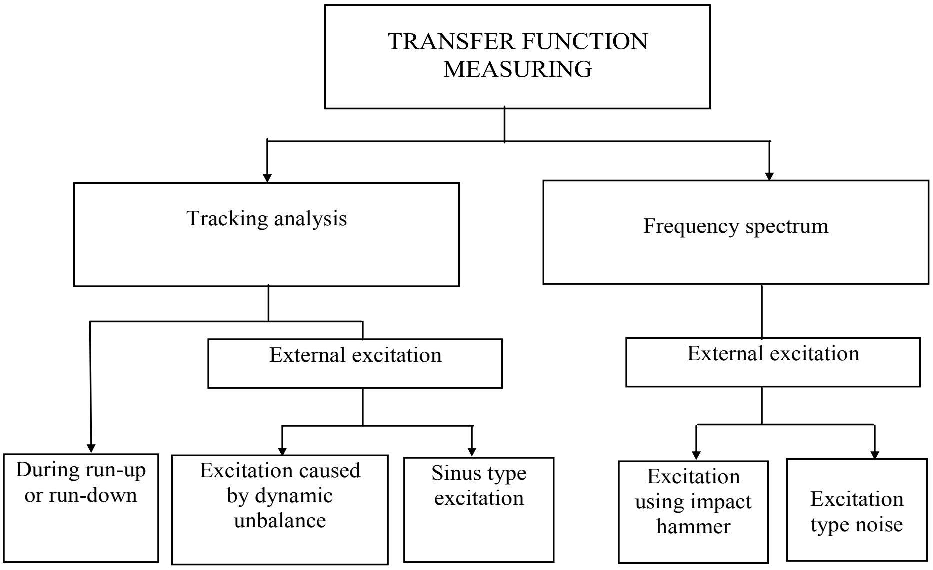


Fig. 2. Method of obtaining the transfer function

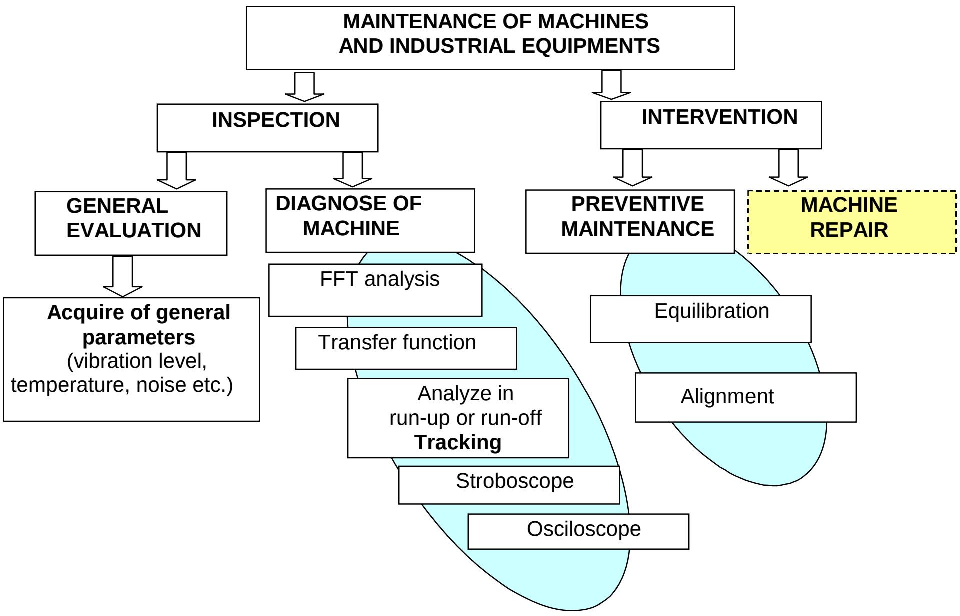


Fig. 3. Different possibilities to operate in diagnose or preventive maintenance of machine tool

The most used methods to measure the transfer function are detailed in fig.2 and different possibilities to operate in diagnose manner in fig. 3.

The transfer function is evaluated as the ratio between the response of the system and the dynamic excitation. To diagnose a machine or equipment the main characteristics offered by transfer function are: the dynamic rigidity or compliance; resonance frequencies; the damping factor; natural modes of vibration.

2. Measurement of the frequency of chip segmentation in turning

The methodology is based on the acquisition of chip segmentation frequencies according to different cutting speeds and feed rates. The measurement of chip segmentation frequencies was performed by three methods:

1) Acquisition, at a high frequency, of cutting forces and Labview FFT signal processing;

2) Chip geometric measurement based on microscopic observations;

3) FFT spectrum acquired using Vibroport 41 (Schenck) simultaneously with the signal for cutting forces [1] in order to validate the segmentation frequency [2] (Fig.4).

During this work, two working parameters were considered: the cutting speed V_c = 60–120 m/min and the feed rate f = 0.2–0.47 mm/rev. The cutting depth was kept equal to a constant value: a_p = 1 mm.

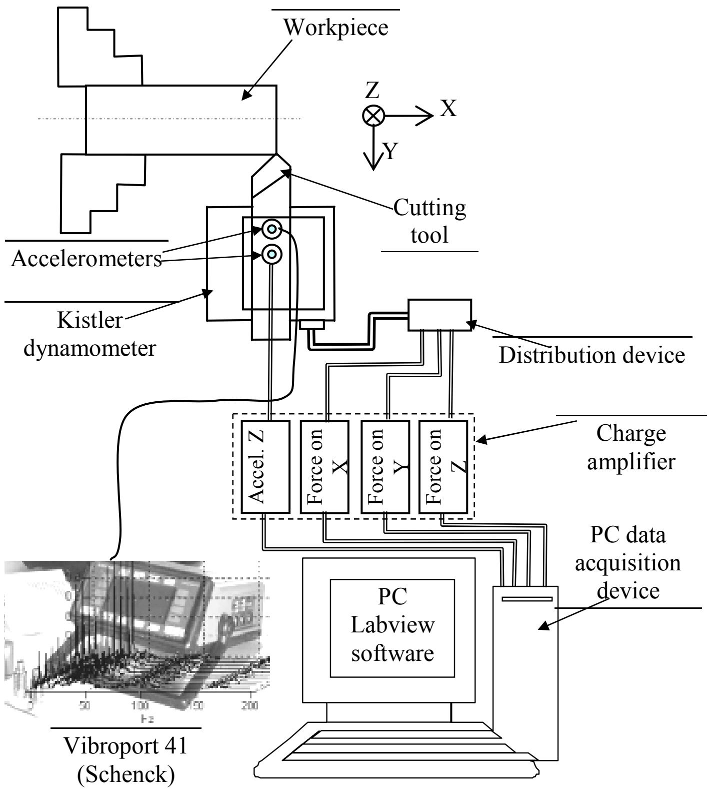


Fig. 4. Experimental acquisition chain in a turning process

In the following, the study of the frequency of the shearing plane formation was proposed. To accomplish the study, first the measurements of cutting force signals at high-frequency sampling were performed, and secondly the geometrical measurements on the chip sawtooth were made, to finally calculate the frequency related to the facet appearing on the machined surface, which was compared with the frequency acquired through Vibroport 41.

Vibroport 41 (Schenck) is a portable apparatus and corresponds to the European Standard EN 10204. It is an autonomous apparatus using two channels for the vibration signal acquisition.

The aim of this section is to propose a calculation procedure dealing with the saw-tooth frequency appearing during machining based on measurements on the chip section. Measurements are made using a microscope.

By considering the mean speed of chip evacuation on the tool rake face and the distance Δx_{chip} measured between two shearing planes, the frequency can be established as:

$$F_{hzCG} = \frac{100 V_s}{6 \Delta x_{chip}} \text{ [Hz]} \tag{1}$$

where

F_{hzCG} = frequency of the formation of shearing planes determined from chip geometry (Hz); V_s = chip slip speed on the tool rake face (m/min); Δx_{chip} = distance between two consecutive shearing planes measured in the direction of the tool rake face (mm).

By assuming that the mass of the deformed metal during machining is constant, the following equation can be written:

$$\rho_1 V_c f\, a_p = \rho_2 V_s e_c\, l_c \tag{2}$$

where ρ_1 and ρ_2 are metal densities before and after the deformation respectively (kg/cm^3); V_c = cutting speed (m/min); V_s =chip slip speed on the tool rake face (m/min); f = feed rate (mm/rev); a_p = depth of cutting (mm); e_c =mean chip thickness (mm); l_c = width of the chip (mm). If the material compressibility is neglected, it is assumed that the ratio ρ_1/ρ_2 is equal to unity. Consequently, the chip slip speed V_s on the tool rake face is given by the equation:

$$V_s = V_c \cdot \frac{f\, a_p}{e_c\, l_c}. \tag{3}$$

The results were obtained demonstrate that the feed rate variation, for a fixed cutting speed, doesn't have a great influence upon the frequency of appearance of the shearing bands. This influence is larger when the cutting speed increases (Fig.5). Frequency also increases when the cutting speed increases; a direct influence of the cutting speed on the chip evacuation speed is observed - equation (2).

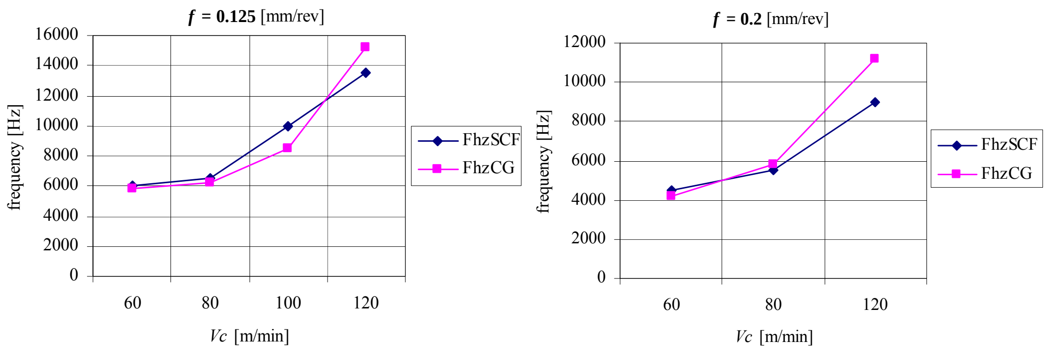
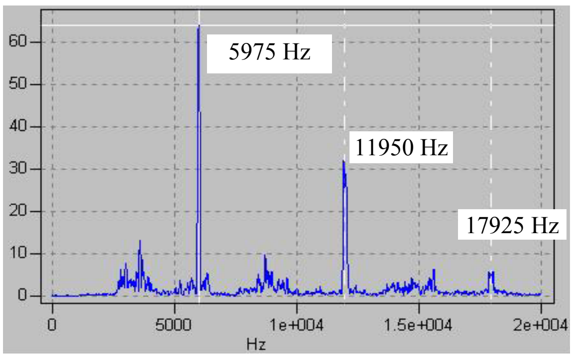


Fig. 5. Frequency accompanying saw-tooth chip formation depending on cutting speed

The main natural frequency values obtained with Vibroport 41 using the module *Transfer Function*, for the assembly tool – toolholder – Kistler dynamometer – support – transversal saddle are the followings: 150 Hz in the Z direction, due to the assembly tool – toolholder, in the case when four screws are used to fix the tool; 850 Hz in the Y direction, 1300 Hz in the X direction and 2400 Hz in the Z direction, due to the assembly transversal saddle and Kistler dynamometer; the natural frequency in the Z direction had a strong influence on the dynamical behaviour of the machine tool assembly.

The figure 6 presents an example of FFT spectrum acquired during hard turning. This is a good example when the chip segmentation frequency was very easy to separate by the machine tool vibrations. Others two significant frequencies were 11950 Hz and 17925 Hz – the first two harmonics.



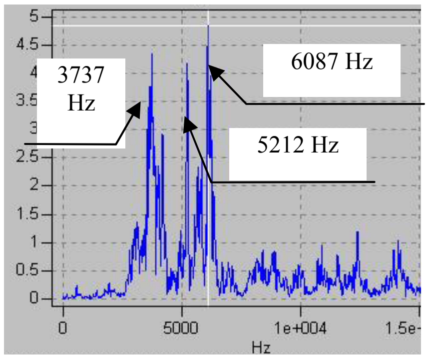


Fig. 6. Test with Vibroport 41;
V_c=80 m/min; f=0.125 mm/rev

Fig. 7. Acquisition using
V_c=60 m/min and f=0.05 mm/rev

The fig. 7 presents one significant example when the separation of the frequency of chip segmentation proved really difficult. The segmentation process had 6087 Hz and the significant vibration of the machine tool manifested at 5212 Hz. It was also important to know and to avoid the frequency due to the instability signal [5]. The useful domain considering the proper signal of transducers was between 3 and 15600 Hz; these limits are imposed by the piezoelectric accelerometers [6,7].

3. Measurement of the spindle vibration of one high-speed milling machine

In order to know the proper domain for High Speed Cutting for specific milling processes the authors propose to begin the research with the vibration of the spindle machine tool (Fig. 8) using *Tracking* analysis module of Vibroport 41 [3,4].

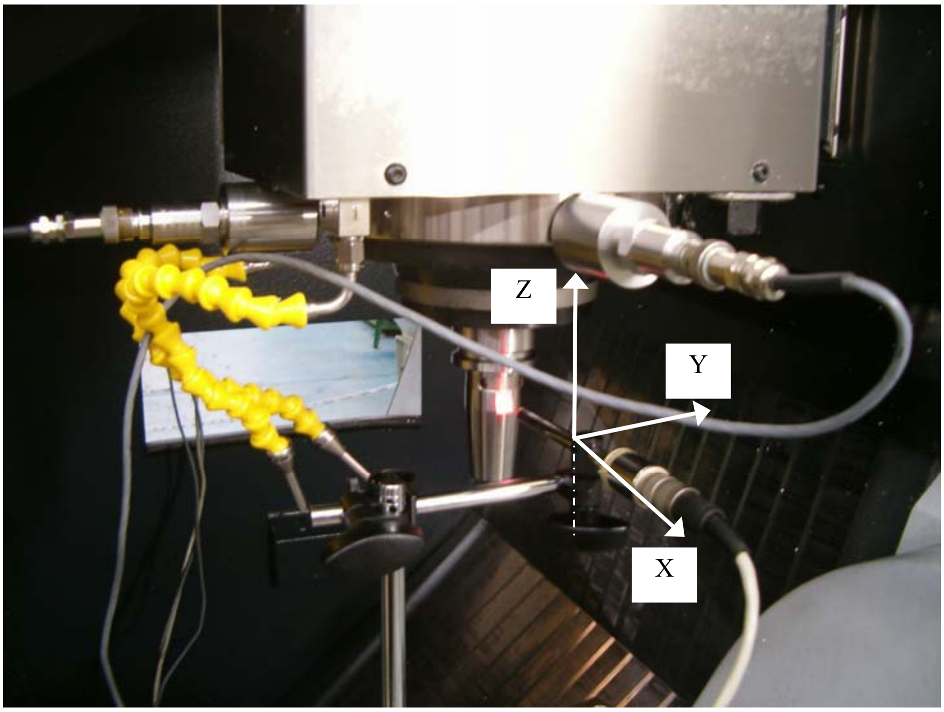


Fig. 8. Accelerometers placement on the spindle of milling machine tool

Natural frequencies of the assembly spindle-bearings (no cutting process) were: 29130 rpm (the first harmonic at 242.5 Hz), 14550 rpm (242.5 Hz) and 12.600 rpm (210 Hz). In figure 9 the tracking signal acquired using Vibroport 41 is presented.

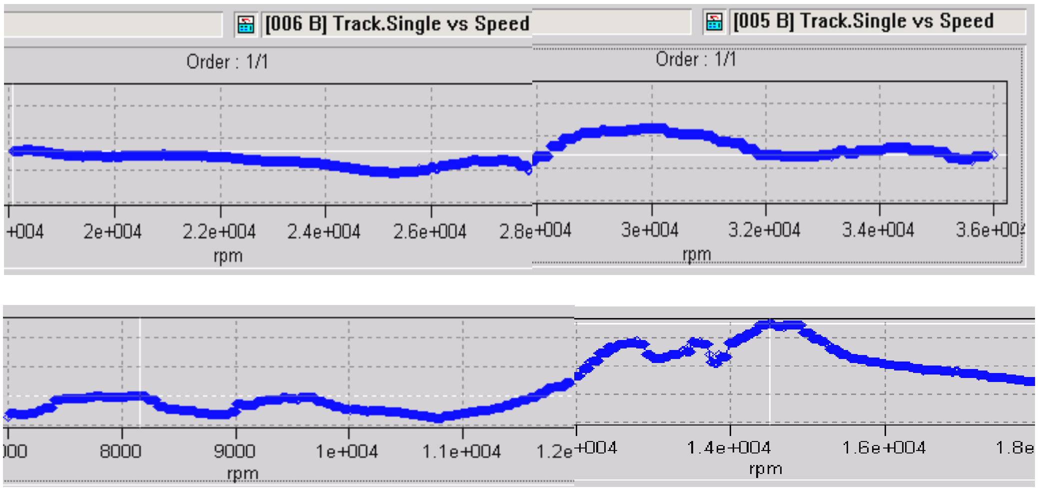
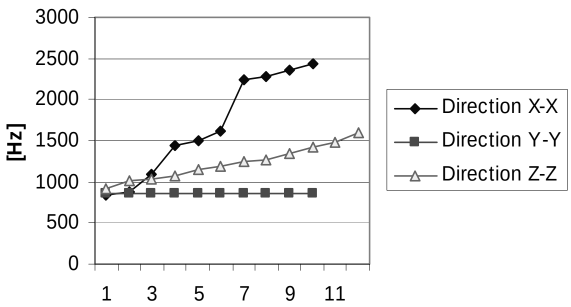
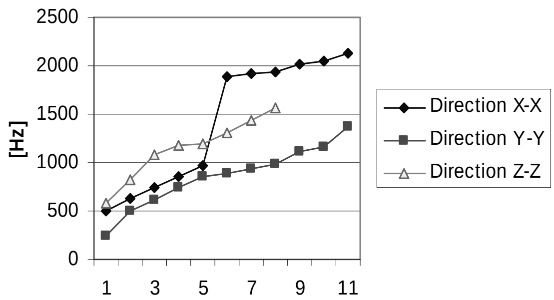


Fig. 9. Tracking signal using speed domain 36000-7000 rpm; direction X-X



a) Table without dynamometer



b) Table with dynamometer

Fig. 10. Influence of the dynamometer on the natural frequencies of the table

The fig. 10 presents the first 10 natural frequencies of the table of the milling machine tool (a) - without dynamometer and (b) with the quartz dynamometer mounted on the machine tool table.

4. Conclusion

The main objective in this research paper was to find the frequency for saw-tooth chip formation (found it on the FFT spectrum). Secondly, it was considered as important to separate the dynamics of the cutting process from the dynamics of the machine tool itself. High Speed Machining and particularly the turning and milling processes have an evolution concerning the limits of the cutting parameters and a good control for these processes is necessary. In this context, the present subject is important and helpful in elaborating a proper model for the cutting process, specifically in the orthogonal hard turning, taking into account the separation of the frequencies due to the machine tool and the frequencies in due of the cutting process. This work was validated by the experimental results based on the measuring of the cutting forces using dynamometers simultaneously with a FFT signal obtained using the Vibroport 41 apparatus and a piezoelectric accelerometer AS020.

Steps are envisaged in the direction of correcting the numerical model for the simulation of the cutting process, in these particular conditions, in order to advance a prediction of the real cutting conditions and to improve the knowledge through a general approach. A present trend in the area of dynamics of the machine tool research is to use sensors with six-axes for force and torque measurement in order to provide full six components of force and torque, namely vertical, lateral, and longitudinal forces, as well as the camber, steer, and torque movements.

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