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SAWTOOTH CHIP FORMATION IN HARD TURNING AND THE APPROACH TO SEPARATE PROCESS SEGMENTATION AND MACHINE ASSEMBLY VIBRATION FREQUENCIES

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***Abstract**: The present paper is a contribution to the investigation of the vibration frequencies accompanying saw-tooth chip formation in the case of hard turning. The study concerns the universal turn Gallic 20 machining with coated carbide of tempered AISI 4340 steel with a Rockwell C hardness of 47 HRC. The main idea in this paper deals with the establishment of a direct relationship between chip morphology simultaneously with amplitude of acceleration component signals derived from acquisition at high frequency and with the width of facets detected on a workpiece machined surface.*

***Key words:** orthogonal hard turning, frequency of chip formation, dynamical behaviour.*

1. INTRODUCTION

The complex phenomenon of cutting is the subject of numerous theoretical and experimental studies. The evolution of technologies tends to increase continuously the cutting speeds, tools life and the performance of material properties. Thus there is a strong need for experimental analyses of high speed and hard cutting processes [2].

The machining of metals by a cutting tool is a process of forming by material removal. It is a widely used process in manufacturing, among others. For many years, the progress of the process has been accompanied by many new problems. Therefore, it has been the subject of many publications.

The general aim of researchers is always the improvement in metal removal. In other terms, it is a question of increasing the metal removal rate while reducing costs. However, there are many constraints other than machine power and torque limitations, *e.g.* qualification criteria such as roughness and surface integrity that must be taken into account during cutting. These involve a good choice of the commonly used working parameters (the cutting depth, feed rate, and cutting speed). As is known by the industrial community, it is not always easy to find these parameters and consequently to control the process. This is due to the complexity of coexisting different physical phenomena such as mechanical, thermal, and metallurgical mechanisms during tool and workpiece interaction. An example that illustrates the necessity to choose, in an optimal way, these parameters is that of hard turning (HT). Indeed, the latter process has been applied in many industrial cases and has not yet been controlled. Frequently, it is used in manufacturing bearings, shafts, gears, cams, and other mechanical components of the machine tools and equipments.

According to Guo and Yen [5], HT has a significant advantage when compared with its competitor process: grinding. This is that HT may induce an equivalent or better surface finish, form, and workpiece size accuracy that grinding does. For scientific reasons and in order to obtain a physical comprehension of saw-tooth chip for-

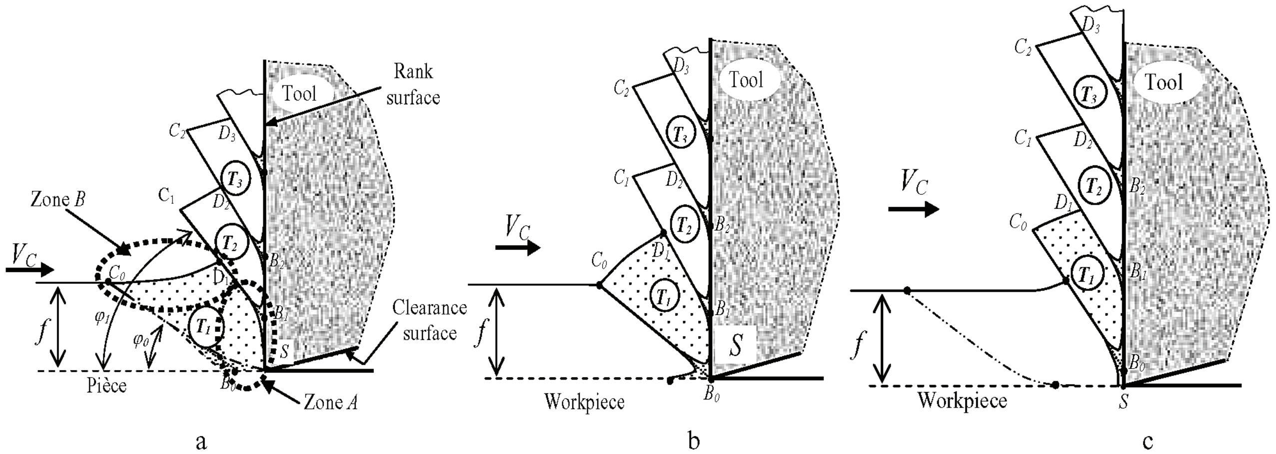


Fig. 1. Saw-tooth chip formation: a – T1 is wedged between rank face and (SC_0); b – T1 has the tendency to escapes to the free side (C_0D_1); c – T1 escapes and gets the saw-tooth shape.

mation, it seems to be essential to explain the manner in which this kind of chip is formed. For reasons of commodity, the present authors proposed to study saw-tooth chip formation in a plane perpendicular to the cutting edge, as shown in Fig. 1 [1].

The latter summarizes the T1 tooth formation cycle. The initial step is characterized by a compression and an upsetting of the new teeth ($C_0B_0B_1D_1$), where two zones are noted: *A* and *B*. Zone *A* is near the tool tip *S* and is subjected to high level stresses. Consequently, this location is wedged between the tool rake face and the limit (SC_0). As the cutting time increases, wedged material has a tendency to escape to the free side (C_0D_1).

Although there have been many significant papers and different methodologies adopted in studying saw-tooth chip formation, it is noted that there have been few papers treating their effect on cutting force components and machined surfaces especially in HT. The present work is focused on the identification of the chip frequency segmentation linked strictly by the process HT and saw-tooth chip resulting from the turning of hardened AISI 4340 steel having 47 HRC hardness.

2. EXPERIMENTAL STUDIES

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 realized 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 (Fig. 2).

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. Angle γ was negative and it is exemplified in the Fig. 3. In the following, it is proposed to study the frequency of the shearing plane formation. For that, firstly, measurements at high-frequency sampling, of cutting force signals were performed, secondly, geometrical measurements on the chip sawtooth were made, and, finally, the frequency related to facet appearing on the machined surface was calculated and compared with the frequency acquired with Vibroport 41.

2.1. Experimental device

The experiments concern straight turning of an AISI 4340 workpiece, which was hardened by heat treatment to 47 HRC. The machine tool and tool insert used consist in a universal lathe (Sumitomo Electric – Gallic 20) and a coated carbide (AC700G) respectively.

The considered insert is referenced CNMA 12 04 04 and is fixed on a tool holder (Sandvik, PCLNR 25 M 12).

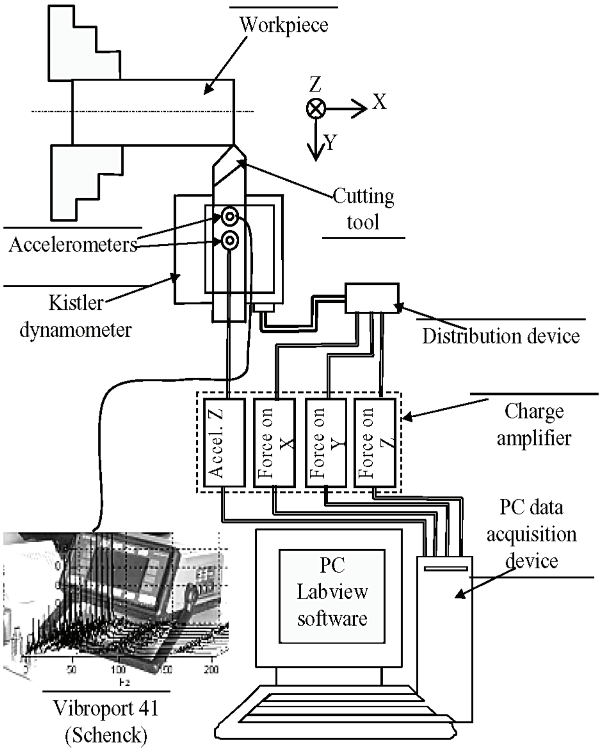
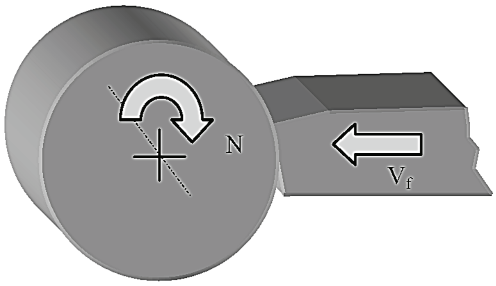


Fig. 2. Experimental acquisition chain.



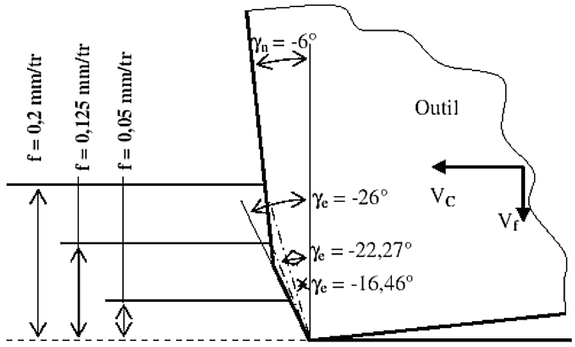


Fig. 3. Tool geometry depending on feed rate parameter.

The measuring equipment is composed of a standard dynamometer (Kistler* 9257B), a charge amplifier, and a high-frequency data acquisition device (National Instrument, NI 4472). The signal acquisition and data treatment were carried out with the LabView software.

2.2. Measurement of the frequency of chip segmentation causing shearing planes

An example of one FFT signal obtained after machining and acquisition, in real time, at a high frequency of cutting forces it shows in Fig. 4 where the presence of an important peak is noted at the frequency F_{hzSCF} (spectrum

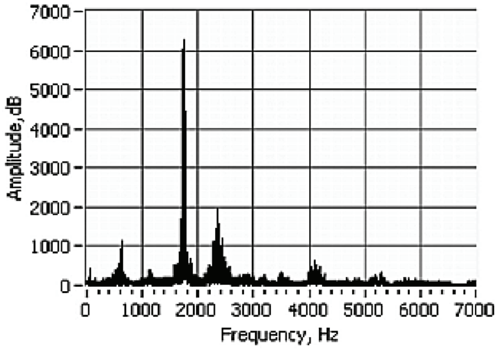


Fig. 4. FFT representation of the force F_Z signal. (V_c = 80 m/min; f = 0,4 mm/rev; a_p = 1 mm).

of cutting forces) equal to 1 750 Hz, with a higher power level. This is clearly the highest frequency identified.

2.3. Measurement of the saw-tooth shapes

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 by 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 (Fig. 5), the frequency can be established as:

$$F_{hzCG} = \frac{100 V_s}{6 \Delta x_{chip}}, \qquad (1)$$

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 metal deformed during machining is constant, it can be written the following equation:

$$\rho_1 V_c f\, a_p = \rho_2 V_s e_c\, l_c, \qquad (2)$$

where ρ_1 and ρ_2 are metal densities before and after 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 cut [mm]; e_c = mean of the chip thickness [mm]; l_c = width of the chip [mm].

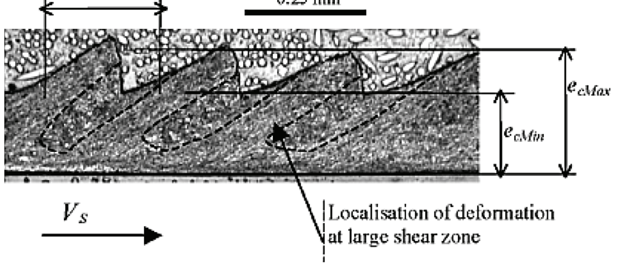


Fig. 5. Saw-tooth chip geometry of machined AISI 4340 (47 HRC) (V_c = 120 m/min; f = 0.2 mm/rev).

If is neglected material compressibility, it is assumed that the ratio ρ_1/ρ_2 is equal to the unit. Consequently, the chip slip speed V_s on the tool rake face is given by the equation:

$$V_s = V_c \cdot \frac{f a_p}{e_c l_c}. \qquad (3)$$

Fig. 6 presents the chip segmentation frequency in dependence with feed rate. The obtained results show that feed rate variation, for a fixed cutting speed, doesn't have a great influence on the appearance frequency of the shearing bands. This influence is larger when the cutting speed increases (Fig. 7). Frequency increases as the cutting speed increases; being a direct influence of the cutting speed on the chip evacuation speed – eq. (2).

Principal eigen frequencies values obtained with Vibroport 41 using module *Transfer Function*, for the assembly tool – toolholder – Kistler dynamometer – support – transversal saddle are the followings:

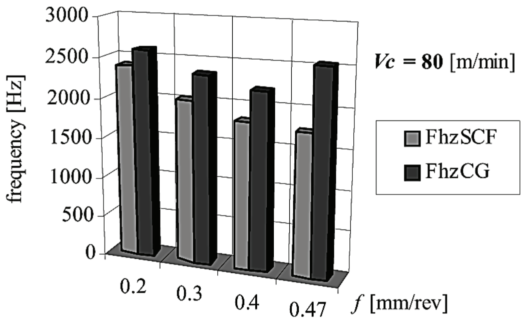


Fig. 6. Frequency variation according to the feed rate.

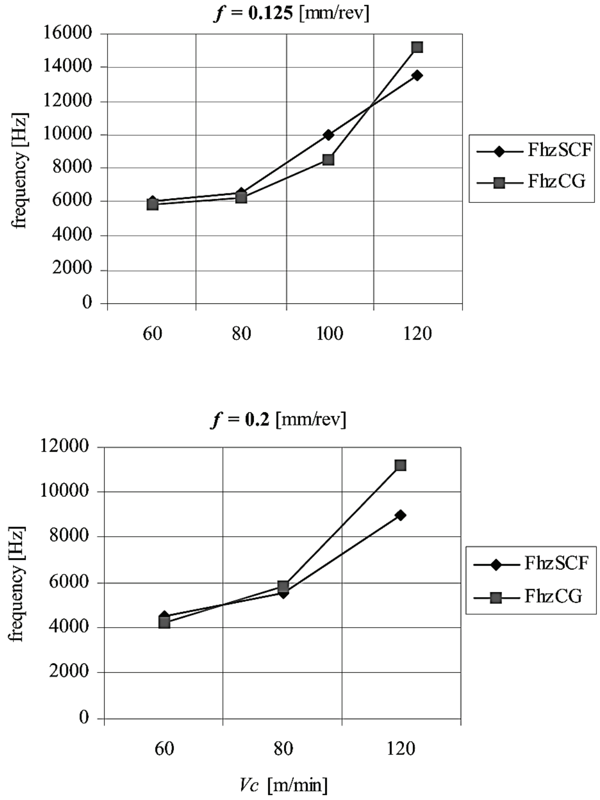


Fig. 7. Frequency accompanying saw-tooth chip formation depending on cutting speed.

- 150 Hz in Z direction, due to the assembly tool – toolholder, in the case using four screws to fix the tool;
- 850 Hz in Y direction, 1300 Hz in X direction and 2400 Hz in Z direction, due by the assembly transversal saddle and Kistler dynamometer; eigen frequency in Z direction had a strong influence on the dynamical behaviour of the machine tool assembly.

The Fig. 8 presents an example of FFT spectrum acquired during hard turning. This is a good example when was very easy to separate the chip segmentation frequency by the machine tool vibrations. Others two significant frequencies were 11950 Hz and 17925 Hz – the first two harmonics.

The Fig. 9 presents one significant example when was difficult to separate the frequency of chip segmentation. The segmentation process had 6 087 Hz and the significant vibration of machine tool had 5 212 Hz highest frequency. Was important to know and avoid the frequency due to the instability signal (Fig. 10).

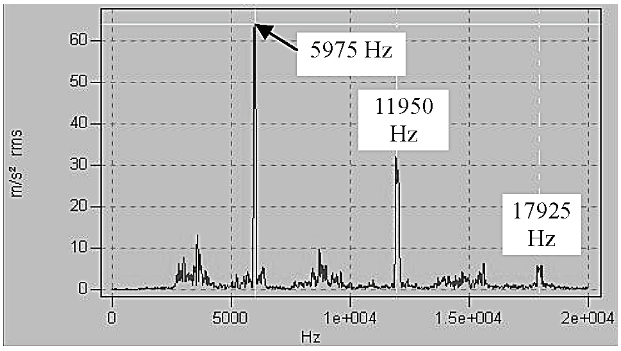


Fig. 8. Test with Vibroport 41; V_c = 80 m/min; f = 0.125 mm/rev.

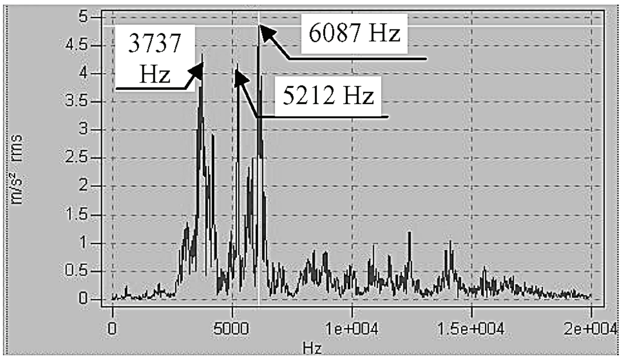


Fig. 9. Acquisition using V_c = 60 m/min and f = 0.05 mm/rev.

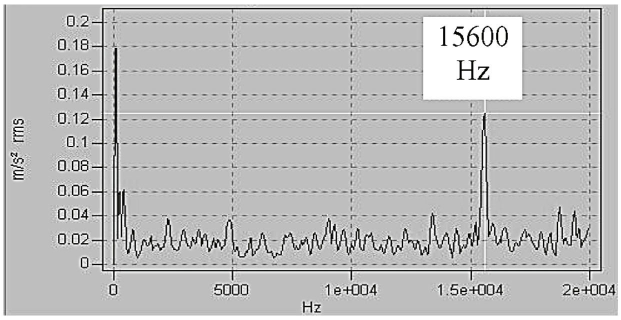


Fig. 10. Frequency limited by the instability signal.

3. CONCLUSIONS

Main objective in this research paper was to find (using experimentation in hard turning cutting process) one correlation between frequency for saw-tooth chip formation (found it on the FFT spectrum) and the chip geometry measured using the microscope. Secondly was important to separate the dynamics of the cutting process by the dynamics of the machine tool.

High Speed Machining and particularly Hard Turning have an evolution concerning on the limits of the cutting parameters and it is necessary to have a good control for these processes. In this context, actual subject is important and it can help to elaborate a proper model for the cutting process, specifically in orthogonal hard turning, taking into account the separation of the frequencies having like cause machine tool and the frequencies having like cause the cutting process.

This work was validated by the experimental results based on the measuring of the cutting forces using a Kistler dynamometer simultaneously with a FFT signal obtained using Vibroport 41 (Schenck) apparatus and a piezoelectric accelerometer AS020.

Next step will be in the direction to correct the numerical model simulating the cutting process, in this particularly conditions, in order to have a prediction of the real cutting conditions and to improving the knowledge by one general approach.

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