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Influence of temperature and microstructure of the workpiece material on energy quanta in cutting process

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ABSTRACT

Purpose: of this paper is on-line identification of the machinability based on the theory of energy quanta power spectra of the measured signal of the cutting force. Identification method is supported by measurements of the instantaneous temperature in the cutting zone for workpieces with the same chemical composition but different microstructure and mechanical properties.

Design/methodology/approach: For measuring the temperature in the cutting zone the direct IFT (Instantly Formed Thermo element) method was used.

Findings: Low carbon steel with a previously cold – deformed microstructure has a better machinability in lower cutting force, smaller energy quanta and lower temperature in the cutting zone as low carbon steel with the normalized microstructure.

Research limitations/implications: The theory of energy quanta as a basis for on-line identification of cutting parameters for optimization and adaptive control of the cutting process in the industry praxis is not yet in use. But it was developed in laboratory research up to the stage when testing in the industry is already possible, where are because of high productivity the demands on work load of machines and the quality of final products much higher.

Originality/value: The method on-line identification on the theory of energy quanta used for that has to be accomplished in real time and has to have the required reliability. The choice of the measured parameter has to be suitable and relevant.

Keywords: Cutting force; Energy quanta power spectra; Microstructure; Temperature in cutting zone

1. Introduction

Modern machining technologies are characterized by computer aided flexible manufacturing which requires accurate definition of the parameters influencing the cutting process, their optimization and on-line control. To ensure a smoothly running manufacturing process, a constant flow of information is essential. Today's highly-sensitive measuring equipment is capable of processing the measured input/output process signal in real time; however certain difficulties in measuring continue to occur due to the complexity of the cutting process. The problem is that all the parameters describing a cutting process cannot be measured directly. On of the most often used and direct ways of defining a cutting process is to measure the cutting forces and their random changes during the process.

Another feature of the cutting process is also in the fact that the process of transforming the unreformed workpiece material into a deformed chip goes on in a dimensionally very limited cutting zone. Chip formation is governed by the mechanism of plastic deformation as a result of mechanical loads on the cutting tool. The input mechanical energy which includes deformation work and friction on contact surfaces is partially transformed into heat energy. This means that during chip formation the workpiece material is in a locally very restricted area exposed to interacting mechanical and thermal loads. It can happen that the temperature in the cutting zone changes to such an extent that the workpiece material undergoes a change in its properties and microstructure. This can lead to a change in the measured parameter which is important for on-line identification of the cutting process. An entirely new concept of on-line identification of the cutting process was introduced by the idea of defining the energy quanta power spectra of the cutting force [1-10].

2. Experimental procedure

2.1. Tested material

The material chosen as the workpiece material was standardized steel with low carbon content ranging from 0.12 to 0.18%C, with the designation C15 in two different microstructural states, i.e. in the normalized state and the cold-deformed state with a 60% deformation. It is clear that, compared with the microstructure of the undeformed steel (C15), the mechanical properties such as tensile strength, yield stress, extension and hardness of the cold-deformed steel (defC15) is substantially changed.

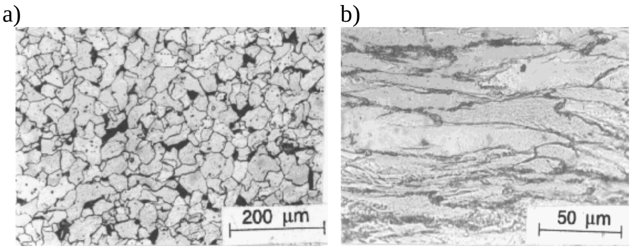

Fig.1. Microstructures of work materials: a) C15 normalized and b) def C15 cold deformed

2.2. Measurement techniques for cutting force and temperature

The process of the transformation of the undeformed workpiece material into the deformed chip goes on in the cutting zone subjected to random changes of the cutting force Fi(t). If the measured cutting force signal in a time domain, Fig. 2, is processed by Fourier transformation (FFT- Fast Fourier Transformation), we obtain a frequency presentation of the random cutting force signal in the form of energy spectra G(f). The entire spectrum power consists of discrete energy particles – energy quanta.

The position of the energy quanta is defined by the frequency interval $\Delta f = (f_{j+1} - f_j)$.

For the estimation of the significance of particular energy quanta, its mean value is used following equation (1) [2]:

$$\boldsymbol{\varepsilon}_i = [\int_{f_j}^{f_{j+1}} G(f)df\,]^{1/2} \tag{1}$$

where: $\boldsymbol{\varepsilon}_i$ is the average energy quanta, $G_{(f)}$ is the energy spectra and $\mathbf{f_j}$ and $\mathbf{f_{j+1}}$ are the frequencies of the two adjacent minimum.

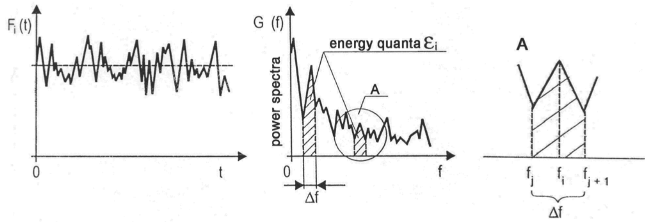

Fig. 2. Identification in cutting [2-3]

For measuring the temperature in the cutting zone in the instant when the cutting edge of the tool through a shear deformation slide transforms the workpiece material into a chip lamella the direct IFT (Instantly Formed Thermo element) method was used. The direct IFT (Instantly Formed Thermo element) method is especially suitable for dimensionally restricted cutting zones, where one member of the thermocouple is simply the thermoelectric potential of the workpiece material [11-15].

In the instant when the chip is being formed in the cutting zone at the same time involves the formation of a welded connection between the workpiece material and the thermo element wire which is inserted into the workpiece. In this way the cutting edge of the tool connects the workpiece material in the cutting zone with the inserted wire and creates a hot junction T_1 of the thermo couple: workpiece-constantan. The other two free ends of the thermo couple have the temperature T_2 and lead via an amplifier into the HP 3667A dynamic analyzer of the signal.

3. Experimental results

The influence of the workpiece material microstructure changes on the changes in the energy quanta power spectra of the cutting force was compared for two cases, i.e.:

- in cutting normalized steel and cold-deformed steel in equal cutting conditions, and
- in cutting the same steel in different cutting conditions.

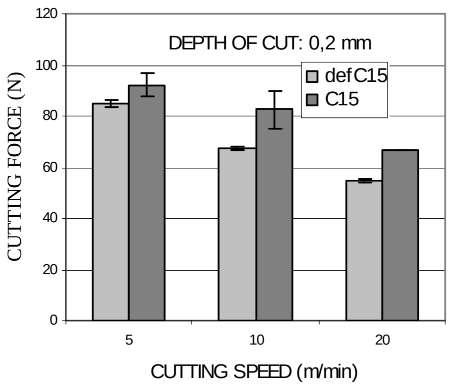

Fig. 3. Magnitude of the cutting force for normalized (C15) and cold deformed (defC15) steels with different cutting speed and depth of cut $a_1 = 0.2$ mm

Figs. 3-4 clarly show that if the depth of cut is increased from a_1= 0.2 mm to a_2= 0.5 mm, then for both microstructure states the mean value of the cutting force is significantly higher as well. By increasing the cutting speed, the cutting force decreases. Here it is interesting to note that in the case of steel (defC15) that has a deformed microstructure due to previous cold deformation and substantially higher strength and hardness, the measured cutting force was always lower than in the case of the undeformed steel microstructure.

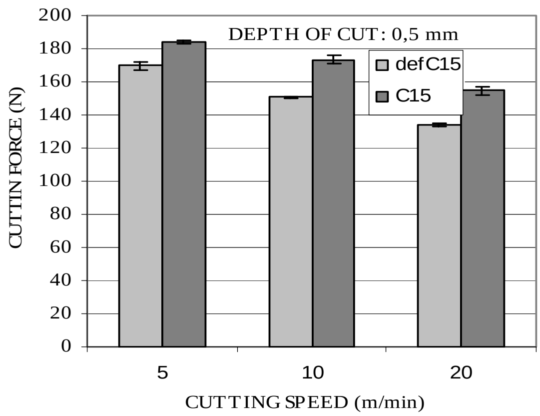

Fig. 4. Magnitude of the cutting force of normalized (C15) and cold deformed (defC15) steels with different cutting speed and depth of cut a_2 = 0.5 mm

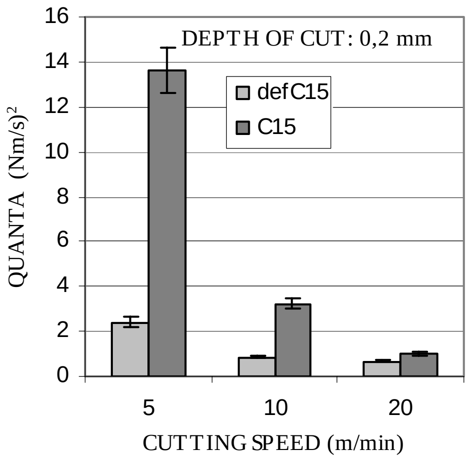

Fig. 5. Relation between energy quanta and cutting speed of normalized (C15) and cold deformed (defC15) steels with depth of cut a_1 = 0.2 mm

Fig. 5 and 6 show the measured and calculated mean values of the energy quanta power spectra $(\bar{\varepsilon}_i)$ of the cutting force as a function of depth of cut and cutting speed for the deformed and undeformed microstructure. From the graphs, we can see that at increased depth of cut from a_1 = 0.2 mm to a_2 = 0.5 mm for both microstructure states the mean values of the energy quanta increase as well.

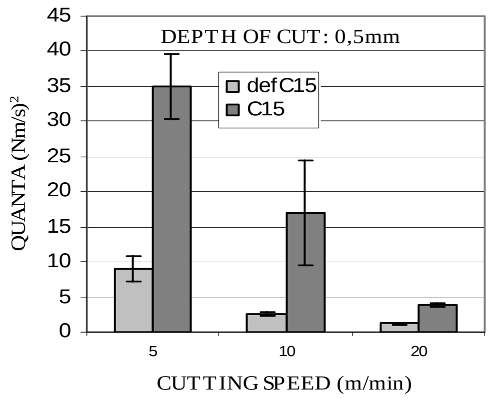

Fig. 6. Relation between energy quanta and cutting speed of normalized (C15) and cold deformed (defC15) steels with depth of cut a_2 = 0.5 mm

In the case of increased cutting speed from v_1 = 5m/min to v_3 = 20 m/min, the energy quanta decrease. Here it is especially important that in equal cutting conditions the energy quanta change significantly if the microstructure state of the workpiece material changes. Irrespective of the cutting conditions, on the steel with the deformed microstructure (defC15), the measured and calculated mean value of the energy quanta were always lower than in the case of undeformed microstructure.

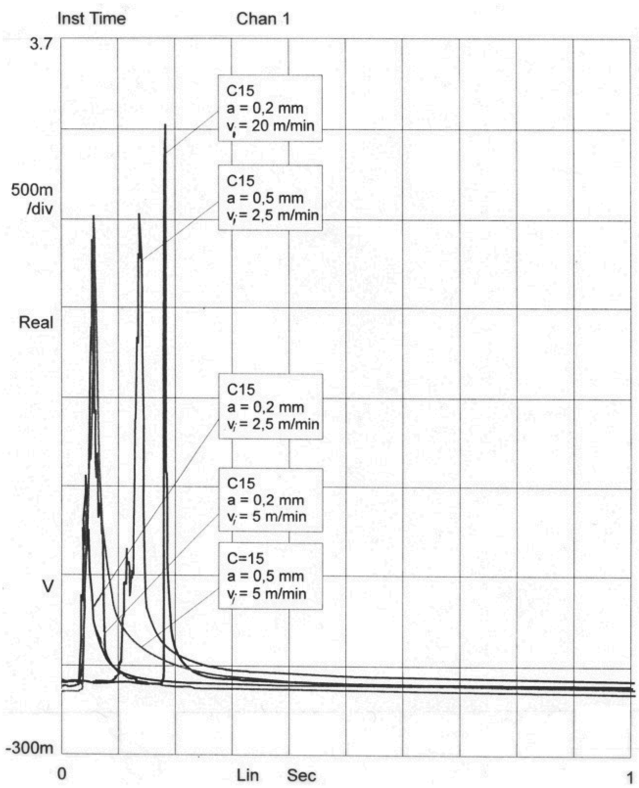

Fig. 7. Signals of thermal potential in cutting normalized C15 and cold deformed steel C15def

The thermal potential signals measured during cutting are shown in Fig. 7. In both microstructure states the height of the thermal potential impulse varies greatly with depth of cut and cutting speed. If the depth of cut is increased from 0.2 to 0.5 mm and the speed from 2.5 to 20 m/min, then the height of the thermal potential impulse increases as well. Here it is especially important to note that the height of the thermal potential impulse changes with the change of the workpiece material microstructure state. Irrespective of the cutting conditions, the height of the thermal potential impulse is in cutting steel C15 with normalized microstructure always considerably higher than in cutting C15def with a previously deformed microstructure.

The value of the thermal potential impulse is in direct connection with the temperature read in calibration of the thermocouple from calibration tables. The temperature in the cutting zone increases for both workpieces if the depth of cut and cutting speed are increasing. It is especially interesting to note that at equal cutting conditions that the temperature in cutting the steel with the deformed microstructure (C15def) is always lower than in the case of the undeformed steel.

4. Conclusions

On the basis of the results of describing the cutting process by on-line identification using the method of energy quanta power spectra of the measured cutting force signal, paying special attention to different microstructure and temperature of the workpiece material in the cutting zone, the following conclusions can be drawn:

- Statistical values of the energy quanta power spectra of the cutting force signal change significantly with the change of microstructure state of the input workpiece material. This confirms that in the case of steel in the cold-deformed state, due to accumulated energy for the formation of chip less deformation work is necessary.
- The use of the IFT method enabled efficient measurements of the temperature in the cutting zone in the very instant when the cutting edge of the tool through a shear slide starts forming the chip lamella.
- In equal cutting conditions the machinability of the steel with a previously cold-deformed microstructure that has a much higher hardness and strength compared to the undeformed microstructure is improved. This is shown by lower measured and calculated mean value of the energy quanta power spectra, as well as lower temperature measured in the very instant of chip formation in the cutting zone.

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