Cutting Process Monitoring by Means of Acoustic Emission Method Part I – New Approach of Acoustic Emission Sensor

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Keywords: cutting process, AE sensor, copolymer foil, piezoelectric transducer

Abstract. Development of modern industrially-consumer society converges to a status, when humans will be gradually supplied by machines. Production without human service will be necessary to supply by machines with artificial receptors, which could be ensure data gathering for processing, analyzing and determination the feedback reactions by suitable decision maker unit. The one from possible sensed values would be acoustic emission signal. Conception of so called intelligent cutting tools presupposed using miniature highly sensitive sensors integrated into the cutting tool body. This part of the contribution is deal with possibility of practical usage of the piezoelectric characteristics of copolymer foils for the acoustic emission sensor as a transducer of a mechanical surface wave into electrical signal.

Introduction

The basic principle of every sophistic sensor a "conventional" and also an "intelligent" (which is fit-out by an unit for data processing and by mathematical equipment giving into relationship measured data with the monitored ones and controlled parameters) is high-quality transducer converting a mechanical quantity (stress wave) into proportional quantity electrical. In the field of AE sensors are nowadays commonly using piezoelectric sensors on base of a piezo-crystal. With development of new materials coming to consideration usage of the piezoelectric features of polymer foils.

Piezoelectric transducer on the base of the copolymer foil

Construction of the copolymer piezoelectric sensor of acoustic emission is based on an accelerometer principle [1] the mathematical relations detailing behaviour of the transducer was described in details in [2]. The schemes of the theoretical and practical realization of the AE transducer are shown in Fig. 1.
Basic equations [2] characterize the behavior of a designed converter. Mechanical stress X applied on piezoelectric element with area S under load mass M generates electric field E from surface:

$$E = g \cdot X = -\left(\omega^2 D_0 M \; g \big/ S\right) \sin \omega t, \qquad (1)$$

where g is piezoelectric voltage coefficient,

- ω - angular frequency of mechanical excitement,
- D_0 - magnitude of vibration,
- M - load mass M,
- S - area of piezoelectric element,

Magnitude output voltage U_0 on piezoelectric element with thickness h is [3]:

$$U_0 = h\,E_{max} = \omega^2 D_0\,M\;g\;h/S\,, \qquad (2)$$

For suppression influence of foil capacitance which lover high measurable frequency range it is used short circuit input for induced charge measurements ($E = 0$):

$$Q = d_{33} \cdot X = -\left(\omega^2 D_0\,M\,d_{33}/S\right)\sin\omega t\,, \qquad (3)$$

where d_{33} is piezoelectric coefficient.

Measurement of current I is frequently performed in technical use:

$$I = \frac{dQ}{dt} = -\left(\omega^3 D_0\,M\;d_{33}/S\right)cos\omega t\,. \qquad (4)$$

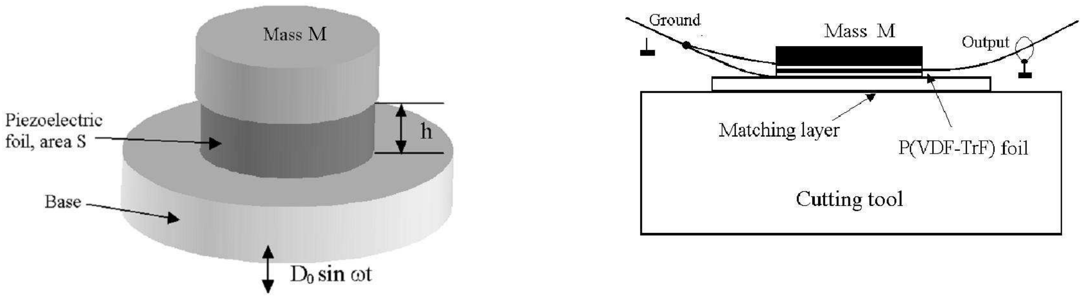

Fig. 1. Scheme of a theoretical and practical realization of the piezoelectric transducer

Results from performed experimental measurements

It have carried out comparison of foil transducers made from the $P(VDF_{75}/TrFE_{25})$ copolymer with piezoceramic AE transducer composed from titanate-zirconate-plumbic $Pb(Zr_xTi_{1-x})O_3$ (PZT). Used foil transducers are characterized by relatively distinct and broad range of registered frequency band up to 500 [kHz], what Fig. 2 illustrates, whereas better response it is possible to see up to frequency 250 [kHz]. According to expectation, it is evident that with the increasing loading mass M decreasing the low frequency of obtained frequency band. This kind of behaviour results from theoretical equation (4). The sensitivity of foil transducers increasing in the range close to 450 [kHz] in the case when were used heavier loading masses. Also is observed a rise of amplitudes in the range around 700 [kHz] especially for the middle loading mass. This case of the narrow frequency range and probably resonant frequency is concerning probably with size correspondence of the wave length of the surface wave and the size of the piezoelectric transducer element. In case of the transducer made from the PZT ceramics was obtained similar spectrum of frequencies. With respect to bigger size of the value of the d_{33} piezoelectric coefficient this ceramics transducer is more sensitive then foil ones. Relatively lower sensitiveness of the $P(VDF_{75}/TrFE_{25})$ copolymer foil it is not significant in this case because on the present this problem can be solved either by the constructional way or by electronic way.

Summary

On the basis of the realized experimental measurements on the deigned transducers are evident, that the measured frequency spectrums excel by the broad frequency band. This feature predestinates

usage of transducers on the basis of the P(VDF_{75}/$TrFE_{25}$) copolymer above all as acoustic emission sensors, which working in wide and high band of frequencies.
The using of polymer foils for the construction of sensor or transducer, which would be a part of the so called intelligent cutting tool appears as promising and perspective way.
The first prototype of the AE sensor realized as the integral part of the homogenous tool body was done and this one is shown on Fig. 3 during a copper alloy machining.

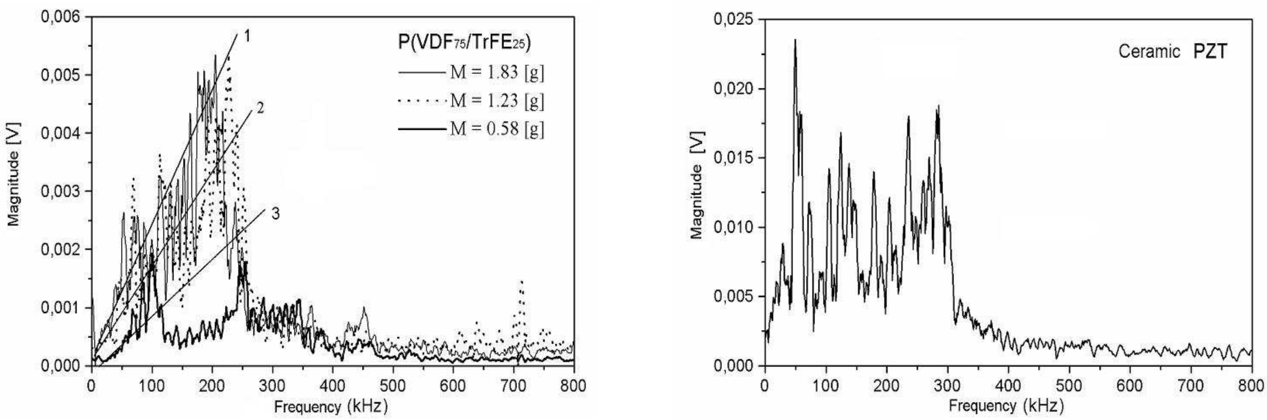

Fig. 2. Comparison of the three foil transducers, loaded by the different mass M, with the piezoceramic transducer

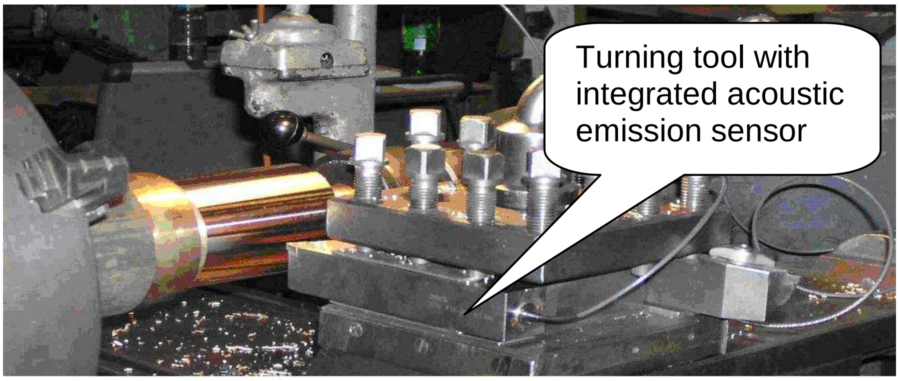

Fig. 3. Photo of turning with instrument with AE sensor integrated into the tool body

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References

[1] KEPLER R. G. and ANDERSON R. A.: *Ferroelectric polymers. Advances in Physics*, 1992, Vol. 41, No. 1, pp. 1-57

[2] ZIZKA, J. – HANA, P. – PRUKNER, V. – HAMPLOVA, L. – BURIANOVA, L.: Design of acoustic emission sensor for intelligent monitoring of machining processes. Part I. – Acoustic emission transducer on the piezoelectric polymer foil base. *In.: Proceedings of the 33. International Conference DEFEKTOSKOPIE 2003.* CNDT 2003, pp. 271-279. ISBN 80-214-2475-3 (in Czech)

[3] http://www.ultrasonic.com

Cutting Process Monitoring by Means of Acoustic Emission Method Part II – Transformation of Acoustic Emission into Audible Sound

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Keywords: cutting process, acoustic emission, audible sound, tool wear, surface roughness

Abstract. The essential requirement for monitoring of cutting conditions during machining is excellent processing of measured out data. Data obtained from machining process obtained by means of acoustic emission sensor, which was discussed in the first part of this article, have high-frequency and continuous character of a white noise. These data are very difficulty processed. There was designed new apparatus for transformation of acoustic emission into audible sound in our workplace. The first step of hereby transformed data is listening by experimentalist ears. There are subjectively possible to recognize differences in audible spectrum, corresponding to different states of the cutting tool. The second step is visualization of this differentness by help of the fast Fourier transform (FFT) in the spectrum graphic chart.

Introduction

The active control of cutting tool state, more exactly cutting tool wear, is very important task of today. Informative signals from the cutting process would be sensed by so called intelligent sensors or at the least by very miniature and smart sensors. Our Departments of Machining and Assembly and Physics used for the design of miniature sensors integrated into the tool-body perspective plastic material – copolymer. Nevertheless the most severe task of the monitoring is to predicate or at least to indicate the state of the machined surface. It is well known that the state of the machined surface heavily depends on the state of cutting tool, more exactly on the cutting tool wear. The relationships between the state of the cutting tool wear and the acoustic emission signals and correlation between both previous quantity and machined surface roughness are sought.

Transformation of acoustic emission into audible sound

It was found and confirmed by lot of experiments that the amplitude distribution of the acoustic emission signal carries information about the cutting tool state [1-3]. This conception brings good results only for cutting tool state monitoring, but this one is not sensitive to chances by machining created surface roughness. Note, that knowledge about the state of the surface made by machining is the most important. Knowledge about cutting edge state is only second-rate. Because the most important, in eyes of producer and consumer too, is the state and quality of the final product, cutting tool is only instrument.
An idea of the tool as a gramophone needle, which copies self-created surface stands on the base listening sounds from cutting. Low frequencies does not bring any information, they are connected with the machine tool noises. The signal of the acoustic emission, because carries high frequency spectrum unloaded by industrial noise, could offer info about interaction between the tool insert and the workpiece. Therefore it was done attempt to try to design by self forces an apparatus for transformation of acoustic emission into audible sound. The designed BBM apparatus is unique and could not be described in details, let be accept as a black box. Nevertheless in Fig 1 is shown a front side of the BBM apparatus.

Fig. 1. View on the BBM - apparatus for transformation of ultrasonic waves into audible sound

Results from the BBM apparatus testing

It were putted forward and done a number of experiments for testing the BBM apparatus directly during turning a specimen from carbon steel with a ferrite-pearlite structure. Machining was realized under following conditions: diameter of specimen D = 70.9 [mm], feed f = 0.1 [mm/revolution], depth of cut a = 0.3 [mm], number of revolutions per minute n = 951.5, cutting speed v = 212 [m/min] (it is by the producer recommended low speed border for sintered carbide inserts).
There are results from the both the insert wear and the surface roughness measurement after specimen machining in the Table 1. The surfaces obtained by turning are shown in Fig. 2. and are characterized by different reflection, which visually characterized different roughness.

Table 1. Conditions of the tool wear and the surface roughness of workpiece

Experiment signification	Cutting tool state	Surface roughness Ra [μm]	Flank wear VB [mm]	Nose wear VC [mm]	Notice
AK_04	Fresh	**0,944**	0,06	0,085	
AK_05	Worn	**1,085**	0,1	**0,298**	**Heavy wear of cutting tool nose!**
AK_07	New	**0,914**	0,00	0,05	

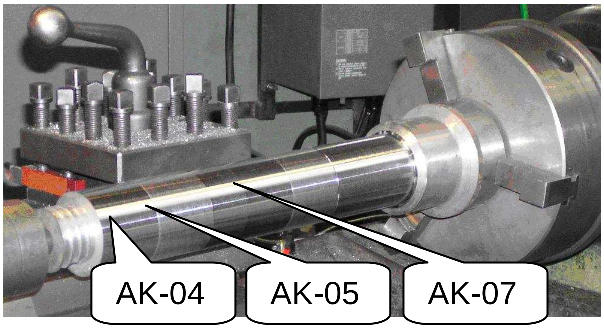

Fig. 2. View on the specimen machined by the tool with the different cutting edge state

The acoustic emission high frequency signal obtained from turning under different tool states was transform down into audible sound, which was recorded for the next study. Firstly was done mere listening during which was found audible differences in signals. This audio finding was confirmed by behaviour of the frequency spectrums made out by Fast Fourier Transformation (FFT), they are in Fig. 3. In the case of new and fresh tool the frequency spectrum is equable in the all range of significant frequencies and their amplitudes reach comparatively high levels. In the case of the worn tool the frequency spectrum of significant frequencies is more limited and amplitudes are lower. Note, that especially significant amplitudes in higher frequency area are decreasing and their occurrence become rare with increase of the tool wear. Just these amplitudes in higher frequencies area are giving sense of certain “briskness” during hearing of the audio record. Whereas an overall decrease and decrement of amplitudes are giving to hearer filing of fusion and with.

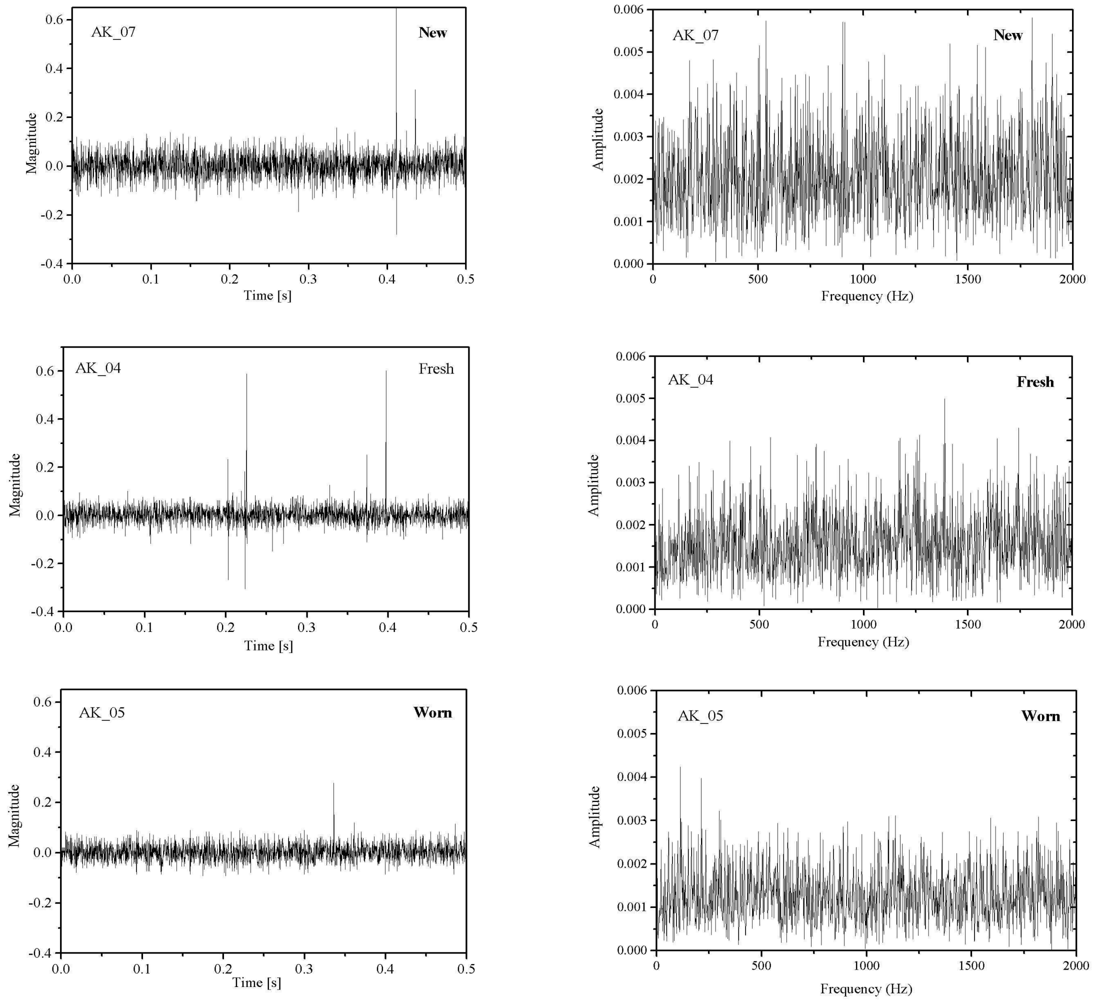

Fig. 3. Plots of rough signals and Fast Fourier Transformations for three states of cutting tool

Summary

On the basis of realized experiments it seems to be efficient to transform high frequency AE signal into the audible sound. The human sensors – ears are able to distinguish more sensitively gentle differences in signal and by this way may show new ideas and direction in signal processing. Further the FFT plots show different character of frequency spectrums and relatively well correlate not only with cutting toll state but also with the machined surface roughness.

Remark: This contribution coheres with solution of the Research project MSM 4674788501, supported by the Ministry of Education of the Czech Republic.

References

[1] ZIZKA, J.: From Skills over the Empirical Knowledge to Intelligent Machining. *In.: Proceedings of the 2nd International Conference on Formal Methods and Intelligent techniques in Control, Decision Making, Multimedia and Robotics.* PJIIT 2000, pp. 238-252. ISBN 83-904403-2-6

[2] POPPEOVA, V.: Cutting tool condition monitoring. *In.: 25th European Conference – EWGAE 2002.* CNDT 2002, pp. II/69-II/76. ISBN 80-214-2174-6

[3] ZIZKA, J.: Neuronal network for tool wear monitoring on the AE signal basis. *In.: 25th European Conference – EWGAE 2002.* CNDT 2002, pp. II/295-II/302. ISBN 80-214-2174-6