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APPLICATION OF NON-PARAMETRIC METHODS FOR MONITORING OF TOOL CHIPPING

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Abstract: *Cutting tool wear is a consequence of a normal wearing process, which is considerably slow, or of a chipping process, which happens instantly and could often lead to tool breakage. The paper presents a methodology for monitoring the tool chipping process. The reliability of monitoring the tool chipping, in particular its initialization, depends on the sensor signal acquisition, processing, and interpretation. Tool chipping is a very fast nonlinear process, and too complex to be described by deterministic models. Not only the cutting process itself, but also the mechanical link (from motors to tool-workpiece interface) is a significant cause of signal deviation and noise. Therefore, knowing the signal power spectra and analyzing them are of great importance for the monitoring of stochastic processes. This paper presents an analysis of the tool chipping process by means of a nonparametric method for the spectral analysis of force, current, and acoustic signals.*
Key words: *tool monitoring, milling, tool chipping, spectral analysis*

1. INTRODUCTION

Chipping of cutting tools usually occurs when a tool is exposed to cyclical stresses, i.e. in intermittent machining processes such as milling. It is a strictly nonlinear process, and sensor signals demonstrate its stochastic behaviour. A signal analysis (Lessard, 2006) in the frequency domain could result in relations connecting fast process changes and signal changes. Since such relations are not known a priori, it is necessary to perform estimation. Methods to be used for the spectra estimation could be parametric and nonparametric (Lijoi et al., 2007). While parametric methods are based on a process model, nonparametric methods are based on the calculation of autocorrelation function, and the calculation of the Fourier transform. Two problems should be pointed out here: the amount of available data is not unlimited, and the data is often corrupted by noise, or contaminated with an interfering signal. Hence, the goal of a spectral estimation based on a finite set of data is to describe the distribution (over frequency) of the power contained in a signal. Among possible nonparametric methods for the estimation of power spectral density of a random signal, a periodogram and the MATLAB Signal Processing Toolbox (MATLAB user's guide) are applied study.

2. PERIODOGRAM

A periodoram is based on the fact that the power spectral density of a stationary random process is a Fourier transform of the autocorrelation function.

$$P_x(e^{j\omega}) = \sum_{k=-\infty}^{\infty} r_x(k) e^{-j\omega k} \tag{1}$$

The autocorrelation function of an ergodic process in the limited interval n=[0, N-1], k=[0, N-1] is calculated as a finite sum, (Marić, 2002) eq. 2:

$$\hat{r}_x(k) = \frac{1}{N} \sum_{n=0}^{N-1-k} x(n+k) x^*(n) \tag{2}$$

With the discrete Fourier transform of autocorrelation function we obtain the estimation of power spectral density, which is a periodogram defined in eq. 3:

$$\hat{P}_{per}(e^{j\omega}) = \sum_{k=-N+1}^{N-1} \hat{r}_x(k) e^{-j\omega k} \tag{3}$$

To express the periodogram directly from the process x(n), we multiply x(n) with the rectangular window $\omega_R(n)$, thus limiting x(n) to interval [0, N-1]. The result is the process x(n) defined in interval [0, N-1] and its autocorrelation function. The application of the Fourier transform results in the final expression for the periodgram, eq. 4, where $X_N(e^{j\omega})$ is the

$$\hat{P}_{per}(e^{j\omega}) = \frac{1}{N} X_N(e^{j\omega}) X_N^*(e^{j\omega}) = \frac{1}{N} \left| X_N(e^{j\omega}) \right|^2 \tag{4}$$

discrete Fourier transform of the process $x_N(n)$.

A periodogram can be used for the spectral estimation of the signal structure. Some of the properties of the periodogram are: omission of the spectrum, resolution, partiality, and consistency, [ ].

The approximation of the power spectrum by a periodogram requires the application of time windows. The basic shape of the window is rectangular, but there is a number of other set and changeable window shapes []. In this study, Welch's method is used to improve the periodogram. The method is based on the division of a set of data into segments (which may overlap). Subsequently, a modified periodogram is calculated for each segment (it is possible to use different windows for each segment, i.e. a modified periodogram). Finally, the mean value of the obtained estimates of the power spectral density is calculated.

3. EXPERIMENT PLANNING

The method of nonparametric estimation of the spectrum power is applied for the estimation of the tool chipping process in the milling of CK 45 steel. The parameters of the machining process were constant. The process of milling was carried out to the point when the tool became worn. In one of the performed experiments, tool chipping was noted and the current, acoustic, and force signals were recorded. In each pass, the tool wear parameter VB was measured. Forces were measured by a Kistler three-component force sensor. An acoustic sensor was put close to the site where the milling process was carried out, and signals of the current were taken directly from the control unit (Mulc et al., 2004), Fig. 1.

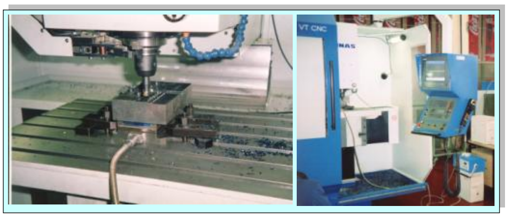


Fig. 1. Equipment used in the experiment

In order to reveal the signal structure, a detailed analysis of the structure of force, current and acoustic signals was carried out. Figure 2 shows the diagrams of forces in which the occurrence of tool edge chipping can be easily noted. The change is abrupt and hard to detect in the time domain.

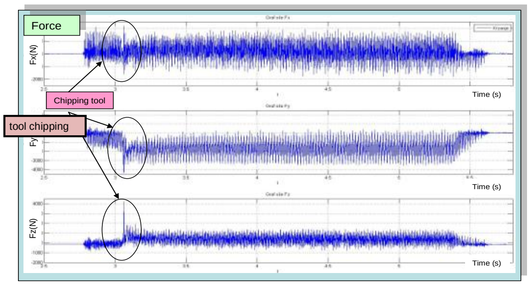


Fig. 2. Force signals with the occurrence of tool chipping

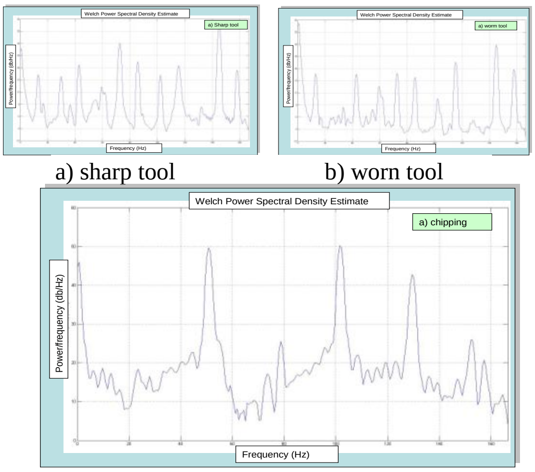
Changes in the signal of the current are similar to those in force signals: they are visible but they do not enable us to draw the right conclusion on the degree of wear.

The power contained in the acoustic signal increases significantly with the degree of wear of the tool and it exhibits periodic behaviour.

PSD Power spectral density		Area below the frequency spectrum curve (*10**5)		
		Sharp tool	Worn tool VB=0.6 mm	Chipping
Force	Fx	1,9800	0,5488	1,4380
	Fy	3,0410	0,9609	8,2550
	Fz	0.5081	0,1570	1,0546
Current	Ix	0,1385	0,1340	4,7485
	Iy	11,6380	21,2650	9,3290
	Is	131,9700	151,5500	105,9000
Acoustic	AE	0,0506	2,1707	0,7911
	AERMS	4,9107	25,0000	23,6650

Tab. 1. Power coefficient in the frequency range

The influence of the signal stochastic behaviour makes a timely determination of the basic state more difficult. A periodogram was used in this study to perform a spectral analysis of the signal. A coefficient that expresses the area below the periodogram curve has been selected. The results of the experiment are given in Tab. 1.



a) sharp tool b) worn tool

c) tool chipping

Fig. 3. Frequency range of the y-axis force signal: a) sharp tool, b) worn tool, c) tool chipping

The analysis of the results shows that the occurrence of chipping could be recorded by means of power coefficients, and thus, the chipping process could be stopped before the tool breakage.

The force signal in the y-axis direction and the current signal in the x-axis direction exhibit the biggest change in the power coefficient of the spectral range. Therefore, a more detailed analysis of the periodogram structure for these two signals has been performed. The frequency range which reacts to changes in the cutting edge wear and to phenomena caused by abrupt changes in chipping or by tool breakage has to be determined.

The diagrams in Fig. 3 show changes in the current spectrum in the x-axis direction. One can see that the frequency structure of the current signal is maintained with small changes in the fall in amplitude when the tool cutting edge is worn, while the frequency structure of the signal is disturbed when tool chipping and tool breakage occur. At the same time, the power contained in the signal is increased in the frequency range with a higher degree of wear, which can be a good indicator for the initialization of chipping.

4. CONCLUSION

A successful design of the monitoring process of machining when tool chipping occurs requires the knowledge of recorded spectra of signals and the spectra of their power. In this study, a nonparametric estimate of the power spectrum in the monitoring process of cutting tool edge chipping is given. A periodogram was used, and the area below the curve was used as a coefficient of comparison. The biggest changes in the coefficient, which can be used for the detection of the initialization of the tool chipping, occurred on the force signal in the y-axis and on the current signal in the x-axis direction. This proves that a periodogram can be a satisfactory estimator in particular situations. The periodogram can be improved by different procedures of window optimization (Thomson, 1998). There is not "the best" method; rather, the selection of "the best" method depends on the signal and on the estimation parameter. In addition, a relatively large set of data is required for the application of nonparametric methods in order to obtain as good results as with parametric methods. Further research conducted by means of spectral analysis estimation would follow a process of a more detailed description of the machining process and an analysis of different conditions of the chipping process.

5. REFERENCES

Lessard, C. S. (2006). *Signal processing of random physiological signals*, Morgan & Claypool, ISBN: 978-1598290387, Texas A&M University

Lijoi, A; Mena, R. & Prünster, I. (2007). A Bayesian nonparametric method for prediction in EST analysis, BMC Bioinformatics 2007, **8:**339

Mulc, T.; Udiljak, T.; Čuš, F. & Milfelner, M. (2004). Monitoring Cutting-Tool Wear Using Signals from the Control System. *Journal of Mechanical Engineering*, 50 (2004), 12; 568-579, ISSN: 0039-2480

Thomson D. J.: Multiple-Window Spectrum Estimates, *Proceedings of Highlights of Statistical Signal and Array Processing, pp.* 344 – 347, *IEEE SP Magazine, June 1998.*, Portland, OR , USA

Signal Processing Toolbox for use with MATLAB, User's Guide, Version 7.10, The MathWorks, Inc., 2010, http://www.mathworks.com/products/signal/

Marić, V. (2002). Nonparametric spectrum estimation (in Croatian),*Available from:* http://spus.zesoi.fer.hr/projekt/2001_2002/maric/estimacija.htm, *Accessed: 2010-05-17*