Monitoring Tool Conditions For Drilling

Ing. Igor Vilcek Ph.D., Ing. Antonie Poskocilova

Abstract: *Requirements for flexible manufacturing have been increasing in the last years. In order to insure effective operation of expansive manufacturing equipment, which has to run automatically and unattended, tool monitoring is important. Therefore, the essential problem to be overcome to achieve the full potential of unmanned machining is the development of effective and reliably sensors systems to monitoring the process and corrective action in case abnormal operation. With increasing wear in the twist drill margin wear causes the increase of the frictional forces between the margin and machining hole wall and leads to tensional vibrations in the cutting tool.*

Key words: *monitoring, drill, coherence function.*

1. Introduction

Requirements for flexible manufacturing have been increasing in the last years. In order to insure effective operation of expansive manufacturing equipment, which has to run automatically and unattended, tool monitoring is important. Therefore, the essential problem to be overcome to achieve the full potential of unmanned machining is the development of effective and reliably sensors systems to monitoring the process and corrective action in case abnormal operation. With increasing wear in the twist drill margin wear causes the increase of the frictional forces between the margin and machining hole wall and leads to tensional vibrations in the cutting tool. This in turn will cause further tool wear and vibrations. If the cyclic process continuous catastrophic failure will occur at a short time. At the moment when these tensional vibrations appear, it is the appropriate time for drill bit change, since from this point on, wear increases rapidly due to the phenomenon of tensional vibrations.

Quante et al, recognized the importance of sensing vibrations in the twist drill for wear monitoring as a mean to overcome the difficulties of the slight sensitivity of the static component of the thrust force to wear. They proposed the use of the distance sensors without contact measuring deflection of the drill in a plane normal to the drill axis. A synchronization device was attached to the spindle emitting 256 pulses per revolution. The signal of the distance sensor was hight pass filtered at 60 Hz to avoid the effect of the spindle speed frequency at 12 Hz. An increase ranging to 5 to 8 times in the signal for a worn drill with respect to the initial value when sharp was reported . The advantage of the system is that since it senses without contact at the tool shank, as was the case with eddy current torque sensors proposed Brinksmeier et al, it can by applied to almost any existing machine tool without structural changes. The sensors are expensive and do not interfere with machining process.

The proposed approaches of cutting force signature analysis to be investigated and compared are the following:
- Static component of cutting forces signal
- Dynamic component of cutting forces signal: Frequency analysis
- Tool failure prediction

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- **Static component of cutting forces signal**

One of the problems observed in the literature on the use of signal features from the static component is the occurrence of false alarms due to the stochastic character of the cutting process and especially due to variations in hardness along the workpiece. Subramian and Cook, 1977 et al. established 5 percent as the maximum allowable variation in workpiece hardness for the static component of torque and thrust force to be used successfully as variables for drill wear sensing. To overcome this limitation and solve the possible false alarm problem, the thrust force-torque ratio is proposed as a method for detected the wear by means of the DC component of the signal.

- **Dynamic component of cutting forces signal: Frequency analysis**

Analysis of the dynamic component of the cutting force signal has been neglected hitherto in most approaches to tool condition monitoring in drilling. This method is expected to be sensitive for detecting tool wear. Frequency domain methods will be applied and several analysis techniques will be explored such as the power spectrum, the power cepstrum, cross spectrum.

- **Tool failure prediction**

It has been observed that violent and sudden oscillations occur in force signal when the tool is reaching the end of its life and is about to fail. This phenomenon is thought to be produced by a certain wear mechanism occurring at the end of tool life, when severe wear is already present, and leading invariably to catastrophic failure. To detect this phenomenon and thus predict tool failure the derivative of the cutting force signal are thought to be sensitive. Other ways of detecting the wear mechanism leading to failure will be explored; by means of frequency domain methods such as cepstral analysis and coherence function among both thrust force and torque signal.

2. Failure prediction by means of the coherence fuction between thrust force and torque signals

The coherence function indicates the extent to which two signals are correlated with each other. In other words, it could be said that the coherence function gives a measure of the validity of the assumption that both signals results from the same particular generating mechanism or source.

The coherence function $\gamma_{xy}(f)$ is defined by:

$$\gamma_{xy}{}^2(f) = \frac{\left|F_{xy}(f)\right|^2}{F_{xx}(f) \cdot F_{yy}(f)}; \quad 0 \le \gamma_{xy}\ (f) \le 1$$

where $F_{xy}(f)$ and $F_{yy}(f)$ are the power spectra of each one signals, also called often autospectra and $F_{xy}(f)$ is

The cross spectrum $F_{yy}(f)$ of $f_x(t)$ and $f_y(t)$ is the forward Fourier transform of the cross correlation function $R_{xy}(\tau)$, which is, in turn, defined by the equation: the cross spectrum.

$$R_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{-T/2} f_x(t) \cdot f_y(t+\tau).dt$$

and gives a measure of the extent to which two signals correlate with each other as a function of the time displacement between them. The cross spectrum can alternatively be obtained from the individual Fourier spectra $F_x(f)$ and $F_{y(f)}$ as follows :

$$F_{xy}(f) = F_x^*(f).F_y(f)$$

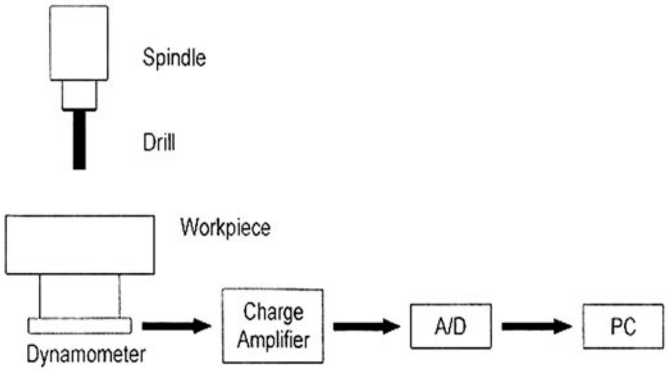
where $F_x{}^*(f)$ is the complex conjugate of $F_x(f)$.

Therefore, three cases are possible. The coherence function can be zero, one or greater than zero and less than the unity. In case $\gamma_{xy}{}^2(f) = 0$ for all frequencies both the signals are completely uncorrelated. In case $\gamma_{xy}{}^2(f) = 1$ for all frequencies both the signals are completely correlated. If $\gamma_{xy}{}^2(f)$ is between zero and one for all frequencies one or more of the following conditions exist: a) even when both signals y(t) and x(t) are caused partially by the same phenomenon or generating source, each is also caused in part by the other phenomena which affect it individually but does not affect the other signal, b) extraneous noise is present in the measurements, c) bias errors are spectral estimation.

3. Experiment set-up
CNC – milling machine
HSS twist drill bits of diameters 2,2 mm Garant Ti AlN

Dept of cut 6 mm
The work material after ISO X4CrNiMo16-5
The experimental workpiece -disk of 100 mm in diameter and 20 mm in thickness .
Thrust force and torque produced by the drilling process were measured by means of a Kistler four-component piezoelectric dynamometer type 9272.
The signals were amplified by charge amplifiers Vibrometer A.G type TA-3/C with two individual channels. The amplified signals were sampled using a data acquisition card on the hard disk of the computer for further analysis.

For data acquisition the software Matlab with Real Time Toolbox was used in order to sample cutting force signals from dynamometer. The sampled data was saved on the hard disk of the computer for further processing and analysis.



4. Result

Coherence function along cutting tool life is shown in fig. 1. It can be noticed that as tool wears and instability begins to appear the value of the coherence function at certain key frequency increases. In this case the sensitive frequency was found about 3500 Hz, but it depends on the natural frequencies of the cutting tool and mainly on the frequencies at which the particular mechanisms of seizure and release and micro welding and tearing out operate, being these physical phenomena essential in the process of excited vibrations in the instability phase prior to catastrophic failure. The physical interpretation of this phenomenon is that when instability appears the distribution of the power spectrum of thrust force and torque signal converges to certain specific frequencies, namely the basic rotational frequency and its harmonics. Then it can be said that the signals loose in some degree their random character to present a certain periodicity. This causes that both signals be coupled, being the final consequence the increase in coherence function. The variation of the coherence function for frequencies about 3500 Hz along tool life is shown in fig. 3.

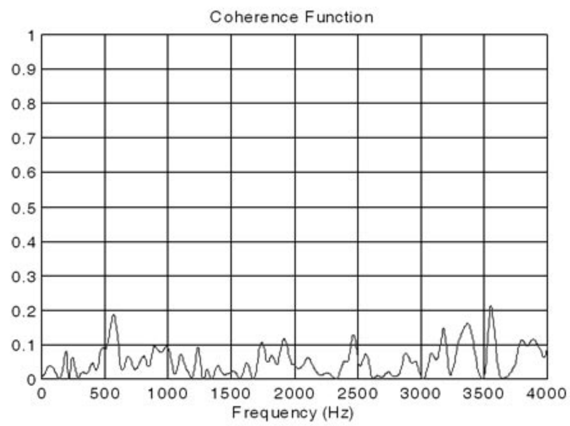


fig. 1:the first hole

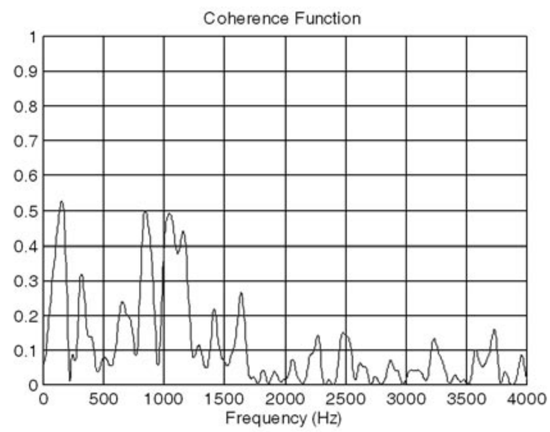


fig.2 :the twenties hole

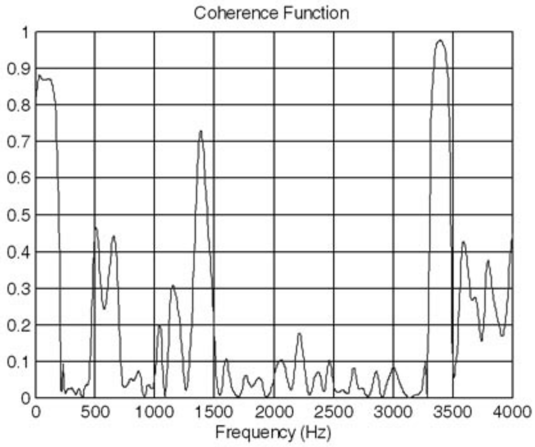


fig.3: the last hole before failure

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