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New Approach in Diagnostics Method for Milling Process using Envelope Analysis

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***Abstract*—**This paper proposes a method to vibration analysis in order to on-line monitoring and predictive maintenance during the milling process. Adapting envelope method to diagnostics and the analysis for milling tool materials is an important contribution to the qualitative and quantitative characterization of milling capacity and a step by modeling the three-dimensional cutting process. An experimental protocol was designed and developed for the acquisition, processing and analyzing three-dimensional signal. The vibration envelope analysis is proposed to detect the cutting capacity of the tool with the optimization application of cutting parameters. The research is focused on Hilbert transform optimization to evaluate the dynamic behavior of the machine/ tool/workpiece.

***Keywords*—**diagnostics, envelope, milling, vibration

I. Introduction

THE whole research is to characterize the three-dimensional manufacturing system, in particular the spindle, the workpiece, to determine the imperfections or the defects of functioning due to the wear, which can modify the precision of the manufacturing. But the vibration appearance is inevitable in the dynamic cutting process particularly in the milling process. The modern CNC milling machines are widely used in modern industry for improved productivity, better precision and variety of products. Since a reduction of the production costs and an increase in the quality of the machined parts are expected, the automated detection of the machining process malfunctions has become of great interest among scientists and industrialists. Failure of cutting tools in milling significantly decreases machining productivity and quality. By the use of a large variety of sensors, monitoring of machining processes represents the prime step for reduction of poor quality and hence a reduction of costs. The dynamic monitoring analysis and replacement of the damaged tool at the right time are very important to assure machining quality and system reliability. Unfortunately, tool breakage detection in milling is difficult due to the complex nature of machining processes and the variable cutting conditions that affect the collected signals. It is desirable to develop a low cost and reliable tool breakage monitoring system for milling process [1], [2]. Demand for better product quality and reliability has led to increased sensor integration in machine systems to enable more comprehensive, accurate, and timely gathering of information on their working status. Various sensors have been developed and employed over the past decades that measure vibration [3] (acceleration), dynamic force [4], acoustic emission [5], or temperature during machine [6] operations for condition monitoring and defect diagnosis. Since vibration signals are directly associated with the structural dynamics of the machine being monitored, vibration measurement has been widely adopted as a popular tool. Effective utilization of the vibration data, however, depends upon the effectiveness and efficiency of the signal processing technique employed to extract characteristic features from the signal and assess how severe the defect in the machine system is and what needs to be done to correct the problem and ensure continuous, safe operation. This indicates that proper signal analysis is a critical prerequisite for clear identification of machine conditions, timely diagnosis of defect severity, and reliable prediction of the remaining service life [7]. This paper proposes a method of vibration analysis in order to on-line monitor the milling process quality. The method used in our research refers to an advanced analysis of vibration to obtain the answer on quality of the milling process and also to identify various defects. In order to reach to objective, an experimental device designed to obtain dynamic information provided by the dynamic system machine-tool/tool/workpiece. The main focus will be on envelope vibration analysis in order to obtain a frequency spectrum in direct connection with the quantity and the uniformity of each tooth own energy and how it is transmitted to the workpiece [8].

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II. Diagnostics Vibration Method

The main aim of the reported research is to investigate the possibility to assess the workpiece surface quality in milling by use of process monitoring. Correlation between the output signals (cutting forces, vibration) and the type of features which appeared on the workpiece surface were investigated by use of time and frequency analysis of the output signals. An envelope method to milling process characterization is taken into account. The vibration signal incurred by the mill cutter is periodic impulsive signal in time domain, is a signal give by accelerator sensor. Based on the signal transfer process, the fault signal transferred into the cutter mill imposes an impulsive motivation on the mechanical system of accelerator sensor [9]. The purpose of this paper is to develop a method for real-time monitoring and analysis of the milling tools during the cutting process. The method used in our research refers to the spectral envelope analysis based on Hilbert transform to identify mechanical defects and obtaining a better response of the milling process and also of the machine. Thus, the objective of the envelope analysis is providing real data on the milling capacity of the tool, tool wear and dynamic functionality of the assembly motor spindle with tool by emphasizing the dynamic behaviour of the bearings (Fig. 1).

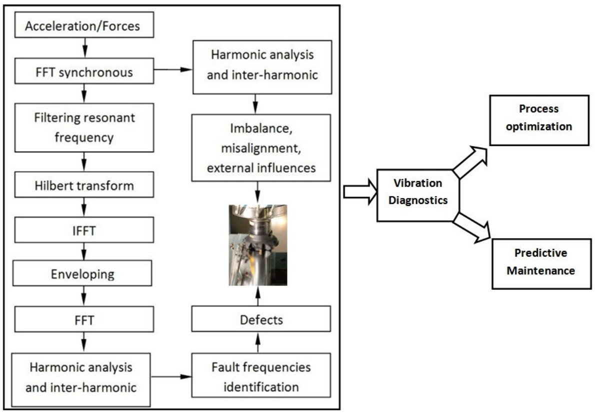

Fig. 1 Diagnostics vibrations method

III. Experimental Procedure

To achieve this research an experimental device is designed to obtain the dynamic information provided by the system machine/tool/workpiece. The experiments were performed on a 3 axis CNC vertical machining centre with 11 kW of power in the spindle motor and a maximum speed rotation of 8,000 rpm. Wait for our goal the recording data of vibrations and cutting forces signals in the same time with rotational speed is absolutely necessary. A Kistler 9257B stationary dynamometer Quartz 3 - Component, a National Instruments NI USB-6216 analogical/digital data acquisition board and Fastview software were used for three axis cutting force measurements, figure 2.

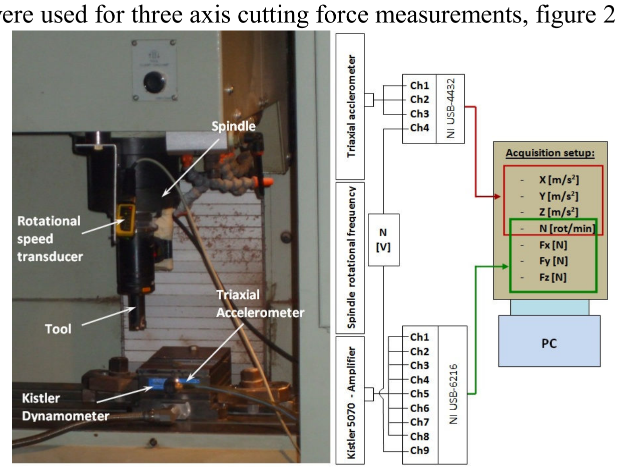

Fig. 2 Setup device for vibration and mechanical actions acquisition

A three-dimensional PCB piezoelectric accelerometer fixed on the workpiece and a B&K unidirectional piezoelectric accelerometer placed on the spindle in radial direction, a National Instruments NI USB-4432 analogical/digital board and Fastview software were used for vibrations measurement. The speed of rotation is achieved through a laser sensor tachometer. The signals were processed with Fastview program, application developed with Digitline Company.

IV. Results and Analysis

To increase the forces and vibrations and to obtain a better response for the monitoring the test was performed on steel materials workpiece E24-2, the tool milling cutter were used here is 490-025C5-08M a Capto C5 system for a BT40 tool holder, with 25 mm diameter and 3 teeth. The study is focused on dynamic behaviour analysis of the mill cutter during the cutting process with 0.5 mm and 1 mm depth of cut, with 157 m/min the cutting speed and 0.1mm/tooth feed rate.

The aim of the envelope method applied to the milling process is achieved by frequency domain processing, consistent in high accuracy synchronous FFT transform, filtering resonance band of workpiece and tool, Hilbert transform [10], [11] followed by Inverse Fast Fourier Transform (IFFT). Next the FFT analyses of the envelope ensure high precision description of the mill cutter to identify the type and amplitude of asymmetry and wear. Each cutter tooth asymmetry is automatically qualified through the harmonic components with a lower frequency than the principal frequency equivalent of teeth number. To detect structural defects that may occur in these machine components, spectral analysis of the signal's envelope has been widely employed [9], [12]. This is based on the consideration that structural impacts induced by a localized defect often excite one or more resonance modes of the structure and generate impulsive vibrations in a repetitive and periodic way. Frequencies related to such resonance modes are often located in higher frequency regions than those caused by machine-borne vibrations, and are characterized by an energy concentration within a relatively narrow band centred at one of the harmonics of the resonance frequency. By utilizing the effect of mechanical amplification provided by structural resonances, defect-induced vibration features can be separated from the background noise and interference for diagnosis purpose [9].

A. Forces

In Figure 3 is presented the waveform signals of forces Fx, Fy and Fz for 1 mm cutting depth for 100 mm length of cut. We see a variable evolution of forces were the amplitude is variable due to vibration system tool/workpiece/chip. The same trend is observed in the case of accelerations were the amplitudes increase of the entry and exit of the tool material. Characterization of dynamic milling process is performed for 1 mm depth of cut because the energy generated by the contact tool/workpiece/chip is very important compared to the depth of cut of 0.5 mm.

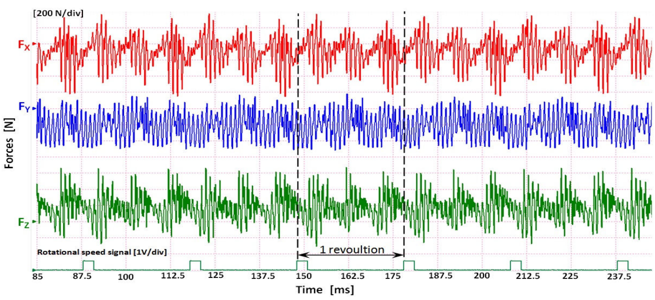

Fig. 3 Waveform signal for forces measurement in X, Y and Z direction for 1 mm depth of cut

B. Vibrations

Figure 4 shows the waveform of the acceleration signal measured on the three directions during milling processing. It can be seen that the amplitudes of the X direction (the feed direction of the tool) and Y (the cutting direction of the tool) are much higher than the Z direction (axial direction of the tool). This is the consequence of the strengths of intense friction on the wall of the hole (energy generated by the contact tool/workpiece/chip) compared with the cutting strength (depth of cut). Vibration analysis continues to apply FFT on the signal measured in time and obtain frequency spectrum due to the milling process. For the envelope method applications requires filtering resonance bands and then use Hilbert transform to find the periodic data impacts of cutter teeth.

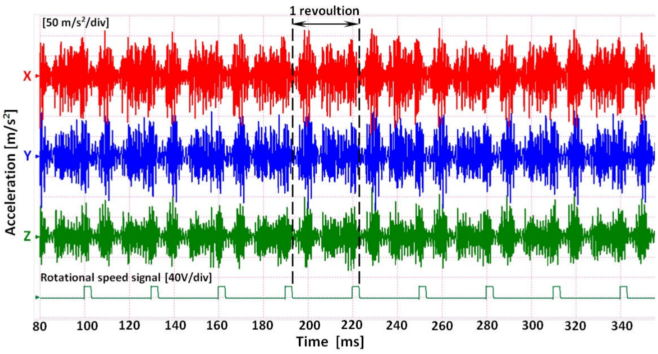

Fig. 4 Waveform signal for acceleration measurement in X, Y and Z direction for 1 mm depth of cut

C. Impact frequency

To know the frequency band to applied the FFT is needed to identify the frequency resonance of the tool and workpiece (Fig. 5). The cutting tool and the workpiece was also analyzed by impact vibrations using a PCB piezoelectric three-dimensional accelerometer and an instrumented hammer with a B&K force transducer in order to identify their transfer function in a broad range of frequencies. Samples were recorded at 25 kHz. Figure 5 show**s** the FFT signal measured in three-directions after the impact hammer impulse [**8**].

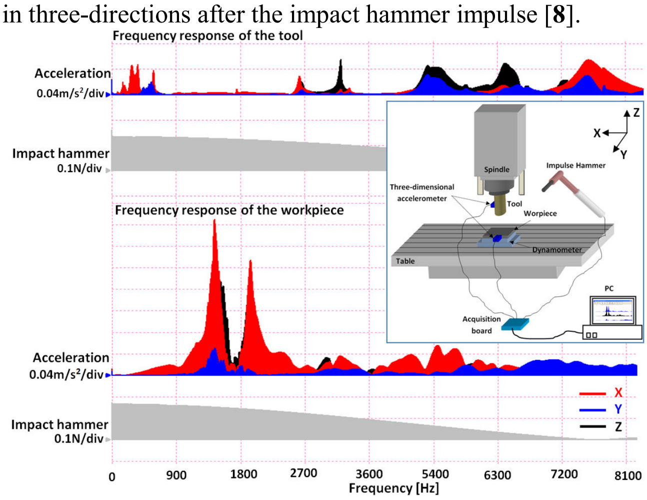

Fig. 5 Frequency responses by impact hammer for the tool and workpiece

D. Envelope analysis

With dynamic information tool and workpiece can apply the enveloping synchronous method to evaluate with high precision the cutting quality of the tool for the vibrations and forces signal.

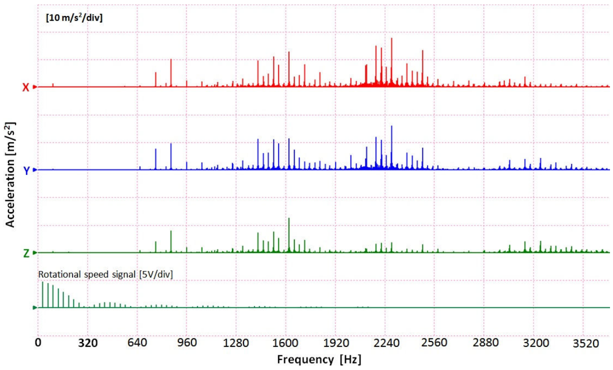

Fig. 6 FFT vibration signal in X, Y and Z direction for 1mm depth of cut

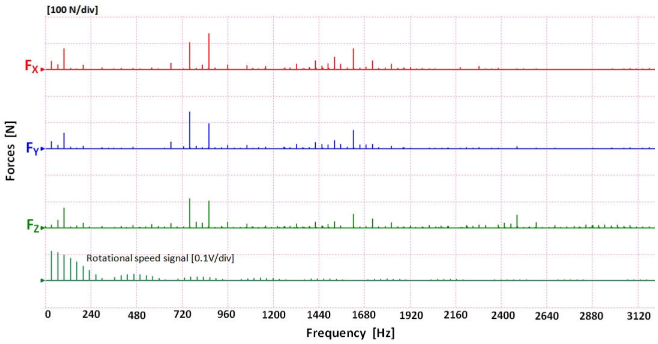

Fig. 7 FFT forces signal in X, Y and Z direction for 1mm depth of cut

The objective here is to accurately track the transfer power by tooth workpiece contact and its harmonic distribution. The The milling process is achieved by frequency domain processing, consistent in high accuracy synchronous FFT transform (Fig. 5 and Fig. 6), filtering resonance band of workpiece and tool, Hilbert transform [6] followed by Inverse Fast Fourier Trans- form (IFFT), Fig. 7 and Fig. 8.

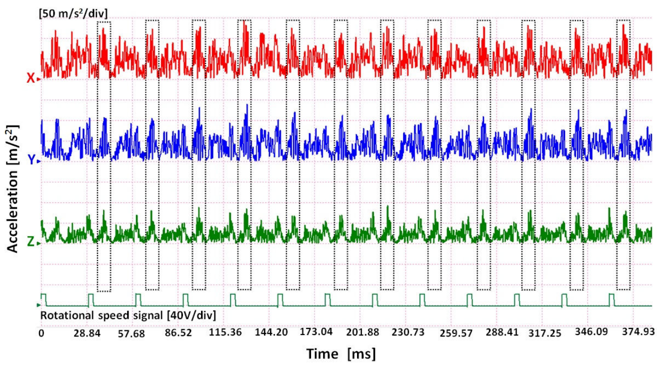

Fig. 8 The envelope vibration signal in X, Y and Z direction

Because we have a tool with three teeth in the cutting analysis was revealed the evolution of each tooth for a complete rotation. It can be seen as one of three teeth working more than the other two, leading to an asymmetry for each revolution of the tool (Fig. 7).

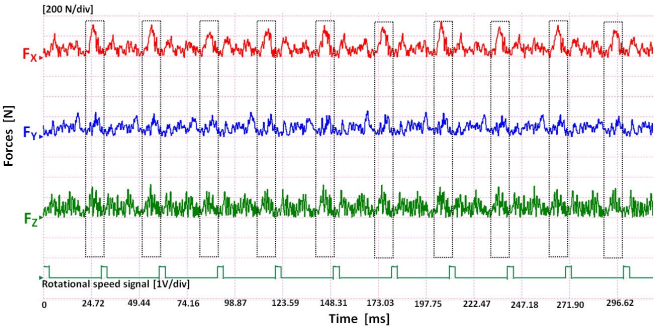

Fig. 9 The envelope forces signal in X, Y and Z direction

In the study of forces we have the same evolution of the cutter teeth, when one tooth removes more material, in comparison with the other two. These shows that the two teeth have reached a first wear stage or an asymmetrical geometry position from the marked tooth (Fig. 7 and Fig. 8). Next the FFT analyses of the envelope ensure high precision description of the mill cutter to identify the type and amplitude of asymmetry and wear (Fig.9). The filter band for the FFT envelope is 900 – 3,600 Hz and takes into account the frequencies during the milling process and the impact frequencies for the tool and workpiece (Fig.5).

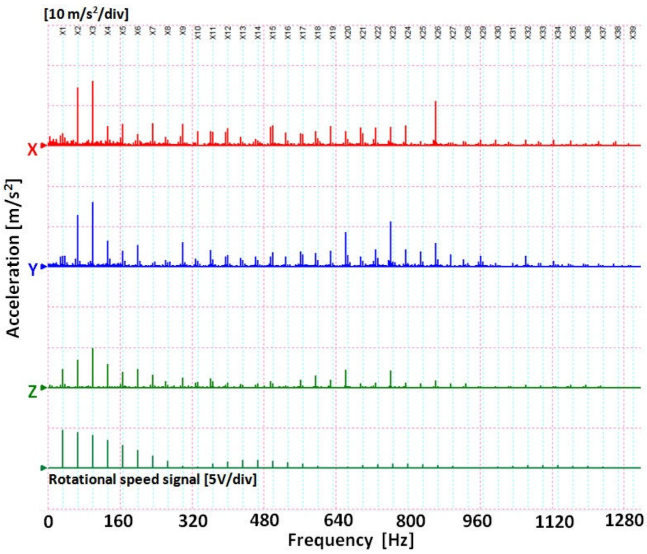

Fig. 10 FFT envelope vibration signal for 1mm depth of cut in X, Y and Z direction

Each cutter tooth asymmetry is automatically qualified through the harmonic components with a lower frequency than the principal frequency equivalent of teeth number. By applying FFT on the signal envelope can be observed harmonic frequency of order 3 corresponding to the activity of the three teeth but very important is the existence of order 2, were the amplitude is very close to the 3nd order harmonic (Fig. 10). This 2nd order harmonic shows the asymmetry existence of the tool cutter. This effect leads to a cause of wear of the teeth cutter or even more to misalignment teeth/tool cutter.

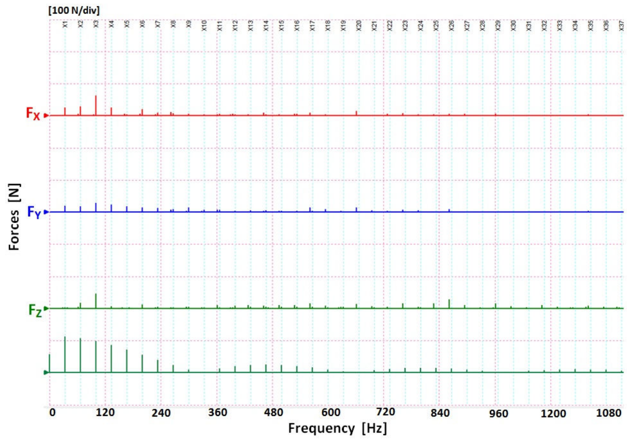

Fig. 11 FFT envelope forces signal for 1mm depth of cut in X, Y and Z direction

The same method is applied in the case of forces, Fig. 11, highlighting the quality of cut and obtained the similarly results with the vibrations.

V. Conclusion

Vibration analysis research of rotating elements allows to develop surveillance techniques by the methods of signal envelope to detect defects on bearings or gears [13], [14]. The transposition of these methods adapted to the field of machining is combined with sampling techniques and signal processing. Applying synchronous FFT and Hilbert transform of the signal were obtained very promising results. This paper proposed a method of a milling diagnostics and dynamic analysis based on envelope analysis method having the purpose to identify and evaluate the dynamic behaviour of the tool during the cutting process. An experimental protocol was designed and developed for the acquisition, processing and analyzing of the three-dimensional vibration and force signal. The vibration signals are the result of a mixture of different sources corresponds to components of machines, making it difficult to identify the state of damage to a particular component. Adapting envelope spectral analysis to characterize the milling tool is an important contribution for the qualitative and quantitative characterization of milling capacity. The vibration envelope analysis is proposed to detect the cutting capacity of the tool necessary for process quality on-line monitoring. In under way this method represents a source for cutting parameters optimization. Is useful both, dynamic characterization of the tool and also for the monitoring process and maintenance. If the vibration acceleration signals are the source of chatter vibration, it would develop the indicators able to detect one of the most problematic phenomena in machining. In the future we are interested in creating a dynamic three-dimensional model [15],

[16] useful in optimizing the milling process which takes into account these results.

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