Quantification of tool wear in micro-milling using Fast Fourier transform of accelerometer data

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***Abstract*— Tool wear in micromachining adversely affects the surface integrity and machining quality of the job in addition to sudden machine breakdowns. In this work, a simple, affordable real-time feedback system is generated which is capable to assess the tool wear in micro milling based on the spindle acceleration employing a motion processing unit. An in-house developed and commercialized machine of CSIR-CMERI named "Multi-Fab" has been used as a test setup on which a motion processing unit was mounted on the spindle. The acceleration data obtained during the micro-milling experiments were collected for three different tools with different pre-existing wear. The acceleration data was further processed using a fast fourier transform. The harmonics obtained from the FFT data clearly reveals distinguishing features to quantify the wear on the tool. The assessed tool wear could be displayed on the machine graphical user interface. The demonstrated method has potential in micromachining centers and shop floor as the feedback system is capable to provide tool condition to the machine operator.**

Keywords—micromilling, tool wear, fast fourier transform, motion processing unit

Introduction

Miniaturization is the new trend in the manufacturing industry, nowadays, its application in the biomedical industry and electronics is quite notable. The need for micro-scale manufacturing of industrial components is getting a spotlight to make the systems to be more compact and to handle them easily. The micro-manufacturing is simply manufacturing the parts to a smaller scale, and hence the products, are produced on the micro-scale [1]. Micro-machining operations are more detailed and complex compared to conventional machining due to size effect mechanics. Micro-machining is a complex procedure as the experiments or the products need to be much detailed and accurate so the micro-tools also need to be sharper to remove the surface of the work piece without any elastic recovery or plowing. The gradual increase of the market for micro-manufacturing cannot be neglected, and this has encouraged many companies to develop their current processes according to these requirements. In an industrial system, regulating the function of a micro-manufacturing system is vital to ensure both productivity and accuracy. There are some limitations that are bottle-necked in the micro-manufacturing system, such as tool wear, surface roughness, and machining stability. But among these limitations, tool wear demands a major attention. Due to the direct interaction with the workpiece, it plays a major limitations in the machining process in terms of surface quality and machining performance. Tool wear is influenced by a number of factors such as the type of tool or the tool morphology or the tool strain. The tool wear creates a drastic change in the stress at the spindle which leads to machining instabilities [2]. It has been estimated that for modern machine tools, the average downtime of a machine tool due to tool wear is 7-20% [2,3], which results in a huge loss in productivity. A constant and reliable monitoring system could prevent these problems.

Though it has been considered that tool wear is imaginary and is difficult to predict. There are many mechanistic models to predict the tool life based on the Taylor tool life equation [4]. These models are deterministic and they do not consider the bottom uncertainty in tool wear [5]. Several reports on tool wear estimation in micro milling operations [6] are available in the literature, and recently a correlation between tool wear and cutting force in diamond turning in single-crystal silicon machining is reported [7]. Malekian et al. [8] proposed the use of various sensors, such as force and AE sensors and accelerometers, in micro-milling operations on various locations of the machine. The method overcomes the crisis associated with the low-frequency bandwidth of the sensors and the complexity of micro-milling processes by fusing the sensor signals collected through the neuro-fuzzy algorithm. The proposed method efficiently estimates the tool wear; however, it demands a long training time for the neuro-fuzzy algorithm to work accurately. [9] Tansel et al proposed Neural network-based usage estimation method that uses force variation and segmental averaging based encoding techniques. In this method, the training took 151 s to train the neural network and was computationally intensive [10]. However, the process for estimation of tool wear specifically for micro-milling operations is not yet available. Keeping the above in mind, in this work, an approach to wear estimation of micro milling wear by using a simple, affordable real-time feedback system is demonstrated. An in-house developed and commercialized micro machining centre by CSIR-CMERI named as "Muti-Fab" was been used as a test setup. A motion processing unit (MPU) MPU-6050 was mounted on the spindle to measure the acceleration of the spindle for every possible tool condition. With the help of instructions stored in memory, MPU delivers the acceleration data along X, Y and Z axes. The acceleration data were collected from a particular set of experiments and the tool wear measured from microscope images for that particular set of experiments were obtained The collected accelerometer data further processed through (Fast Fourier Transform) FFT to evaluate the effects on wear on acceleration harmonics using signal processing.

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Experimental Procedure

Materials

An in-house developed "Multi Fab" micro machining centre was used as. This setup was a commercialized micro-machining setup which has an indigenously developed CNC machine controller. A motion processing unit MPU6050 was mounted externally on the spindle to collect the accelerometer data for our experiment. FR-4 copper clad laminated sheets were used as the work piece material. The experiments were conducted using three preexisting wear lengths in milling bit of 500 µm diameter. The tool used is shown in Fig 1 and the tool specifications are as in TABLE 1.

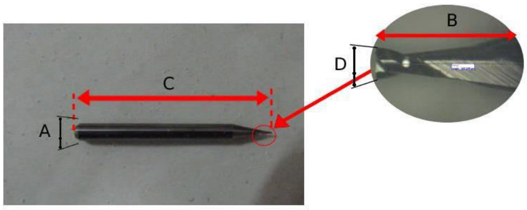


Fig.1. The tool used in our experiments

TABLE I. TOOL SPECIFICATIONS

Parameters	Values
Shank Length(C)	36mm
Shank Diameter(A)	3.15mm
Tool Tip length(B)	1mm
Tool Tip Diameter(D)	0.5mm
No. of flutes	2
Corner	Square
End cutting Edge	Square end with the center cut
Shank	Straight shank
Nack	Taper nack

The experimental set up is shown in Fig 2.

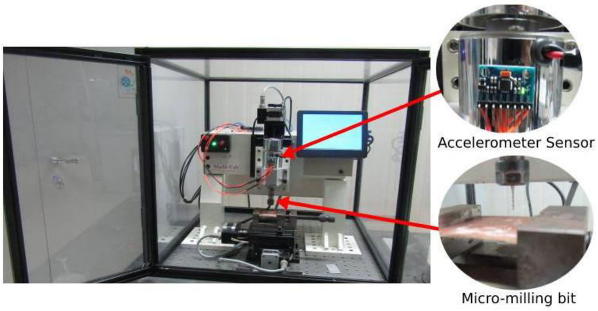


Fig.2. The experimental set up used

Methodology

Micro milling experiments were conducted using the stated tool with preexisting flank wear generated using µ-EDM. Wear lengths of 0.1, 0.2 and 0.3 mm respectively were generated on the tool. A new tool acted as the control sample. Micro milling operations were conducted with feed velocity 100 µm/min, depth of cut 400 µm and spindle velocity 7000 RPM. Acceleartion data collected from accelerometer sensor rigidly mounted on the spindle along Y axis was subjected to fast fourier transform (FFT). The magnitude of harmonics at 0.8 Hz frequency used as a quantification indicator for tool wear. The flow chart of the method is shown in Fig 3.

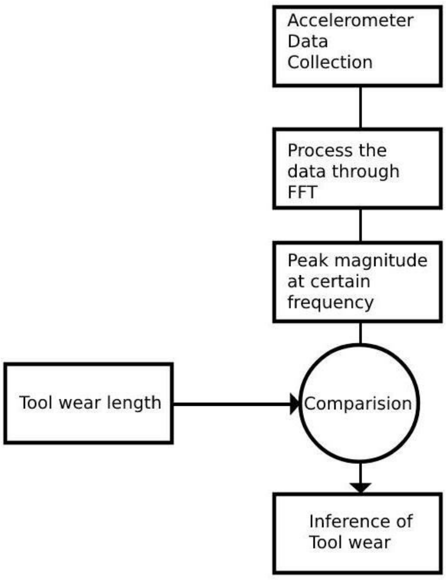
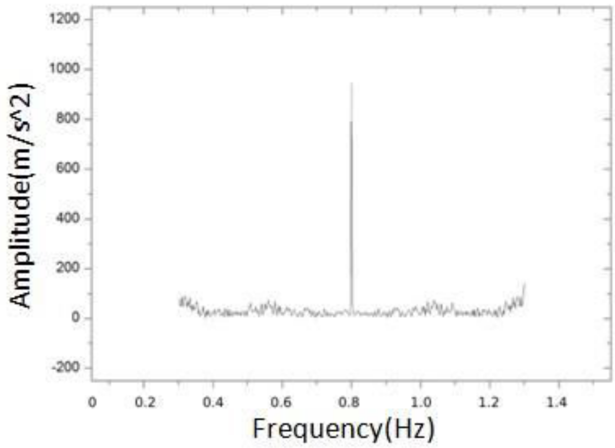


Fig.3. Flowchart for tool wear quantification

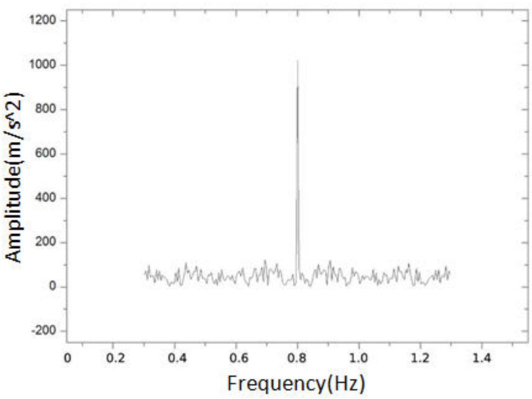
Result and Discussion

Result

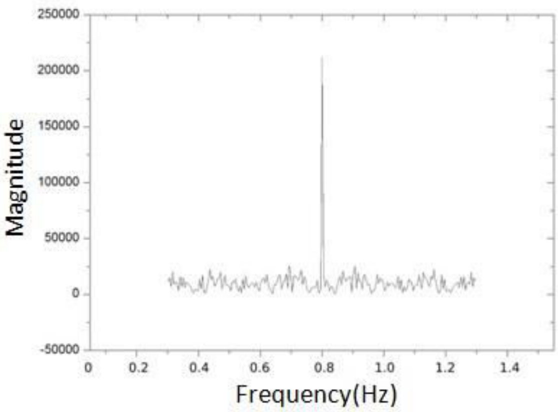
The results obtained using FFT of the accelerometer data for new tool and tool with wear lengths 0.1, 0.2 and 0.3 mm respectively are shown in Fig 4.



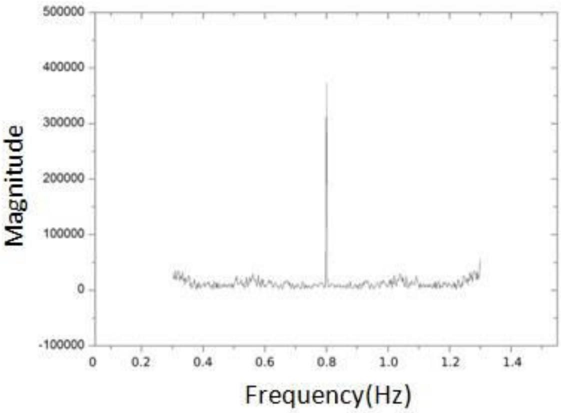
(a)



(b)



(c)



(d)

Fig. 4. Fourier spectrum of acceleration for (a) new tool (b) tool with wear length 0.1 mm (c) tool with wear length 0.2 mm (d) tool with wear length 0.3 mm

As found in the Fig 4, with increase in tool wear, the magnitude at frequency 0.8 Hz increases. This fact is a quantifying factor for tool wear measurement.

Conclusion

Micro-manufacturing is the ongoing trend and fast emerging industry. The continuous maintenance is important for every micro-scale industrial system. As we discussed earlier, tool wear is among one of the major limitations of a micro-manufacturing system. In this research, it has been found that the variation in tool wear results in a variation of the magnitude of a certain harmonic frequency in the FFT plot obtained from accelerometer data of spindle. This frequency is specific for an individual CNC machine. As most CNC controllers are dexterous enough to conduct FFT operations owing to its lower computational complexity as compared to other methods, the proposed method has potential to quantify tool wear in shop floor applications.

Acknowledgment

The research was funded by CSIR- Major Lab Projects MLP 210712, Titled: Field Deployment of Indigenous four axis controller for multi process micro machine and MLP222912, Titled: Process technology for large area fabrication of micro nano patterned hydrophobic surfaces.

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