Jurnal
Teknologi

Full Paper

MONITORING THE FLANK WEAR USING PIEZOELECTRIC OF ROTATING TOOL OF MAIN CUTTING FORCE IN END MILLING

N.H.M. Tahir[a], R. Muhammad[b], J. A. Ghani[a], M. Z. Nuawi[a,c], C. H. C. Haron[a]

[a]Department of Mechanical and Materials Engineering, Faculty of Engineering and Build Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor
[b]Department of Mechanical Engineering, Faculty of Engineering, Syiah Kuala University (UNSYIAH), 23111 Darussalam, Banda Aceh, Indonesia
[c]Centre for Automotive Research, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia

Article history
Received
18 December 2015
Received in revised form
10 March 2016
Accepted
25 April 2016

Corresponding author:
jaharahaghani@ukm.edu.my

Abstract

Tool condition monitoring (TCM) system in the industry are mainly used to detect tool wear, breakage and chatter on the tool. Tool wear of AISI P20 under various cutting conditions have been investigated in end milling using cutting force signals due flank wear progression. This study is focused on the piezoelectric sensor system which is integrated on rotating cutting tool for tool wear monitoring system in milling process. The signal captured by piezoelectric sensors are analyzed in time and frequency domain. The signal amplitudes of main cutting force, F_c in time domain are increased, while the peak of the amplitude in frequency domain is decreased as the flank wear and cutting speed increases. By using 3D I-kaz™ statistical analysis method, the relationship and correlation between I-kaz coefficients, Z^∞ values with resultant flank wear width data, *VB* are proved. The results show that 3D I-kaz™ statistical analysis method can be effectively used to monitor tool wear progression using a wireless telemetry system during milling operations.

Keywords: Rotating dynamometer; piezoelectric; cutting force signals; milling process

Abstrak

Sistem pemantauan keadaan mata alat (TCM) di dalam industri kebiasaannya digunakan untuk mengesan haus mata alat, kerosakan dan gelatuk pada alat. Haus mata alat bagi AISI P20 keadaan pemotongan yang berbeza telah diuji pada proses akhir pengisaran menggunakan isyarat daya pemotongan akibat perkembangan haus rusuk. Kajian ini adalah tertumpu kepada sistem penderia piezoelektrik yang disepadukan pada mata alat yang berputar untuk memantau keadaan mata alat ketika proses pengisaran. Isyarat ditangkap oleh penderia piezoelektrik dianalisis dalam domain masa dan domain frekuensi. Isyarat amplitud pada daya pemotongan utama, F_c dalam domain masa meningkat, manakala puncak amplitud dalam domain frekuensi pula menurun apabila haus rusuk dan halaju pemotongan meningkat. Dengan menggunakan kaedah analisis statistik I-Kaz 3D, hubungan dan kolerasi antara pekali I-Kaz, nilai Z^∞ dengan paduan lebar haus rusuk, *VB* dapat dibuktikan. Keputusan menunjukkan ba hawa kaedah analisis statistik I-Kaz 3D boleh digunakan dengan berkesan untuk memantau perkembangan haus pada mata alat menggunakan sistem telemetri tanpa wayar semasa operasi pengisaran.

Katakunci: Dynamometer berputar; piezoelektrik; isyarat daya pemotongan; proses pengisaran

1.0 INTRODUCTION

Machining process is commonly considered as secondary process in manufacturing operations and widely used in the manufacturing industry in the world. According to [1], more than 70% of machining processes are used in the manufacturing industry in the world. Machining process, also known as metal cutting mechanics involves the interaction between the surface of the tool and work piece [2]. In the machining process, there are several phenomena occur during the cutting process and can be measured such as cutting force, vibration, acoustic emission, torque, surface finish, sound etc. The wear and breakage of cutting tools will affect the accuracy of dimension and the surface quality of machined work pieces, even breakdown the machine. Tool wear dramatically affects the texture of the machined surface. The texture of machined surfaces has been shown to be promising for tool wear monitoring [3]. In the industry, tool condition monitoring (TCM) system is mainly used to detect tool wear, breakage and chatter on the tool. This system is required to obtain high quality production and to avoid machine downtime due to equipment failure due to severe tool failure. The main goal of developing TCM systems is to increase productivity and hence competitiveness by maximizing tool life, minimising down time, reducing scrappage and preventing damage.

Generally, TCM can be classified into two major categories; direct methods and indirect methods. A direct method of wear prediction such as visual inspection based on surface textures are used for wear estimation are not cost effective and reliable as tool wear monitoring system. [4] have investigated a simple and inexpensive vision system to monitor flank wear during milling using the implementation of texture-based segmentation. Indirect methods involve a data acquisition signal during machining process and then the signal will analyse to estimate the tool wear.

During the cutting process, cutting mechanism is very important to understand because it is the main purpose why to measure cutting forces. [5] claimed that cutting forces are actually related to tool wear in machining operations and can be used in predictive tool. In metal cutting process, analysis and prediction of cutting forces generated during metal cutting process is a crucial requirement and come from the cutting forces. Cutting force is strongly associated with mechanical cutting process, and the application of dynamometers to measure them during machining is important to investigate, monitor and optimize the manufacturing process.

Typically, to capture the cutting force signals, most of the previous researchers developed the dynamometer system with the appropriate sensors. Dynamometer is the one of the popular method to measure the cutting force which is based on strain gauge and piezoelectric sensors. Recently, rotating dynamometer which is inserted into the spindle becomes a popular topic to view. The sensor is mounted around the beam in transducer in dynamometer or directly attached to the tool spindle to measure the cutting forces. The interesting about the rotating dynamometer is the cutting forces can be measured on the rotating tool independently with the size of work piece compared to stationary dynamometer [6].

Piezoelectric sensors have been proved to be a versatile tool in the measurement of machining processes and it widely used for research and development in the industries. Piezoelectric sensors use the piezoelectric effect to measure pressure, acceleration, pressure, force and vibration. There are several of researchers are applied the rotating dynamometer based on the piezoelectric sensors to capture the cutting force signals [7-11]. With the raws signal generated from sensors, the flank wear width, *VB* can be determined. Flank wear is measured every time during the machining operation until it reaches the desired criterion. The produced cutting force signals are then analysed in time and frequency domain.

In this study, the tool wear monitoring system is using wireless telemetry system based on inductive coupling as data transmitter [12]. The force sensing element or transducer used in this system is based on piezoelectric film, polyvinylidene fluoride (PVDF) of a cross beam type, and it is capable of measuring three components of cutting force which is main cutting force (F_c), thrust force (F_t) and perpendicular cutting force (F_{cN}) in milling and also in drilling process.

The advantage of this rotating dynamometer is its flexibility as it can be assembled with a variety of cutting tools size and geometries and it also could be used to study the tool condition monitoring systems, optimizations, machine tool design and also dynamics of the cutting process. This paper will describe the application of a low-cost sensor, piezoelectric for monitoring online cutting tool wear by measuring main cutting force, *Fc* and analysing its signal using a new statistical-based method called Integrated Kurtosis-based Algorithm for Z-filter Technique (I-Kaz™), pioneered by [13].

2.0 EXPERIMENT SETUP

In this study, The experiment is divided into 2 sections which are machining operation that consist of piezoelectric sensor signal capture and flank wear measurement on the cutting tool. The experiment is carried out by end milling of AISI P20 tool steel using a single insert coated tungsten carbide (Kennametal ADKT103504PDERLC) with coated grade KC725M.

These experiments were performed using a DMC 635 V eco CNC milling machine under dry cutting condition, see Fig. 1. To generate the raws data of cutting force, three piezoelectric sensors were embedded into the rotating tool of milling process based on inductive coupling for detection the tool. In metal cutting, cutting speed (V_c), feed rate (*f*) and depth of cut (D_c) are the main controlling parameters that influences the machining operation. There is a close relation between the cutting tool workpiece interaction and cutting forces and surface quality [14,15]. The cutting condition used in the experiment is shown in Table 1.

Table 1 Cutting condition for experiment test

Set	Cutting speed, V_c (m/min)	Feed rate, f_z (mm/rev)	Depth of cut, Dc (mm)
1	200	0.2	0.6
2	375	0.2	0.6

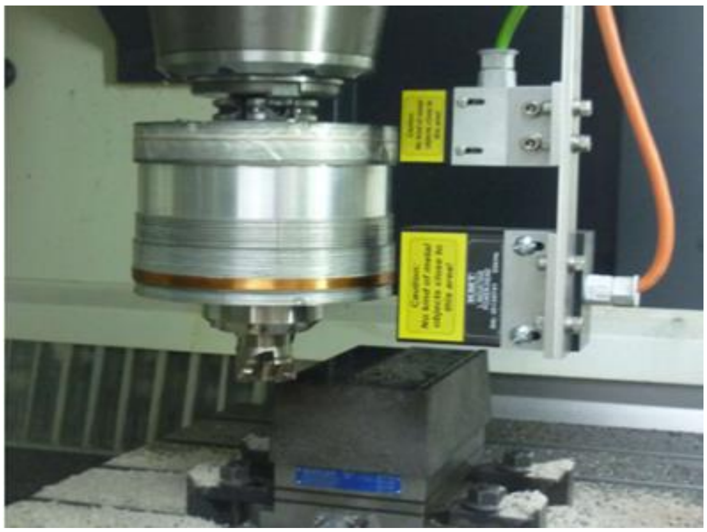


Figure 1 Rotating dynamometer with inductive wireless system

The cutting force signals were collected at sampling rate of 5 kHz using a wireless telemetry system, and then analyzed by the computer using signal analysis based on the I-kaz 3D methods as described by [12].

The advantage of I-kaz^{TM} method is the characteristic of signals can be obtained in time and frequency domain and its sensitive to amplitude and frequency changes [12]. Raw signal decomposition makes the frequency range is divided into three fractions are decomposed into three different axes raw signal of axis x, y and z. Time domain signal is split into three frequency range of as showed in Table 2.

Table 2 Time domain in three frequency ranges

Axis	Frequency Range	Value
x	low frequency range (LF)	0 - 0.25 $f_{max.}$
y	high frequency range (HF)	0.25 f_{max} -0.5f_{max}
z	very high frequency range (VF)	0.5 f_{max}

During the milling operation, the insert was periodically removed from the tool holder, and the flank wear was measured using a microscope. The flank wear data were recorded since the first cutting pass until the flank wear reached 0.3 mm according to the standard recommended value in defining a tool life end-point criterion based on ISO 3685-1993.

3.0 RESULTS AND DISCUSSION

3.1 Piezoelectric Signal and Tool Wear

The raw signals of the cutting forces in three axis are analysed in time domain as showed in Figure 2. The time domain is plot in different of cutting forces which is main cutting force (F_c), thrust force (F_t), and perpendicular cutting force (F_{cN}). This figure shows that the main cutting force, F_c is higher than the thrust force, F_t and the perpendicular cutting force, F_{cN} during the milling process.

Figure 3 presented the main cutting force, F_c in time domain for both sets at the sepecific flank wear. Based on the Figure 3, the amplitude of the main cutting force signals continues to increase as increasing of the flank wear, *VB* until the criterion of *VB* = 0.3 mm is met, reaches 0.06 V for both sets. It clearly seen that the tool flank wear caused main cutting force, F_c increased. Besides that, the increasing of cutting speed, *Vc* also makes the signal amplitude increased.

Figure 4 below showed the amplitude of the main cutting force signals in frequency domain for both sets. Based on the Figure 4a, at the spindle speed of 1592 rpm (*Vc* = 200 m/min), it generated 27 Hz for the tool passing frequency, and when the spindle speed is increased to 2986 rpm (*Vc* = 375 m/min), the tool passing frequency also increased to 49.8 Hz, see Figure 4b. That's mean, these frequencies are still lower than the low natural frequency of 470.5 Hz.

3.2 I-Kaz™ Statistical Analysis

The results of the I-kaz 3D graphical representation plot with I-kaz coefficient, Z^{∞} based analysis of the main cutting force, F_C signals during the first cutting until flank wear for both sets are shown in Figure 5. Prior to plotting in three axis representations, the signals are decomposed into three frequency ranges. From this figure, the results visually show that the space of scattering in both main cutting force is increased due

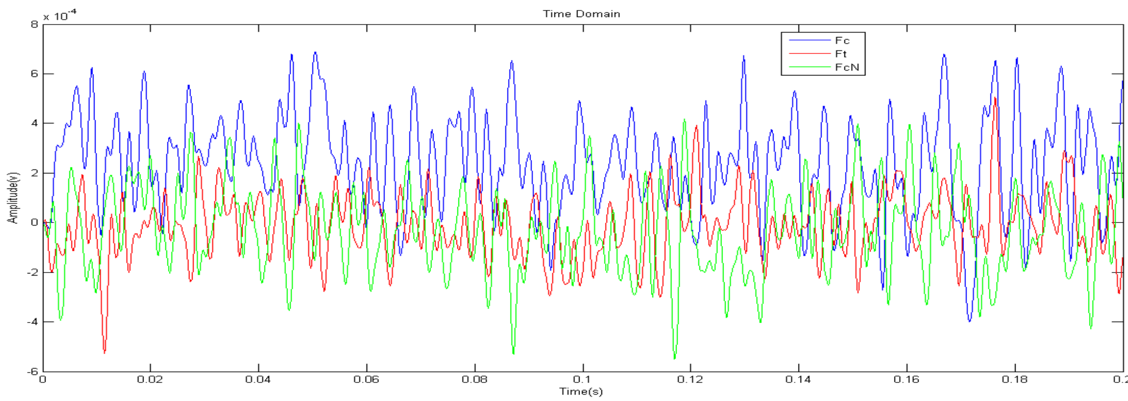
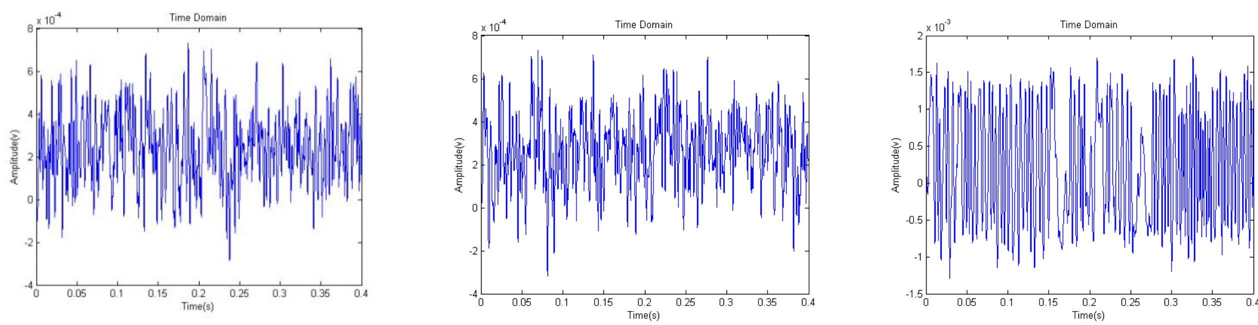


Figure 2 Plots of cutting force signals in time domain at *Vc* = 375 m/min

Set 1 : *Vc* = 200 m/min

***VB* = 0 mm** ***VB* = 0.089 mm** ***VB* = 0.302 mm**



Set 2 : *Vc* = 375 m/min

***VB* = 0 mm** ***VB* = 0.100 mm** ***VB* = 0.325 mm**

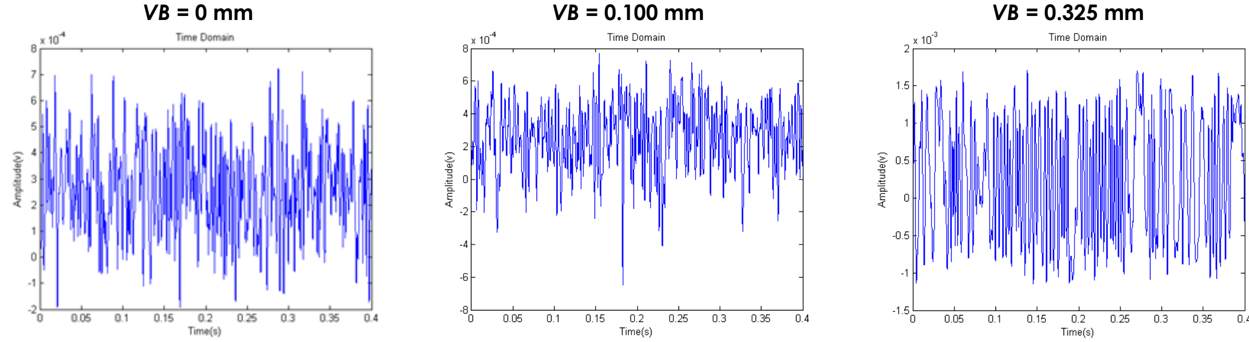
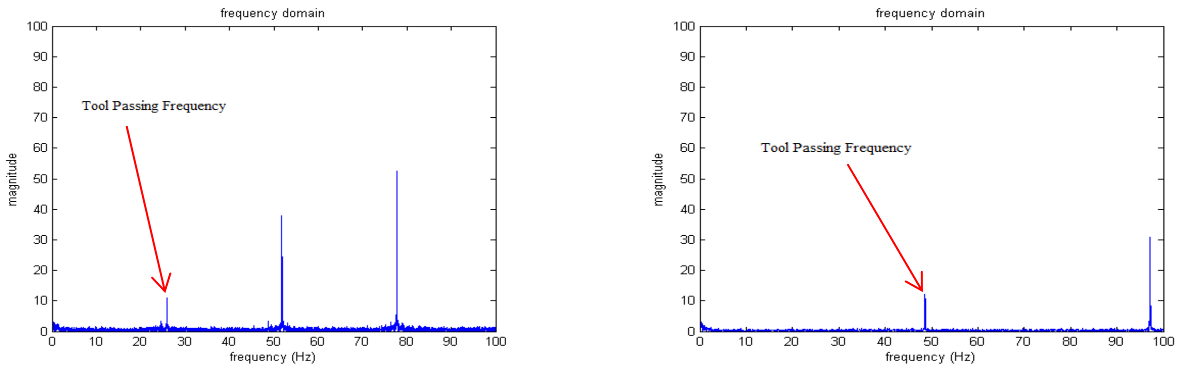


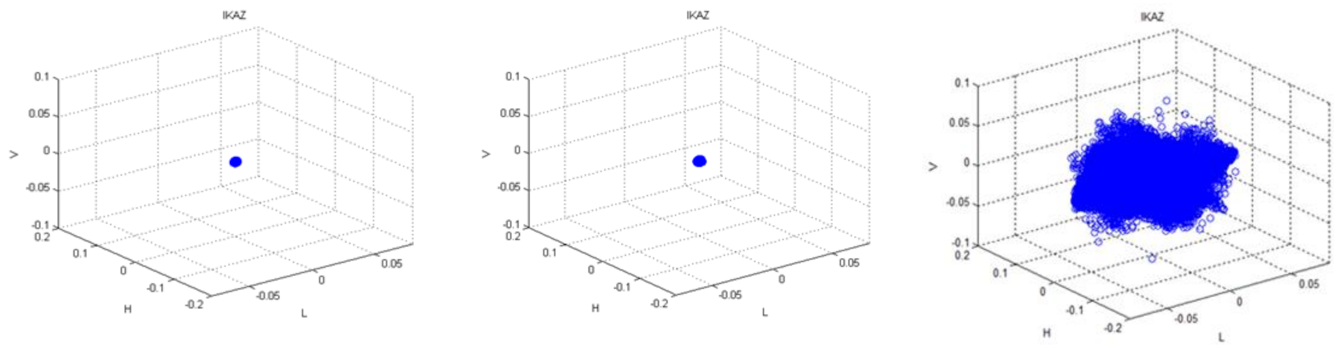
Figure 3 Frequency domain for *Fc* at specific flank wear, *VB* for both sets



(a) *Vc* = 200 m/min *(b)* *Vc* = 375 m/min

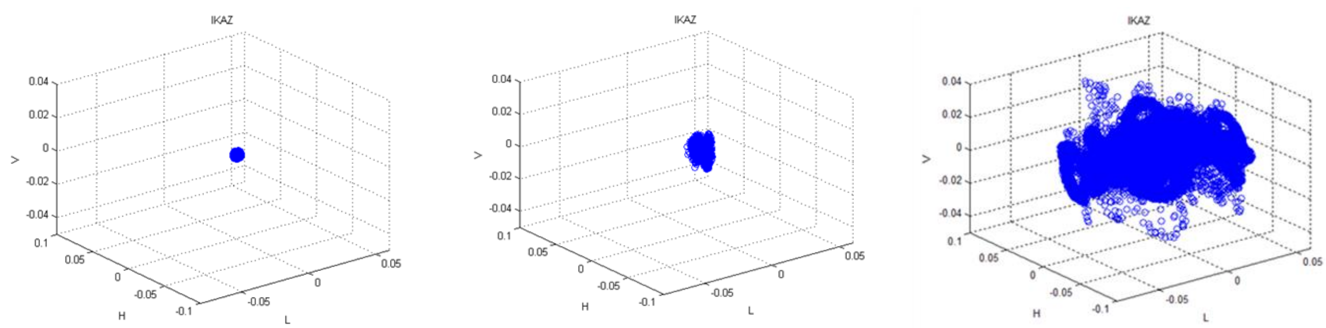
Figure 4 Tool passing frequency throughout the machining process

Set 1 : Vc = 200 m/min



VB = 0 mm *VB* = 0.089 mm *VB* = 0.302 mm

Set 2 : ***Vc*** **= 375 m/min**



VB = 0 mm *VB* = 0.100 mm *VB* = 0.325 mm

Figure 5 3D Ghrapical representation of I-kaz tool wear for both sets

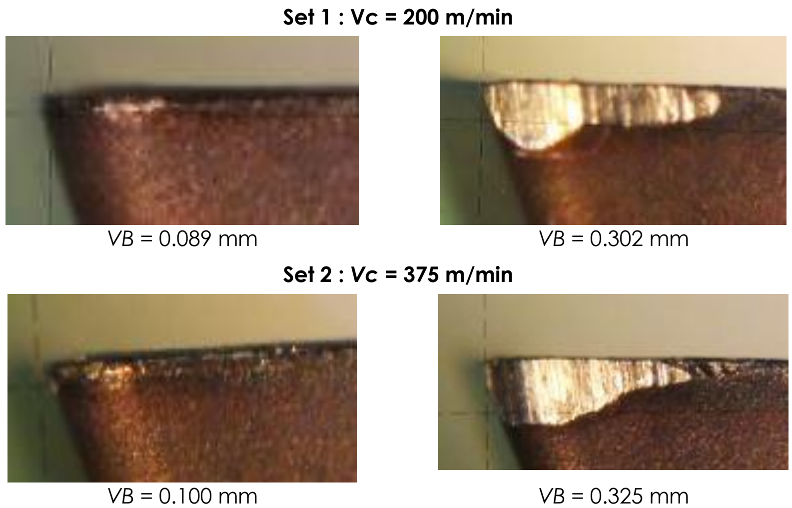


Figure 6 Flank wear's width by microscope for both sets.

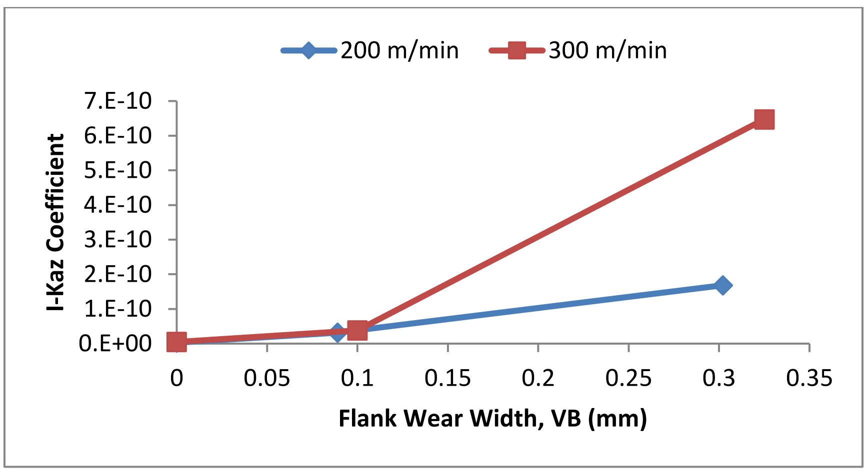


Figure 7 Graph of I-kaz coefficient, Z^{∞} against flank wear width, *VB* (mm)

to progression of flank wear during the milling process. I-kaz graphic is growing until the wear criterion is met. The value of I-kaz coefficient, Z^{∞} becomes higher due to the increasing of flank wear width. Based on Fig. 5, at the beginning of wear formation, graphic design shape is small and after the tool wears out, the graphic design shape is changed and become bigger for the both sets. The flank wear width for Set 1 and Set 2 can be clearly seen in Figure 6.

The values of I-kaz coefficient, Z^{∞} and flank wear width for each set of experiments are also presented in Table 3. Based on these table, the values of Z^{∞} are increased as increasing the tool wear until wear criterion is met. The increasing of the value of Z^{∞} is due to the widening of the contact of surface area between the work piece and the tool. Therefore, the enhancement amplitude of the main cutting force, F_c resulting the larger value of Z^{∞}. This is the same with what has been stated by previous studies in which a larger Z^{∞} value indicates higher degree of data scattering and vice versa [12].

The comparison graph for data correlation between each set is presented in Fig. 7. Based on Fig. 7, it is clearly seen that the value of Z^{∞} become higher and the graph curves upward for both sets due to the increasing of Z^{∞} values until wear criterion is met. From this figure, note that the graph curve for Set 2 is higher than curve for Set 1. The value of Z^{∞} is rising due to the increasing of V_c.

Table 3 Value of I-Kaz Coefficient with flank wear progression

Set 1 : 200 m/min		Set 2 : 375 m/min	
VB, mm	Z^{∞}	VB, mm	Z^{∞}
0	2.5701E-12	0	4.6863E-12
0.089	3.1748E-11	0.100	3.7825E-11
0.302	1.6826E-10	0.325	6.4733E-10

4.0 CONCLUSION

According to above results demonstrate that the wireless system using embedded sensors into the rotating tool in the milling process, it can excellently detect the change of tool wear. From the present study, the followings can be concluded:

(a) The three piezoelectric sensors were embedded into the rotating tool of milling process based on inductive coupling for detection the tool wear using cutting force signals has been presented and the implementations of analysis in time and frequency domain also are given.
(b) The signal amplitudes of main cutting force, *Fc* are increased as increasing of the flank wear.
(c) As increasing the cutting speed, *Vc*, the peak of the amplitude in time domain is become higher.
(d) The value of Z^∞ is rising due to the increasing of V_C.
(e) As shown in main cutting force signals, the proposed method gives satisfactory results for monitoring tool wear change during the milling process.

Acknowledgement

The authors would like to thank the Government of Malaysia and Universiti Kebangsaan Malaysia for their financial support under Grants 03-01-02-SF0843.

References

[1] Yu, G. 2002. Tool Wear Monitoring in Turning Operations using Ultrasonic Wave and Artificial Neural Network, Milwaukee: The University of Wisconsin.
[2] Singh, N. 1996. *System Approach to Computer- Integrated Design and Manufacturing*. New York : John Willey & sons.
[3] Kassim AA, Mannan MA, Mian Z. 2007. Texture analysis methods for tool condition monitoring. *Image Vision Computer*. 25:1080–1090.
[4] Choudhury, S.K. and S. Rath. 2000. In-Process Tool Wear Estimation In Milling Using Cutting Force Model. *Journal Material Process Technology*. 99: 113-119.
[5] Oraby S. E., Hayhurst D. R. 1990. High-Capacity Compact Three-Component Cutting Force Dynamometer. *International Journal of Machine Tools and Manufacture*. 30 (4): 549–559.
[6] Kaya, B., Oysu, C., Ertunc, H. M. 2011. Force-Torque Based On-Line Tool Wear Estimation System For CNC Milling Of Inconel 718 Using Neural Networks. *Advances in Engineering Software*. 42 (3): 76-84.
[7] Kistler, 2012. Brochure of Cutting Force Measurement. Retrieved from: http://www.kistler.com/CH_en-ch/ 46_ Product Finder_ Manufacturing 3000.-.17/ Product- Finder-Manufacturing.html. Also Retrieved from: <http:// www. kistler. com/ CH_en-ch/46_ Product Finder_ Manufacturing/ 3000.-.17/ Product- Finder-Manufacturing.html>. (Assessed on: July 9, 2014).
[8] Kuljanic E., M. Sortino. 2005. Tool Wear Estimation Method – TWEM Using Cutting Forces In Face Milling. *International Journal of Machine Tools and Manufacture*. 45: 23–34.
[9] Karabay, S. 2007. Design Criteria For Electro-Mechanical Transducers And Arrangement For Measurement Of Strains Due To Metal Cutting Forces Acting On Dynamometers. *Materials and Design*. 28 (2): 496-506.
[10] Totis, G., G. Wirtz, M. Sortino, D. Veselovac, E. Kuljanic and F. Klocke. 2010. Development of a dynamometer for measuring individual cutting edge forces in face milling. *Mechanical System Signal Process*. 24: 1844-1857.
[11] R. Muhammad, J. A. Ghani, M. Z. Nuawi, C. H. C. Hassan. 2014. A Wireless System and Embedded Sensors on Spindle Rotating Tool for Condition Monitoring. *Advanced Science Letters*. 20 (10): 1829-1832.
[12] M. Z. Nuawi, M. J. M. Nor, N. Jamaludin, S. Abdullah, F. Lamin, C. K. E. Nizwan. 2008. Development Of Integrated Kurtosis-Based Algorithm For Z-Filter Technique. *Journal of Applied Sciences*. 8(8): 1541-1547.
[13] Liang S. Y, Perry S. A. 1994. In-Process Compensation For Milling Cutter Run Out Via Chip Load Manipulation. *Journal Engineering Industry*. 116(2):153-160
[14] Bayoumi A. E, Yu ¨cesan G, Kendall L. A. 1994. An analytic mechanistic cutting force model for milling operations: a theory and methodology. *Journal Engineering Industry*. 116(3): 324-330