The 7th Jordanian International Mechanical Engineering Conference (JIMEC'7)
27 - 29 September 2010, Amman – Jordan

The EFFECT OF TOOL FIXTURING QUALITY ON THE DESIGN OF CONDITION MONITORING SYSTEMS FOR DETECTING TOOL CONDITIONS

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ABSTRACT

Condition monitoring systems of machining processes are essential technology for improving productivity and automation. Tool wear monitoring of cutting tools is one of the important applications in this area. In this paper, the effect of collet fixturing quality on the design of condition monitoring systems to detect tool wear is discussed. The paper investigates the difference in the system's behaviour and the changes in the condition monitoring system when the cutting tool is not rigidly fastened to the collet. A group of sensors, namely acoustic emission, force, strain, vibration and sound, are used to design the condition monitoring system. Automated Sensor and Signal Processing Selection (ASPS) approach [Al-Habaibeh et al., 2010] is implemented to address the effect of the tool holding device (collet) on the monitoring system and the most sensitive sensors and signal processing method to detect tool wear. The results prove that the change in the fixturing quality could have significant effect on the design of the condition monitoring system and the behaviour of the system.

Keywords: Collet, Condition Monitoring, Milling, Machining Operation, Signal Processing, Sensor Fusion, Tool Wear.

1. INTRODUCTION

Fixtures are essential devices in production systems as they are required in most of the automated manufacturing, inspection, and assembly operations. Fixtures locate precisely a work piece or a cutting tool in a given orientation and position to allow the machining or measuring process to be accurately performed. There are many standard work holding devices such as jaw chucks, machine holder, drill chucks, collets, which are commonly used in workshops for general applications such as machining and measuring, [Robert et al., 2008].
Collets have proven to be as useful on today's CNC equipment, with state-of-the-art control systems, as they were on the early engine lathes and multi-spindle automatic machines from the 1920s, [McIlwraith, 2005]. Surprisingly, after more than 90 years of successful applications, there is still no better workholding element for the new high-tech, high speed spindles than the workholding collet, [Daniel, 2004]. Collet remains a proven solution for most metal –working applications, and 90% of manufacturing processes use collet chucks while the other 10% use hydraulic chucks, [Destefani, 2002].

For any manufacturer, accuracy of machined components is one of the most critical aspects. Faults in machining can be defined as any deviation in the position of the cutting edge from the theoretically required value to produce a workpiece of a specified tolerance [Ramesh et al., 2000; Govender, 2001].

In end milling, there are four major sources of faults which are geometric and kinematics' errors, temperature induced errors, fixturing errors and cutting forces errors.

The correct installation of the tool in the collet is important to prevent unnecessary strain on the collet and to ensure a proper fit. Engineers should use a collet designed to fit the tool shank diameter and the tool's flute should not extend into the collet; doing so can score the inside of the surface, as well as force debris into the collet, putting the entire assembly off-balance and potentially damaging the spindle. These errors will effect the stability of machining operation, [CNC Catalog, 2009]. Consequently, the cutting tool and the collet which holds it are a major source of error, in addition to tool deflection, tool wear, vibration and burr formation, [Uriarte et al., 2007].

Although advances in fixture design have greatly improved fixture accuracy and repeatability, fixture faults (or errors) are still a major cause of quality variation. Where most of the literature on fixture analysis has emphasised the positions of fixture elements on the workpiece rather than the contact condition between the mating surfaces. In addition, significant research has been conducted in the area of machine fault detection/diagnosis, but relatively little has been done on fixture fault detection and monitoring, [Yeh and liou, 2000]. The effect of fixturing systems on the design of condition monitoring systems is an area which is not significantly covered in literature.

Studies performed in industry have shown that the main causes of downtime are end of tool life (wear) and tool breakage and they account for 40 to 45% of downtime in milling, turning and drilling operations, [Rakowski, 2003]. Hence Condition monitoring is normally used as a strategy to detect or prevent such faults using Tool Condition Monitoring (TCM)), [Brophy et al., 2002]. Manufacturers who used TCM systems have documented savings of 3 to 5% of manufacturing costs [Montronix, 2003]. A condition monitoring system consists of sensors, signal processing stages, and decision making systems to interpret the sensory information and to decide on the essential corrective action. The success of any TCM system is dependent on two factors, the quality of the data acquired by the sensors and the diagnosis algorithm used to analyse the sensory information and determine tool state, [Al-Habaibeh et al., 2002].

The effect of fixturing type on machining signals has been investigated by [Al-Habaibeh et al., 2003]. The results showed that the fixturing type could have some influence on the captured machining sensory signals.

This paper investigates the effect of collet fixturing quality on the design of condition monitoring system. The hypothesis is that the collet fixturing quality will change the dynamics of the system introducing different variables and parameters which makes the design of tool condition monitoring a complex task.

2. TOOL FIXTURING SYSTEMS

Conventional split-steel collets provide maximum gripping efficiency only at actual bored or nominal capacity. They loose parallelism when chucking bars due to the size over or under this capacity. This significantly reduces gripping strength and accuracy. Rubber collets are used in some cases to avoid the problem of contact and the flexibility of rubber can provide the freedom of the steel slot to create full contact with shaft or tool as shown in Figure 1.

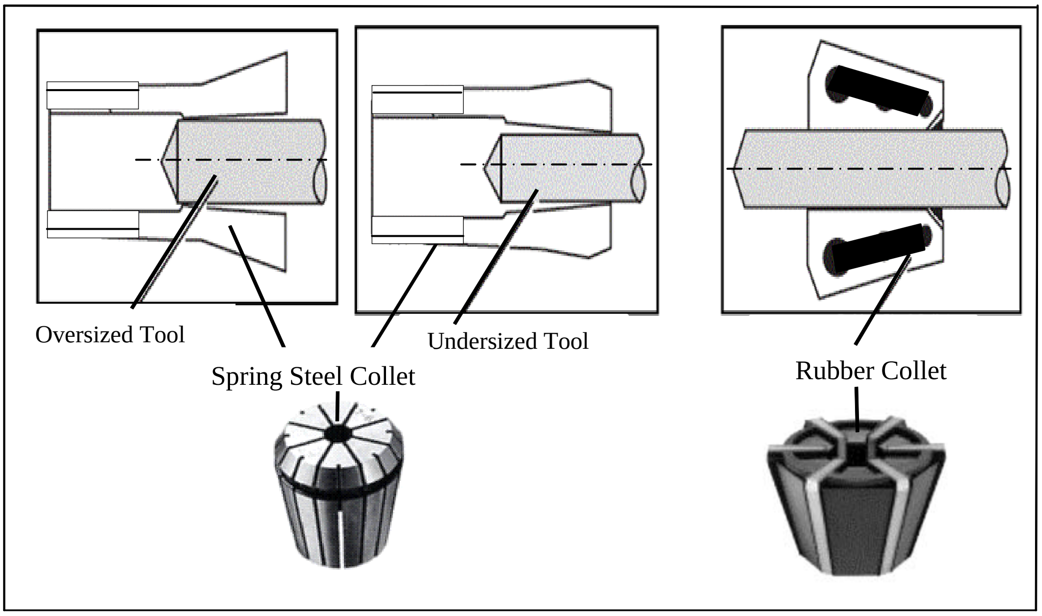


Figure 1: The difference between Rubber collet with other types in gripping parts

The first author [Abbas, 2001] has investigated the area of collet design in previous research work and it has been found that the nature of contact between mating surfaces could be categorised into three groups, namely full, partial and point contact as shown in Figure 2. The objective is to reach to the full contact by increasing the applied load without exceeding the yield stress for the work piece or tool to avoid plastic deformation. In this research, a novel approach of using rubber sleeve on the cutting tool is used to emulate loose and flexible contact between the mating surfaces.

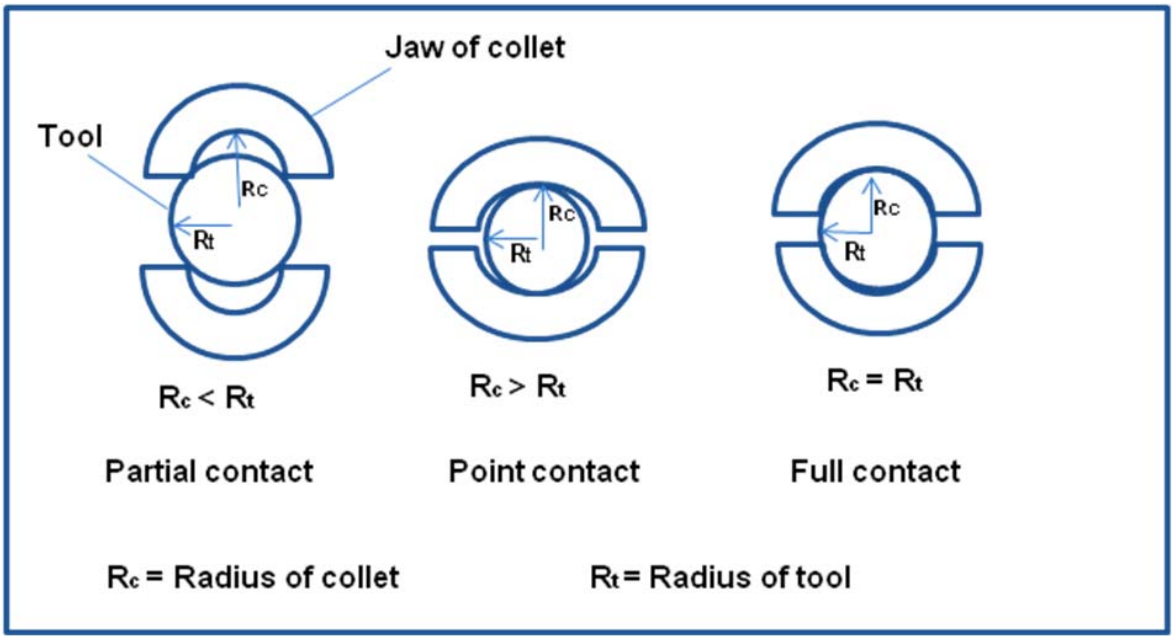


Figure 2: Types of contact between the collet and tool surfaces, [Abbas, 2001].

As seen from previous discussion, there is limited work in the effect of collet type on the design of condition monitoring systems. Also, there is limited literature on the relationship between collet type, material and other design parameters on the quality of the machining process and efficiency of the clamping system.

The proposed clamping system of using rubber sleeve is presented in Figure 3. A rubber sleeve will be used between the spring steel collet and the tool to emulate loose collet, and the effect of this on the design of the condition monitoring system will be investigated.

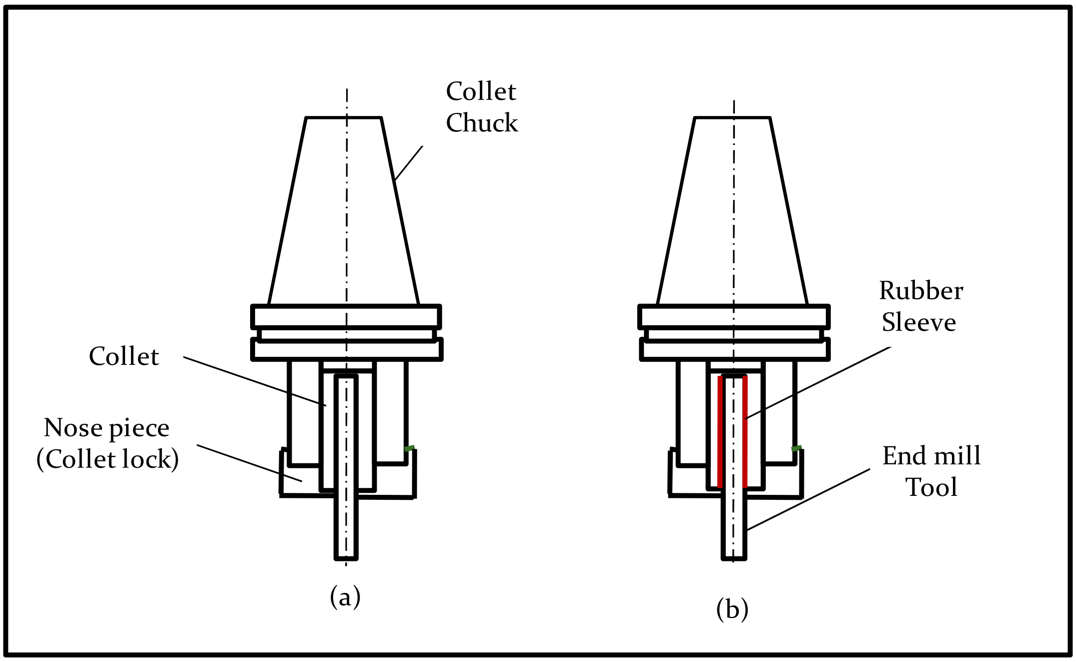


Figure 3: A schematic diagram of a normal tool fixturing system (a) and the one with introduced rubber sleeve (b).

3. EXPERIMENTAL SETUP

As illustrated in Figure 4, the experimental work of the condition monitoring system of this study is performed on a milling CNC machine type (DENFORD). Several sensory signals are used in this study including cutting forces (Fx, Fy and Fz), strain, accelerometer (vibration), Acoustic Emission sensor (AE), and microphone for measuring sound. The force signals are monitored using 3-component Dynamometer (Kistler 9257A) and the work piece is fixed on the dynamometer. The dynamic and quasistatic force signals are monitored using a strain sensor (Kistler 9232A). Both the force dynamometer and the strain sensor are connected to a 4-channel charge amplifier (Kistler 5070A). The AE sensor (Kistler 8152b111) is attached to the workpiece to monitor AE signals transmitted during machining and connected to AE coupler (Kistler 5125B). The accelerometer (B&K4366) is mounted on the moveable table of machine and connected to charge amplifier (Kistler 5001). Ssound signals are collected using a microphone (type –EM400) placed in the direct vicinity of the workpiece. All the wires and cables of the sensors are connected to a National instrument connection box (SCB-100). The signals are monitored using data acquisition card NI PCI-6071E from National Instrument using special data acquisition software written using the National Instrument CVI programming package. The experimental work is performed on milling machine using Aluminium workpiece. The milling process is carried out at the conditions as shown in the Table 1.

Table 1. The machining parameters of the milling process.

Machining condition	specifications
Feed rate	250 mm/min
Depth of cut	0.22 mm
Coolant type	No coolant (Dry)
Spindle speed	2490 RPM
Diameter of tool	3mm
Material of tool	Solid Carbide (End mill Solid Carbide)
Type of tool	End mill Tool(4 Flutes, Uncoated)

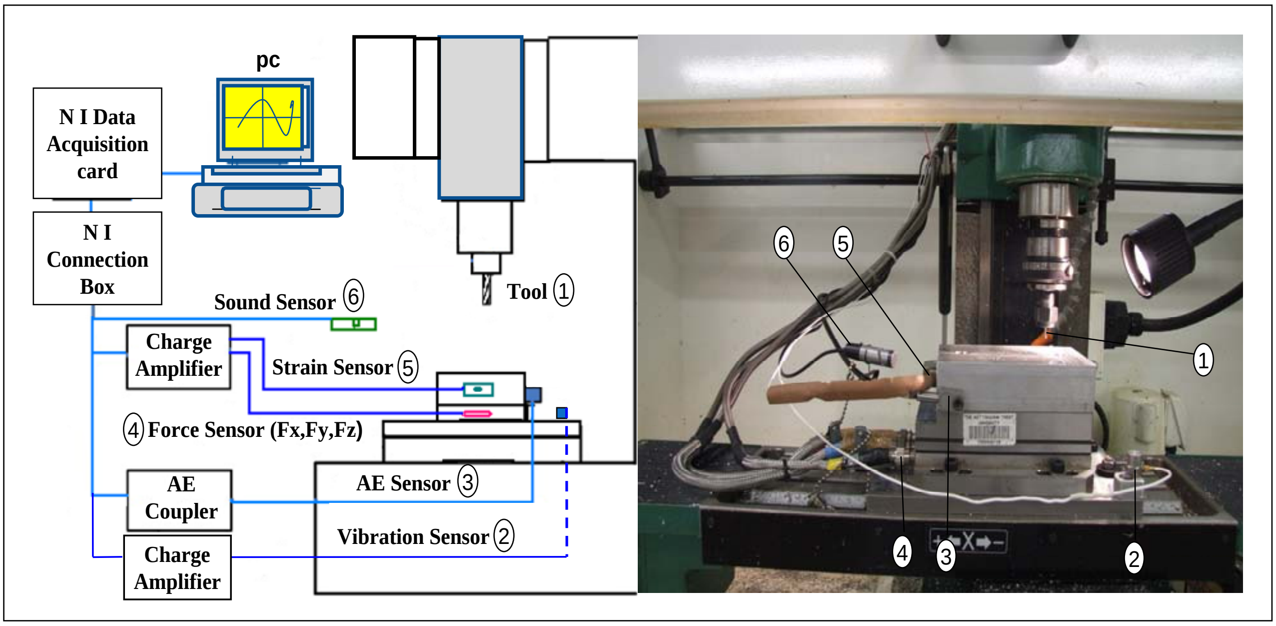


Figure 4: Schematic diagram of experimental setup for the monitoring system on milling machine.

4. EXERIMENTAL RESULTS AND DISCUSSION

The shank of the tool is covered by a rubber sleeve to emulate a fixturing system with low rigidity. The tests start with a fresh tool and finished with completely worn tool as shown in Figure 5. Figure 6 presents the data from both tools, normal and with the rubber sleeve. The raw signals for the tools are collected from the sensors to monitor 43 machining runs/samples for each type of tools as illustrated in Figures 6 and 7. Because milling process has complex machining signals, it has been found difficult to predict the most sensitive signals and signal processing methods to tool wear directly from raw data. Therefore, signal processing and analysis is needed to extract the important information from the signals (i.e. Sensory Characteristic Features (SCFs)).

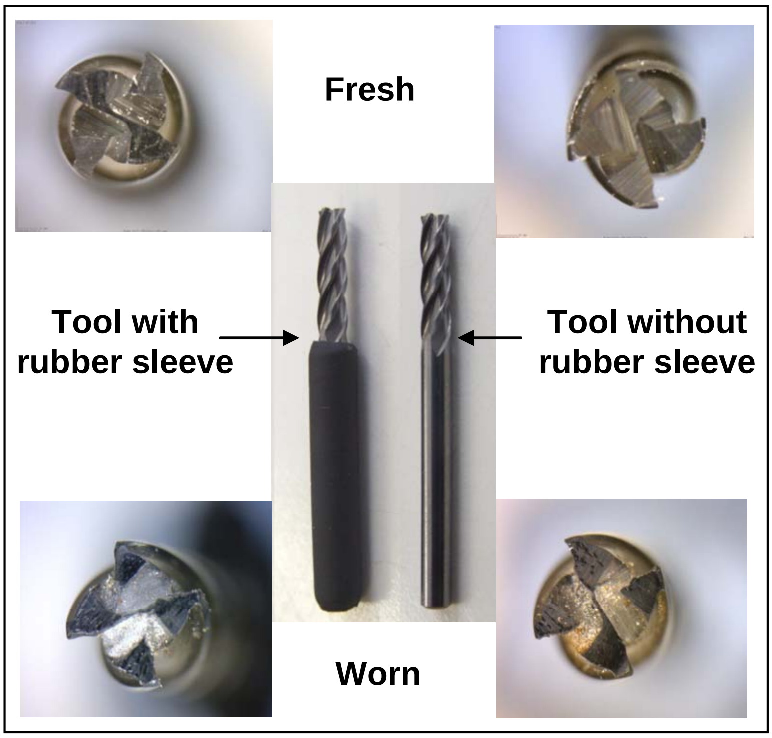


Figure 5: The two states of the milling tool (fresh and worn tool).

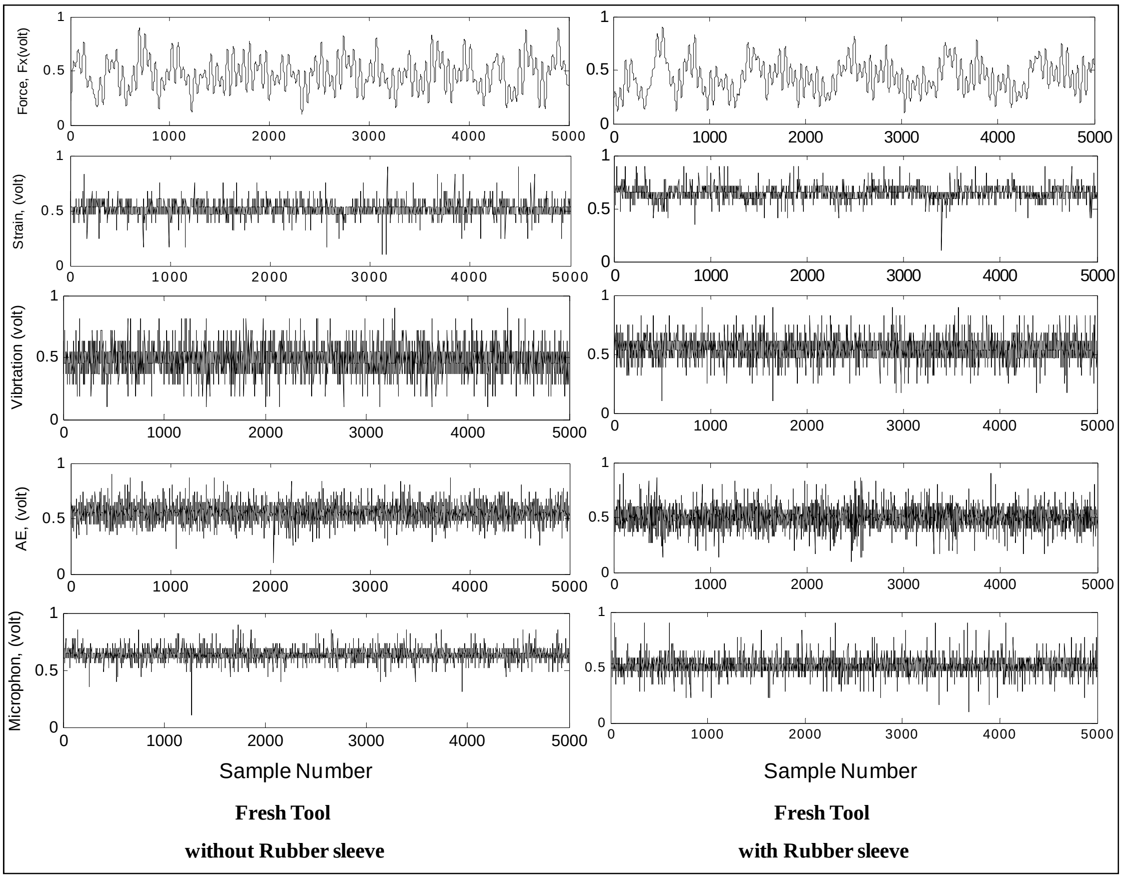
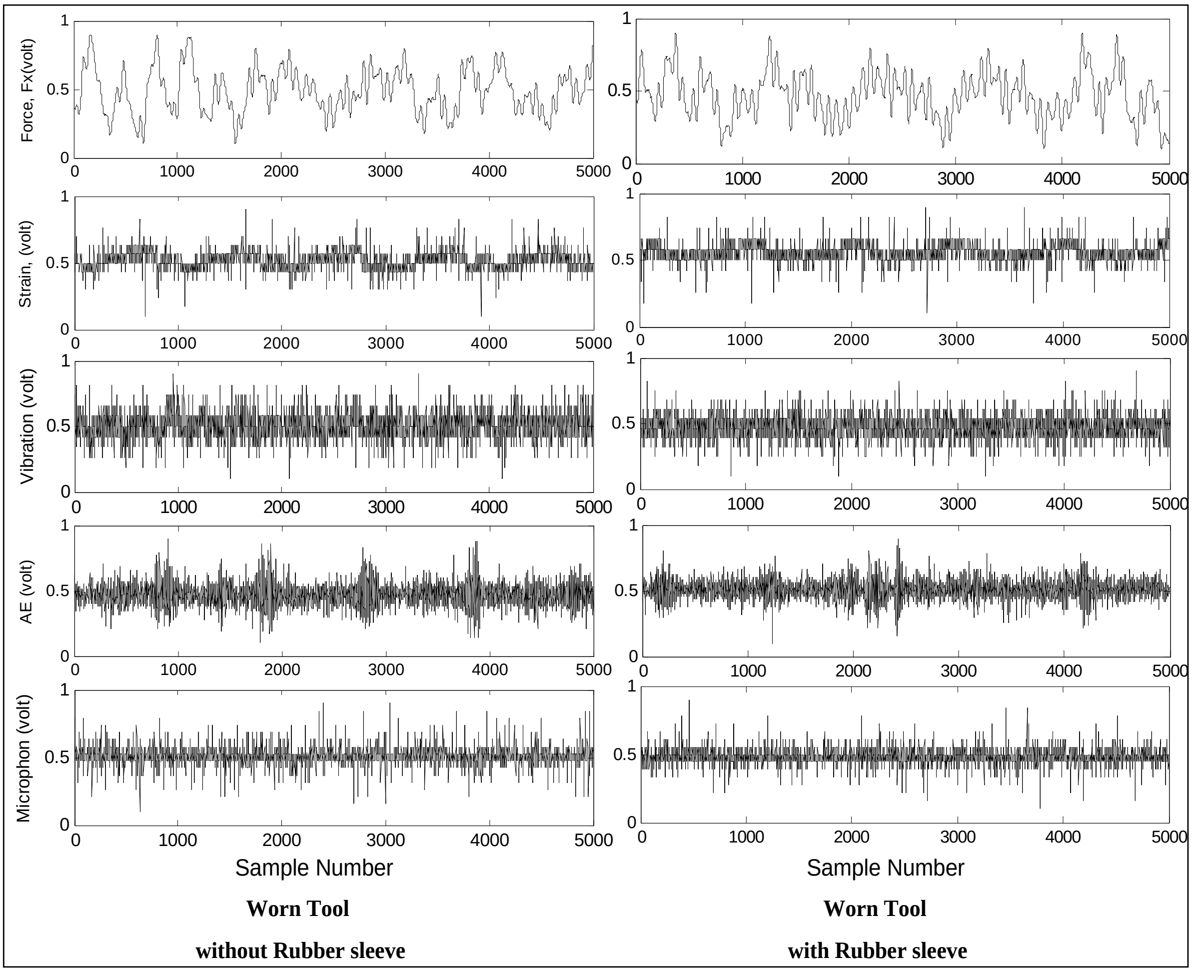


Figure 6: Example of the raw signals of the machining process for both conditions (fresh tool).



Worn Tool

without Rubber sleeve

Worn Tool

with Rubber sleeve

Figure 7: Example of the raw signals of the machining process for both conditions (worn tool).

The raw signals are processed using several time domain signal processing methods to extract the Sensory Characteristic Features (SCFs). The signal processing methods used are maximum (max), minimum (min) ,standard deviations (*std*), the average (μ), the range, the skew, kurtosis value (K) and power. The 8 signal processing methods are used to process the 8 sensory signals to construct an Association Matrix ASM of (8 × 8) which allows the investigation of 64 sensory characteristic features (SCFs) for the design of the monitoring system. The SCFs are arranged according to their sensitivities to tool wear based on the absolute slope of the linear regression method as shown in Figure 8. Figure 8 presents examples of high, medium and low-sensitivity SCFs to tool wear.

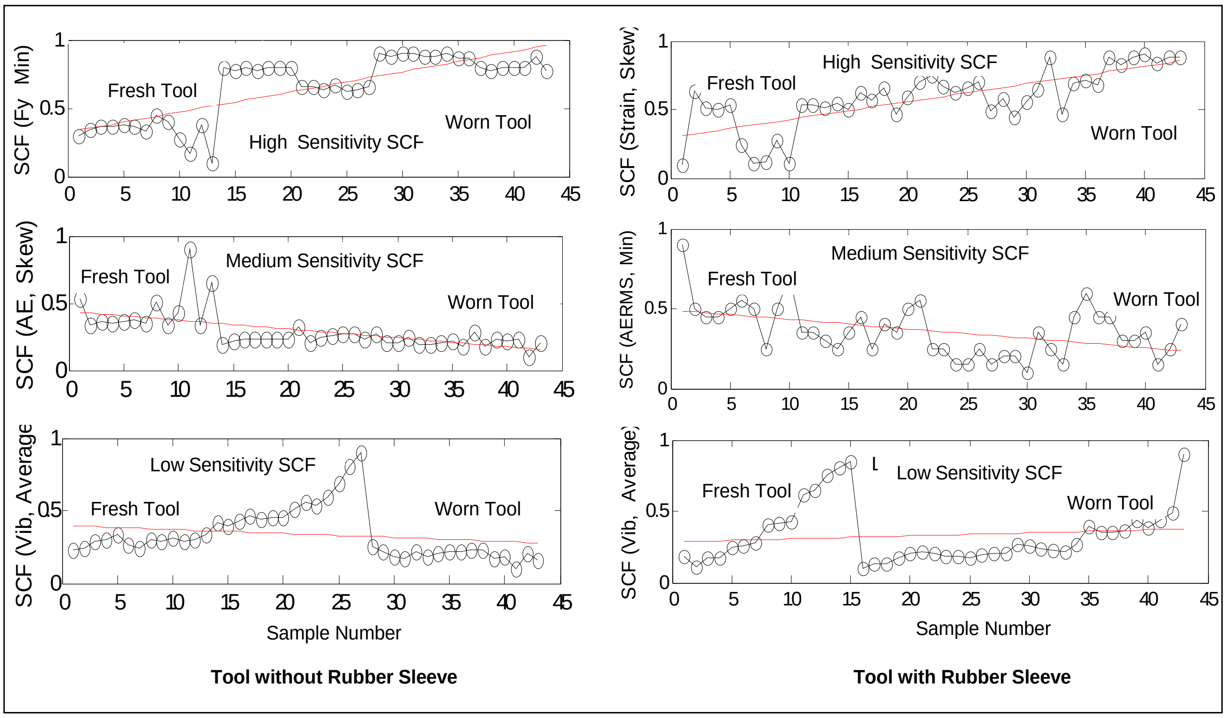


Figure 8: Example of low, medium and high sensitivity SCF for the tools.

The SCFs are visually inspected and it has been found that SCFs with high absolute slope show higher sensitivity to the fault. Table 2 presents the highest sensitive SCFs as detected by the ASPS approach. Notice that Table 2 and Figure 8 prove that the change in the characteristic of the fixturing system has caused change in the most sensitive sensors and signal processing systems that can be used to detect tool wear. For example, with normal fixturing system, force signals are found to be the most sensitive to detect tool wear. However, with the rubber sleeve system, strain and sound signals are found to be the most sensitive signals to detect tool wear.

Table 2: The most sensitivity of the Associated matrix of the system.

Tool without Rubber sleeve			**Tool with Rubber sleeve**		
Sensor	**Signal Processing Method**	**Sensitivity**	**Sensor**	**Signal Processing Method**	**Sensitivity**
Fy	Min	0.7015	Strain	Skew	0.6401
Fy	Average	0.6509	Microphone	Power	0.6182
Fx	Average	0.6377	Microphone	Std	0.6051
Fy	Range	0.6107	Strain	Std	0.5838
Fy	Std	0.5281	Vibration	Kurtosis	0.5583
Fz	kurtosis	0.4902	Microphone	Kurtosis	0.5422
Fy	Max	0.4507	Fy	Average	0.5061
Fz	Range	0.4505	Fy	Min	0.5000
AERMS	Max	0.4472	Microphone	Range	0.4967
AERMS	Std	0.4228	Fy	Max	0.4889

5. CONCLUSION

Recently, more attention has been directed towards improving sensor fusion techniques to detect or predict faults in manufacturing processes. This paper has investigated the effect of collet fixturing quality on the design of condition monitoring systems to detect tool wear. The paper has investigated the difference in the system's behaviour and the changes in the condition monitoring system when the cutting tool is not rigidly fastened to the collet which is emulated using a rubber sleeve. A group of sensors, namely acoustic emission, force, strain, vibration and sound, have been utilised to design the condition monitoring system. Automated Sensor and Signal Processing Selection (ASPS) approach [Al-Habaibeh et al., 2010] has been implemented to address the effect of the tool holding device (collet) on the monitoring system and the most sensitive sensors and signal processing method to detect tool wear. The results indicate that the change in the fixturing quality has caused variation in the dynamics of the system and demonstrated significant effect on most sensitive sensors and signal processing methods for the detection of tool wear. Therefore, this paper has proved that minor changes in the setup of the machining operation could have significant influence on the condition monitoring system.

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