CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The development of accurate and reliable machining process models has received considerable attention from researchers. The development can also enhance the quality of the product by ensuring that the surface and geometrical specifications are within the tolerance zone. Most tools fail either by fracturing or gradual wear. During gradual wear, the tool will reach its limit of life by either flank wear or crater wear. Among wear on various cutting faces of the tool, the flank wear face is the deciding criterion for tool failure.

Tool wear can be estimated by either direct measurement or by indirect methods. Direct methods are not favored by industry as these involve stoppage of production process for measurement of tool wear. In the indirect methods, measurement of process signals like cutting forces, spindle speed, motor current and power, vibration and acoustic emission are significantly affected by wear phenomenon. As withdrawal of the cutting tool is not required for the above methods, these are suitable for online condition monitoring. Due to the inherent complexity of the cutting processes and its dependence on a large number of cutting process parameters such as material properties, speed, feed rate and depth of cut, etc development of an efficient on-line tool condition monitoring method independent of the process
parameters are to be identified to achieve consistent quality and controlling the overall cost of manufacturing by machining.

In recent years, many researchers have contributed towards automating the cutting process. The development of a fully automated machining system can be realized with the aid of robust and practical methods, fitted to sense the amounts of tool wear. This enhances the quality of the product by ensuring that the surface and geometrical specifications within the required tolerance zone. Tool wear is one of the important factors affecting the optimization of manufacturing process parameters and production. Tool condition monitoring techniques are to be identified to increase the reliability of the cutting tool.

**1.2 TOOL CONDITION MONITORING SYSTEM (TCMS)**

A tool condition monitoring system is used for the following purpose.

- Check and safeguard machining process stability
- Machining tolerance is maintained on the workpiece to acceptable limits by providing a compensatory mechanism for tool wear effects.
- Machining tool damage avoidance system

The variety of process parameters like cutting speed, feed rate, and depth of cut, hardness, and diameter were used in metal cutting environment to predict the cutting tool state by earlier researchers.
Cuppini et al (1990) focused on continuous monitoring method of tool wear in a turning process based on experimental relationship between wear and cutting power. For the above investigation, the important parameters of workpiece properties, cutting speed, feed and depth of cut that influence tool wear were not taken into account. Yellowley and Lai (1993) suggested an approach using force ratio for monitoring tool wear. In their research, a direct relationship between force ratios and tool wear was not considered.

Yan et al (1995) were of the opinion that Acoustic Emission (AE) signals are more sensitive to variations in the cutting conditions and noise. Hence, AE is suitable for predicting tool breakage than the tool wear. Tansel et al (1991) and Lee et al (1989) have argued that the acoustic emission is dependent on the structure of the cutting material with its signal reflecting from machine tool setup. During metal cutting a small amount of acoustic emission is generated. This acoustic emission is not a suitable for tool wear indicator in monitoring applications; however it can be used to good effect in detecting tool tip breakage and fracture that produce large acoustic emission.

Lister (1993) was of the opinion that acoustic emission signals available on the entire machining area, choosing a suitable area to place the acoustic emission sensor to trap sufficient acoustic emission signals and understanding of the acoustic emission path that required special attention.

Luke Huang et al (2001) have used multiple regression models to predict surface roughness of a machined work piece in turning process. The earlier researchers have not cross-examined the impact of individual factors and factor interactions on surface roughness.
The techniques used by earlier researchers are capable of detecting and diagnosing tool wear and surface roughness of the workpiece related to particular classes of faults.

To effectively implement automated tool failure sensing in flexible manufacturing analysis, it is essential to fully understand the relationships between the variables and tool failure.

Based on the above survey, it is aimed to develop an accurate and reliable machining process model and to investigate the optimal performance of the tool life and surface roughness.

1.3 OUTLINE OF THE THESIS

The organization of various chapters with brief contents is provided.

Chapter 2 Literature review - Reviews of earlier research papers on tool wear occurring during metal cutting are presented in this chapter. The focus is on typical application scenarios along with their correlation to tool wear experimental conditions. The methods used for analysis include:

- Cutting forces
- Vibration signatures
- Acoustic emission
- Tool temperature
- Ultrasonic and optical measurements
- Workpiece surface finish quality
- Workpiece dimensions
- Stress/strain analysis and
- Spindle motor current.
The proposed research aims to develop accurate and reliable machining process models for optimal performance by using non-traditional optimization procedures. These procedures are interfaced to the modeling and simulation of machining process to investigate the optimal performance of tool life and surface finish for higher productivity considering vibration of the tool.

Chapter 3 Problem definition - After reviewing the literature the following problem was defined. Tool wear is an extremely complex phenomena influenced by many variables such as cutting speed, feed rate and depth of cut. In recent years several researchers have placed great emphasis on sensing tool wear on-line with a combination of measurements such as acoustic emission, tool temperature, cutting forces (Static and dynamic) and vibration signature (acceleration signals). These techniques are only capable of detecting and diagnosing tool wear and failure relating to particular class of faults. Consequently these techniques seldom find applications in industrial environments. In order to overcome this situation, an easily operatable technique considering various characteristics is needed. In order to accomplish this task, it is essential to fully understand the relationships between the various characteristics and tool failure. The development in computer technology has made faster computation possible and economically viable for most users.

Chapter 4 Models development - In this investigation, tool flank wear and surface roughness have been taken as response (output) variables during turning process. The impact of input factors like the cutting speed, feed rate, depth of cut, force ratio and nose radius on tool flank wear is evaluated by using Response Surface Methodology (RSM) and Back Propagation Neural Network (BPNN) models.
The main and interaction effects of the input factors on flank wear and surface roughness have been plotted. This helps in selecting quickly the process parameters to achieve the desired quality of machining surface by controlling the wear of the cutting tool. The predicted values of the flank wear and surface roughness by both techniques are compared with the experimental values and closeness with the experimental values has been determined.

The following conclusions are arrived based on the results of the investigations.

- The tool flank wear and surface roughness models shows that good matching have been achieved between experimental and predicted values. The proposed models have been used to predict flank wear and surface roughness of the workpieces.

- The interaction plot shows that at constant feed rate the flank wear increases slowly at all levels of depth of cut at low cutting speed. At higher cutting speed, higher depth of cut, the flank wear has an increasing trend. This is due to the positive effect of cutting speed on flank wear and the increase of cutting forces.

- The force ratio can be used to monitor the flank wear reliably and the flank wear increases with increasing in force ratio (Ff / Fc) linearly.

- The increase in cutting speed resulted in better surface finish but increasing the feed rate resulted in decreased surface finish.

- A larger nose radius at higher depth of cut with the softer material can produce a smoother surface.

- The outcome of two models (RSM and BPNN) comparison results shows that the average errors of flank wear and surface
roughness values of BPNN models have come closer to the experimental values.

- The relationship between surface roughness and flank wear values for both BPNN and RSM methods are compared with experimental values. The prediction techniques (RSM and BPNN) values are closer to the experimental values.

**Chapter 5 Sensitivity analysis** – In this research, sensitivity analysis was been performed and compared with the relative impact of input parameters on tool flank wear and surface roughness. This type of analysis enables the measurement of the accuracy of the important parameters and to determine the input parameters exerting the most influence upon model outputs.

The investigation outcomes are given below.

- The sensitivity of flank wear to the three input parameters cutting speed, feed rate and depth of cut was analyzed. Based on the plot, the cutting speed is more sensitive than depth of cut. If the cutting speed is increased the sensitivity of feed rate decreases.

- The variation of depth of cut causes small changes in flank wear and change of cutting speed also affects the flank wear. It is concluded that sensitivity of cutting speed is higher than that of depth of cut. The change of cutting speed and feed rate are more useful to control the flank wear.

- The comparison of the sensitivity of four input parameters cutting speed, feed rate, depth of cut and nose radius on surface roughness. The result shows that the surface roughness is more sensible to the cutting speed than the other parameters.
The variation of cutting speed causes more changes in surface roughness.

The change in depth of cut and nose radius affects the surface roughness. It is concluded that sensitivity of cutting speed is higher than that of other parameters. The change of cutting speed is more useful to control the surface roughness.

**Chapter 6 Dynamic behavior of cutting tool** - In this study finite elements analysis was used to analyze the stability of machining process. The tool model is shaped in ANSYS software based on the real dimensions. Modal analysis, harmonic and transient dynamic analyses were performed. The vibration characteristics of tools with and without laminates were compared.

The following conclusions are drawn from the investigations

- With the introduction of laminates, the damping ratio increased and the time taken for the vibration to decay was considerably reduced.

- The tool was modeled using a 3D model and its natural frequency was found to be 125.91 Hz corresponding to first bending natural frequency, damping ratio is 0.00285. It was found that the time taken for vibration to reduced to zero for the HSS tool was 4.0 seconds.

- The ultra thin brass metal rubber laminates was introduced and 3D model of tool with metal laminates was modeled and its natural frequency was found to be 126.28 Hz and damping ratio was 0.0200 corresponding to the first bending natural frequency. It was found that the time taken for vibration to
become zero for the HSS tool with ultra thin brass rubber laminates is 2.9 seconds. The introduction of laminates the damping ratio was increased and the time taken for the vibration to decay was considerably reduced.

- During machining by cemented carbide insert tool with brass rubber laminates, the time taken for the amplitude to decay to zero and damping was not increased.

Chapter 7 An investigation on damped tools - The experimental analyses were performed using laminates between tool holder and tool. The vibration of the HSS tool, Carbide insert tool and cantilever workpiece were predicted and its effect on surface roughness were analyzed. The analyses resulted in the following directions.

- The amplitude of vibration of tool was reduced using thin rubber layered metal laminates between tool holder and insert for HSS and carbide insert tools. The machining process using with the brass laminates was found to be better results than with copper and steel laminates.

- Machining stepped workpiece at higher speeds produces continuous chips with better surface finish. For the different cutting speeds carried out in this study, speed at 515 rpm yielded continuous chips towards better surface finish.

- During the machining operations with laminates (brass and copper laminates), it was observed that the chatter frequency was found to be away from the natural frequency. The amplitude of vibrations was reduced for machining operations with brass laminates than any other laminates.
• Machining stepped workpiece at slow speeds with laminated tools, the copper laminates were better results than with brass and steel laminates. For machining operations with brass laminates the natural frequency of the workpiece was close to the chatter frequency. It was observed that copper and steel laminates were better control over brass laminates.

• Machining slender workpiece with laminates yields better vibration control than machining without laminates. All three types of laminates were found to be suppressing the amplitude at higher speeds.

• A vibration control system for turning was developed and tested for controlling machine tool vibration, resulting in increased productivity and improved surface finish.

Chapter 8 Conclusion – The summary of the research findings were as follows

• It is observed from the study that the proposed mathematical models help the manufacturing community to predict the tool life and improve the surface finish of the components machined.

• The tool flank wear model and surface roughness model shows that good matching were achieved between experimental and predicted values. The developed models are recommended to use for predicting flank wear and surface roughness of the workpiece.

• The impact of input parameters on tool flank wear and surface roughness of the workpiece were evaluated by using Response
Surface Methodology (RSM) and Back Propagation Neural Network (BPNN) models.

- The dynamic behavior of the solid tool and tool with laminates were simulated using ANSYS for analysis. The tool stiffness, natural frequency, damping ratio and time taken for complete decay of amplitude of vibration were observed. The modal analysis, harmonic analysis and transient dynamic analysis using FEM were performed to estimate the natural frequency and damping ratio of the slender and stepped workpiece. With the introduction of laminates between tool and tool holder, the damping ratio was increased and the time taken for the vibration to decay was considerably reduced and thereby tool stiffness was increased.

- Vibrational amplitudes were measured along the length of the workpieces during cutting process using laminates and without it. Surface finish of the machined workpieces was measured and results were compared and validated through theoretical predictions and “Design of Experiments” approach.

The scope of further research is discussed. The major references and list of publications based on the present research work are listed.