CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Metal cutting process is widely used in manufacturing industries. It is estimated that about 15% of the value of all mechanical components manufactured worldwide is derived from the machining operation. Conventional method of cutting metals at low cutting speeds is gradually getting replaced with high speed machining. HSM has added benefits like better surface finish, low residual stress, less work piece distortion, increased production rate and lower manufacturing cost. Among several high-speed metal cutting processes, high speed milling is a fundamental machining operation used in the manufacture of aerospace components, monolithic structures, dies, and mould cavities. End milling is the most common metal removal operation used in the manufacture of the above components. The issues related to tool wear, machine tool vibration, surface finish of work piece, process monitoring and adaptive control are certain areas where lot of research work is undertaken.

End milling is a method of metal removal from a work piece by feeding it past a rotating tool with one or more cutting teeth. A typical end-milling tool is shown in Figure 1.1. The most common process parameters related to end milling are cutting speed, feed rate, axial depth of cut and radial depth of cut. In case of high speed milling, the cutting speed and feed rate are generally high. The most common method of identifying high speed milling
machines is based on the DN value. It is a number relating the spindle bearing bore (D) and the maximum rated revolutions per minute (N) of the spindle. HSM machines typically possess cutting speed ranging from few hundreds to 1500 m/min. Also spindle power to spindle speed is used to define HSM. Conventional machines have high power at low speeds ranging from 186-372 Watts/rpm, whereas HSM possesses values less than 3.72 Watts/rpm.

![Figure 1.1 End milling tool](image)

1.2 TOOL WEAR

Tool wear is defined as the change in the shape of the tool from its original shape, during cutting, resulting from the gradual loss of tool material. In HSM, tools are subjected to extremely severe rubbing process. The cutting tools very soon reach unacceptable level of wear and results in poor surface finish and dimensional precision. This demands frequent change of cutting tool to guarantee the desired product quality. It is therefore necessary to monitor tool wear which has a direct effect on the quality of surface finish, dimensional accuracy and ultimately the cost of the part produced.
Tool wear monitoring encompasses two major domains - breakage detection and wear detection. In the current work, progressive tool wear detection is attempted. By monitoring tool wear and reacting on real-time, it is possible to avoid the production of waste. With an accurate estimation of tool wear it is even possible to adjust the position of tool in order to meet geometric specifications and to control tool wear rate in order to guarantee a certain surface quality of work piece.

Considerable research has been carried out in the area of tool wear monitoring using direct and indirect tool wear sensing techniques. Artificial neural network (ANN), fuzzy systems or both have been used to model the non-linear dependencies between features extracted from measured signals and corresponding tool wear. However, these methods had their own drawback and therefore are not practically implemented. Some of them are not precise and are not generalized. Therefore researchers are still aiming at realizing a practical tool condition monitoring system.

Tool wear monitoring is difficult, because, machining processes are non-linear time-variant systems, which makes them difficult to model. Also machining conditions influences tool life. Therefore one has to get convinced that a generalized model will never work, as far as tool wear monitoring is concerned. The methods are to be specifically designed to suit individual machine tool/processes.

Despite lot of research and technological development, on-line control of process based on real time data is limited. This is particularly apparent when conditions of extreme cutting speeds, materials or product geometry are used in manufacture. To be on the safer side, the most conservative choice of parameters is selected to avoid product or tool damage. In contrast improved process understanding and development of reliable,
advanced process monitoring and adaptive control could improve the productivity and accelerate product development.

In this context, it is essential to carry out a detailed study on tool wear in high speed milling and study the feasibility of developing an on-line tool condition monitoring and real-time adaptive control system to improve the dimensional accuracy and surface finish of work piece and deliver consistent part quality.

1.3 AIM AND SCOPE OF THE PRESENT STUDY

1.3.1 Aim

The primary objective of this research work is to develop an on-line tool wear monitoring system to estimate the progressive tool wear in HSM. The developed tool wear monitoring system is to be used in developing tool wear compensation system for improving dimensional accuracy and adaptive control system for improving surface finish of components produced in HSM. A process capability study is to be carried out to evaluate the new process. The above work will be accomplished in four modules. Figure 1.2 shows the methodology used to accomplish the objectives.

1.3.2 Scope

- To develop an on-line, indirect tool wear monitoring system for progressive tool wear monitoring and accurate estimation using acoustic emission (AE) technique and artificial neural network (ANN) in HSM.
Figure 1.2 Methodology

METHODOLOGY

MODULE 1
- Establishment of HSM Setup
  - Experimental Investigation to Predict Tool Wear using Acoustic Emission Technique
    - Experimentation with Different Cutting Parameter-L9 Array
      - Data Acquisition with AE Sensor
        - Development of ANN Model
          - Tool Wear Prediction
  
MODULE 2
- Experimental Investigation for Optimization of Process Parameters in HSM
  - Experimentation with Different Cutting Conditions using Taguchi’s L9 Array
    - Data Acquisition with Accelerometer
    - Cutting Force Measurement
    - Periodic Surface Finish Measurement
    - Analysis of Results using ANOVA

MODULE 3
- Process Monitoring & Adaptive Control
  - Self Adjusting On-Line Tool Wear Compensation using Acoustic Emission Signals
  - Adaptive Control-Spindle Speed Correction to Improve Surface Finish

MODULE 4
- Process Capability Study
- Quality HSM Products
➢ To optimise the cutting conditions like cutting speed, feed rate and depth of cut and observe the responses like cutting force, component vibration and surface finish in HSM.

➢ To develop self-adjusting on-line tool wear compensation system to improve dimensional accuracy of HSM components.

➢ To develop an adaptive control system to improve surface finish of components produced in HSM.

➢ To evaluate the new processes, using process capability studies.

1.4 THE PRESENT WORK - A BRIEFING

1.4.1 Literature survey

Literature on HSM, indirect tool wear estimation, sensors, mathematical models and adaptive control are available. Also literature on process capability studies for special cases like repeated trends, Taguchi’s design of experiments (DoE), sensors interface and software are available. Few literatures are discussed in detail in chapter 2.

1.4.2 Development of experimental set-up

In order to accomplish the objectives of the present work, an experimental set-up comprising of 3-axis vertical CNC machining center with high speed spindle and other sensors and instruments are established. The details of the experimental set-up, end milling cutter, work piece and other related accessories and tools are presented in chapter 3.
1.4.3 Tool wear monitoring using acoustic emission technique

The experimental procedure followed in the tool wear monitoring using acoustic emission technique is discussed in chapter 4. Taguchi’s DoE is used to arrive at optimum number of experiments. The experiments for tool wear estimation in end milling are carried out as per ISO 8688-2 (E)(1989). Nine experiments are conducted for various cutting conditions. The AE signals and corresponding tool wear measured are used to obtain correlation between tool life and tool wear. The experimental results are used to develop an artificial neural network (ANN) using back propagation algorithm, for estimation of progressive tool wear in HSM.

1.4.4 Optimisation of process parameters in HSM

The quality of machining in HSM is significantly affected by tool wear. Methods for indirect measurement of surface finish either using cutting force or vibration will help in development of adaptive control system. Prior to that in order to have a better understanding of the process, an optimisation of process parameter using Taguchi’s DoE is attempted. Chapter 5 is on optimisation of process parameters like cutting speed, feed rate and depth of cut for minimum cutting force, vibration amplitude and better surface finish. Also a method to improve surface finish by varying cutting speed is discussed in this chapter. The above study is used in development of adaptive control in high speed milling for improved surface finish.

1.4.5 Process monitoring and adaptive control

Based on experimental study in chapter 4 and 5, self-adjusting on-line tool wear compensation system and adaptive control system is developed for high speed milling machine. The development of self-adjusting on-line
tool for tool wear compensation and Adaptive control based on constraints (ACC) for constant cutting force and improved surface finish are discussed in detail in chapter 6. The hardware and software used and the experimental study along with process capability study are discussed in this chapter.

1.4.6 Summary

The summary of results obtained from tool condition monitoring system, optimisation of cutting parameters in HSM, self-adjusting on-line tool, ACC and process capability studies are presented in chapter 7. Comparisons of the quality of parts produced with and without tool wear compensation system and adaptive control system is carried out in this chapter. The chapter also summaries the main contributions of the dissertation and outlines the potential directions for further research.

1.5 CONCLUDING REMARKS

Based on the study it is observed that there is significant improvement in quality of components produced using adaptive control in HSM. It is understood that, if on-line tool wear is estimated accurately, it can be used to establish tool change policy, adaptive control, economic optimization of machine operation and complete automation of machining operation. The most conservative method of cutting parameter selection or experience-based selection can be replaced with advanced process monitoring and adaptive control for decision of parameters considering real-time process variables. The results of the process capability studies are encouraging and would help in reducing rejections and also narrow down tolerance band of HSM components. Thus accurate methods of on-line tool wear monitoring and adaptive control system for improved component quality is suggested in this study.