CHAPTER 1

INTRODUCTION

Vibration is an undesirable phenomenon in machining processes. It results in the reduction of material removal rate (MRR), poor surface finish and increased tool wear. Tool chatter is a primary component of machine vibration and affects the process directly. It causes instability to machining process leading to loss of control over the process. Hence, many researchers have attempted to study and suppress the tool chatter problems. The techniques used for chatter suppression can be broadly classified as active damping and passive damping. Both techniques have their own pros and cons. Hence it becomes necessary to study both techniques and compare the performance of them to know the best chatter suppression method. This forms the basic motivation for choosing chatter suppression problem and taking up this study.

In recent years, many works have been reported for turning operation. The dynamics and governing phenomenon may vary from operation to operation. Hence, one has to study the individual process characteristics in order to handle the tool chatter problem in an effective way. Boring is another operation that is widely used in industries. Studying the chatter suppression of boring operation will add value to the literature and useful to many industries. Hence, chatter suppression of boring tool was chosen for this research work. In active damping techniques, the tool chatter has to be predicted in advance and the control signal is to be given to damper in order to suppress the chatter in on-line basis. The design of such intelligent
controller is a challenge. This study proposes three such predictive algorithms to be used for controller design. This chapter gives a brief introduction to the problem under investigation, possible solutions and outlines the organization of the thesis.

1.1 TOOL CHATTER IN MACHINE TOOLS

Two major types of vibrations occurring in machining are forced vibration and self-excited vibration. The unbalance of rotating members, servo instability, or force on a multi-tooth cutter may result in forced vibration. The cutting tool oscillates at the frequency of the cutting force. When this frequency is close to a natural frequency of the tool, large amplitude vibrations due to resonance occur. Self-excited vibration or chatter is the most important type of vibration in machining process. Two mechanisms known as regeneration and mode coupling are the major reasons for machine–tool chatter. The former is due to the interaction of the cutting force and the workpiece surface undulations produced by preceding tool passes. Regenerative chatter occurs when cuts overlap and the cut produced at time ‘t’ leaves small waves in the material that are regenerated during each subsequent pass of the tool. The regenerative type is found to be the most detrimental to the production rate in most machining processes. If regenerative vibrations become large enough that the tool does not contact the workpiece as a result multiple-regenerative chatter occurs.

Mode coupling is produced by relative vibration between the tool and the workpiece that occurs simultaneously in two different directions in the plane of cut. In fact, mode coupling usually occurs when there is no interaction between the vibration of the system and undulated surface of the workpiece. In this case, the tool traces out an elliptic path that varies the depth of cut in such a way as to bolster the coupled modes of vibrations. The amplitude of self-excited vibration increases until some non-linearities in the
machining process limit this amplitude. Self-excited frequency is usually close to a natural frequency of the cutting system.

1.2 CHATTER SUPPRESSION TECHNIQUES

Regenerative chatter is due to a closed loop interaction between two independent entities: the machine tool structural dynamics and the dynamics of the cutting process. Any method of chatter suppression tries to influence one of the two entities, so that the ultimate goal of higher stability is achieved. Prominent among the methods of influencing the cutting process is online control of spindle speed. This is effected in two ways, either by the "spindle speed selection" method or by "spindle speed modulation". Changing the spindle speed to the stable part of the stability lobe diagram can stabilize an unstable machining operation.

The control unit monitors the frequency content of the vibrations of the cutting tool and identifies if a self-excited chatter vibration component exists in the sensor signal. If a chatter frequency is identified, the chatter control program is invoked, which searches for the closest spindle speed where the stability is the highest. If such a speed is found, a speed change command is sent to the driving motor of the spindle. If no such favorable speed is found, the program commands the reduction of the axial width of cut. The method uses a simplified calculation of the stability lobe diagram from the identified chatter frequency. Since boring operations are associated with changes in the structural resonant properties, due to changing of machine configurations and dimensions of the workpiece, stability lobe diagrams are not unique and are dependent on the machining condition. In that respect, for proper functioning of the algorithm, a thorough knowledge of all possible stability limits is necessary.
In order to handle such a situation, an adaptive control strategy for changing the feed and the axial depth of cut in the milling operation was proposed with an aim of maximum utilization of the capacity of the machine. The method involves detection of the dominant chatter frequency by sensing the sound, emanated in the cutting process by a microphone and analyzing its frequency content. The cutting force signal, sensed with dynamometers, is usually used for chatter monitoring. In that case identification of the chatter frequency may be difficult.

Another approach is to use audio signals since generation of a loud noise is typical of an unstable milling process. The sensed audio signal should normally contain a distinct peak, corresponding to the chatter frequency. This makes chatter detection more efficient than using a dynamometer. The method does not require the knowledge of the stability lobe diagram for stabilization of chatter. However, there are some limitations. The technique performs well if there is a single dominant natural frequency of the structure. In reality, more than one structural mode may be involved in chatter. The control strategy works well in the high spindle speed regions, where there are well separated lobes. Convergence may be poor in the low spindle speed regions, where the stability lobes overlap each other and in situations where multiple structural modes contribute to chatter. The method also requires stoppage of machine feed every time the spindle speed is changed. The procedure also requires the chatter instability to be triggered in order to identify it and then take a corrective action. This may be detrimental to the life of the machine tool.

Another popular on-line method for chatter avoidance is the spindle speed modulation technique. This involves a continuous periodic modulation of the spindle speed with a very low frequency. The technique is however costly and limited by the inertia of the rotating parts of the machine.
Online control of the tool geometry is also used to suppress chatter. It is well known that an adjustment of the tool clearance and rake angles to cause more rubbing between the tool and the metal surface, results in dissipation of energy and stabilization of chatter.

Vibration control during machining process is an important strategy to suppress chatter vibration. The aim of this strategy is to reduce the relative displacements between the tool and the workpiece and thus suppress chatter. Chatter control through active damping is adopted in the present study. The motivation behind this choice arises from many studies, which emphasize on the relationship between damping and stability of the machining process. A piezoelectric actuator with necessary data acquisition system is used for active suppression of chatter vibration in boring operation. In this study, the active suppression of chatter is achieved by magneto-rheological (MR) fluid using suitable controller.

1.3 PROBLEM DEFINITION

Boring tool bar is generally longer than turning tool and hence, it is more prone to tool chatter. This study focuses on chatter suppression in boring operation by active damping using magneto-rheological fluid damper and passive damping by impact dampers. While using active damper through magneto-rheological fluid (MR), the damping co-efficient of MR fluid has to be changed instantaneously according to the tool chatter in order to suppress the chatter. This can be achieved by an intelligent controller. The design of such controller in this problem will be done using ‘regressive models’. The present study makes use of multiple linear regression, Support Vector Regression (SVR) and Artificial Neural Networks (ANN) as regressive models for changing the damping co-efficient of the MR damper. To validate
the results the regression models were implemented with MR damper, which works on feedback loop taking vibration as the input from the boring tool. From the results of this study a suitable regression model is to be suggested to suppress the chatter.

1.4 HIGHLIGHTS OF THE WORK

In the present study, improvement of the damping capability of boring tool and suppression of chatter vibration using active damper is analyzed. In active suppression of boring tool chatter, MR damper is used. For design of controller for MR damper, three regressive model were used, namely multiple linear regression, Support Vector Regression (SVR) and Artificial Neural Networks (ANN). For each of the model, the performance of regressive model was studied to change the damping properties of MR damper and the best model was chosen. It is found that the performance of Artificial Neural Networks is better comparing to other two models which are considered in the study. The regression models were implemented with MR damper which works on feedback loop taking vibration as the input from the boring tool. The reduction in boring tool chatter is reported.

The present research work has been started with an idea of suppression of chatter vibration by passive techniques. Upon proceeding with conceived idea it is observed that the scope of the research would be better if active suppression technique is employed to suppress the chatter vibration. Hence chatter suppression by passive technique has been given in the Appendix 1. The inertia mass of the dampers have been increased to suppress the chatter vibration by passive damping technique. The materials selected for the dampers are nitinol, tungsten carbide and tungsten-nickel-copper alloy. Finite elements analysis has been performed to study the dynamic behaviour of tool using the selected different damping materials. The main contribution
of the current study reveals that the natural frequency of the boring tool has been enhanced with dampers. From harmonic and transient analysis, it is observed that there is reduction in amplitude of vibration with respect to the frequency and time taken to decay the amplitude of boring tool with dampers. Hence the result of finite element analysis of tungsten-nickel-copper alloy damper shows that there is a significant improvement in dynamic behaviour when compared with other damping materials.

1.5 ORGANISATION OF THE THESIS

Chapter 1 gives a brief introduction to the problem under investigation and contribution of the thesis.

Chapter 2 describes a summary of literature review conducted as part of this study and highlights the recent work carried out by other researchers. The chapter also brings out the research gap which forms the basis for the present study.

Chapter 3 provides the details of the experimental set up, sensors used, data acquisition and experimental procedures.

Chapter 4 discusses the results of linear regression model for changing the damping co-efficient of the MR damper for active chatter suppression.

Chapter 5 presents the results and discussions of regression model built through support vector regression.

Artificial neural networks regression technique was used for changing the damping co-efficient of the MR damper for active chatter suppression and results are presented in chapter 6.
Chapter 7 gives the summary of results of regression models built in the present study for the purpose of comparison. The relative performance of one model with respect to the other is discussed. The conclusions drawn out of the present study are presented along with some future scope for the enhancement of the present work.