CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The developing of a methodology for drill wear monitoring is now playing an important role in the manufacturing world. Drill wear and failure monitoring has aroused interest among many researchers and research organizations. The background and motivation for this interest is that drill wear monitoring is considered important for the following reasons: The increasing demands such as quality control, cost reduction, are driving the performance of modern machine tools and require the improvement of methods for process monitoring and control. Simultaneously, guaranteeing reliable production process and stable product quality is of central importance to industry; Cost effective unmanned production is possible in practice only if there is a reliable method available for tool wear monitoring and breakage detection.

The economical tool life cannot be fully benefited from without efficient methods for tool wear monitoring because of the variation in tool life. Where sudden tool failures are to be avoided, tool changes need to be made based on conservative estimates of tool life. This does not take into account sudden failures and at the same time leads to an unnecessarily high number of tool changes, because the full tool life is not benefited from and valuable production time is therefore lost; Drill wear influences the quality of the surface finish and the dimensions of the parts manufactured. The quality
of the surface finish and the dimensions are linked to the unmanned operation, i.e. if the quantity of drill wear is not monitored, the unmanned machining might lead to poor quality.

1.2 DRILLING

Drilling is a machining process by which a hole is produced or enlarged by the use of specific type of end cutting tool called the drill. It is usually the most effective and economical method of producing holes in solid materials. Drilling of holes can be regarded as one of man’s earliest machining achievements and it is one of the most widely used manufacturing processes (HMT 2006). Drilling machine is one of the simplest, moderate and accurate machine tool used in production shop and tool room. It consists of a spindle which imparts rotary motion to the drilling tool, a mechanism for feeding the tool into the work, a table on which the work rests and a frame. It is considered as a single purpose machine tool since its chief function is to make holes (Jain 2003).

1.3 CUTTING PROCESS IN DRILLING OPERATION

Drilling differs from turning, because the twist drill is a multi-edge tool which cuts with five cutting edges (two lips, two leading edges and chisel edge). Cutting forces that act on the drill during cutting are shown in the Figure 1.1 Force F at each point ‘A’ of the lips can be resolved in to component forces Fx, Fa and Fz acting on axes X, Y, and Z. The Fy forces act on the drill lips in the opposite direction. They are equal in magnitude if the lips are ground symmetrically. Hence, the resultant force acting on the drill along the y-axis equals zero. The axial force Fx acting along the drill is

\[ F_{ax} = 2F_s + F_e + F_r \]

In drilling, the main work of cutting is effected by the lips of the drill, where as the chisel edge, whose cutting angle is 90°, crushes the
metal with the force $F_e \approx 0.5 F_a$. The total moment of the cutting force is
$M_t = M_x + M_e + M_m$.

[Diagram of forces acting on a drill during cutting]

**Figure 1.1 Force acting on a drill during cutting**

As the drill wears on the flanks, the axial force and its moment rise; for instance, with the flank wear reaching 1mm, the axial force and its moment increase by 60 to 80 percent (Jain 2003).
1.4 INFLUENCE OF VARIABLES AFFECTING THE DRILLING

1.4.1 Machine Variables

The efficiency of any machining operation depends on the overall rigidity of the system consisting of the machine tool, the cutting tool and the workpiece. The machine on which the material is to be machined should be rigid and should have sufficient power to withstand the induced cutting forces and minimize deflections. If the machine is not sufficiently rigid and has less power, the tool life will be reduced in addition to affecting the accuracy and surface finish (HMT 2006).

1.4.2 Tool Variables

Of all the factors governing drilling, the most basic is cutting tool. Without tools made from the proper tool material and having proper geometry, a cutting operation cannot be performed efficiently, even though all other machining variables are closely controlled. If the cutting tool is not optimized, the material removal rates must be reduced to obtain a reasonable value of tool life, otherwise machining costs will be increased. Proper tool geometry is essential for efficient machining operations, and it should be chosen depending on the work material and machining conditions. Surface finish is largely influenced by tool geometry and it can be controlled within limits by properly choosing tool geometry. The workpiece material and size configuration determine the type of machining operation and the cutting tool to be used. Because of the cutting forces involved, the tool deflects causing a detrimental effect on the tool life, surface finish and dimensional accuracy (HMT 2006).
1.4.3 Work Material Variables

The type of work material also influences the torque, thrust force, vibrating signals and cutting current signals in drilling. Generally, hardness, tensile strength, chemical composition, microstructure, degree of cold work, shape and dimensions of work, rigidity of workpiece, and strain hardenability can be taken as a basis for determining the influence of the workpiece material (HMT 2006).

1.4.4 Cutting Conditions

Cutting speed, as a variable, has the greatest influence on tool life. The relationship between the cutting speed and tool life is expressed by the Taylor’s equation: \( v_T^{-1/k} = C \). Where, ‘T’ is tool life in minutes, i.e. actual cutting time between resharpening and indexing, ‘v’ is cutting speed in m/min and ‘C’ is constant whose value depends on the tool material and work material. \(-1/k\) is exponent whose value depends on the tool material and work material. Tool life is proportional to the cutting speed and machinability based on tool life. The tool life at a given cutting speed is also influenced by the dimensions of cut, namely, the feed and the depth of cut.

The dimensions of cut influence the cutting forces and material removal rate. However, the limiting factors are power, rigidity of the machine job, fixturing, rigidity of the tool, the maximum permissible deflections of the machine and work consistent with requirements of accuracy, and surface on the job. Surface finish is also affected to a large extent by the dimensions of cut, especially by the feed rate. With increase in feed rate, the surface finish deteriorates rapidly (HMT 2006).
1.5 VARYING CUTTING CONDITIONS

By knowing the wear limit and the drilling process characteristics of various work materials, it is possible to work out the optimum cutting conditions to be employed during drilling. Suitable factors have to be used depending on the nature of the surface conditions of job, depth of hole, cutting fluid used, rigidity of drilling machine fixtures, etc. Generally, torque, thrust, cutting current signals and the power values are of interest in selecting suitable cutting conditions depending on the power of the machine (HMT 2006).

Most of the indirect approaches have been developed for fixed cutting conditions in practical applications; however, the cutting conditions are not fixed; therefore, a wear estimation strategy that operates under varying cutting conditions is much needed (Koren et al 1991). So, the proposed on-line drill wear process model was developed with various cutting parameter conditions (cutting speed, feed, and drill diameter) and different work materials.

1.6 WEAR IN DRILLING

1.6.1 Drill Wear

Wear in drilling is a progressive procedure but it occurs at an accelerated rate once a drill becomes dull. During this procedure, the cutting forces increase, temperature of tool rises, and drill point deformation and immediate loss of sharp edges occur. After a certain limit, tool wear can cause catastrophic and sudden failure of the tool without any warning that causes considerable damage to the workpiece and even to the machine tool.
It is a good practice to sharpen the drills as soon as they get worn out to a certain extent. Excessive wear increases the cutting forces and produces increased temperature during drilling, which in turn may temper the cutting edges. The actual cutting ability of the drill is reduced with increased wear, resulting in poor surface finish over-size holes, built-up edge along the lips, noise, etc. Also, if the resharpening is delayed, more material has to be ground off than is otherwise necessary. From the economy point of view, it is therefore necessary to fix a limit for the wear, after which the drill has to be resharpened (HMT 2006).

### 1.6.2 Measurement of Drill Wear

In a drill, wear occurs mainly on the flank surface, being predominant at the outer corner and the chisel edge. The wear can be measured on a tool maker’s microscope or with a brinell magnifying lens (HMT 2006).

![Diagram of flank wear](image)

**Figure 1.2 Measurement of flank wear**

Figure 1.2 shows the width of the wear on the flank face of the drill wear and also shows the average flank wear computed by measuring the wear
in each section, and then taking the arithmetic average, i.e., Average Flank Wear = (A+B+C+D)/4. The wear was measured at periodic intervals of the cutting time for each drill. Wear mark was measured at a point where the wear is maximum (Lin and Ting 1996).

1.6.3 Drill Wear States

Drill wear states can be classified as the function of tool life, which is obtained from the tool maker’s microscope. Drill wear consists of the following states: initial wear state, normal wear state, moderate wear state, ultimate or end wear state, and worn out state as a function of tool life. The initial wear state consists of the wear rate upto 0.1 mm. Normal wear state consists of the wear rate from 0.1 to 0.2 mm. This wear state is the initial position of the wear rate value. Hence, it will not create any damage to the tool and machine. Moderate wear state has a wear rate value of 0.2 to 0.4 mm. In this state the tool has moderate wear. The ultimate wear state is the severe state of wear. In this state the wear range lies from 0.4 to 0.6 mm. It shows the exact wear matter in the output graph. In the ultimate wear state, the tool has to be replaced. The final wear state is worn out state. These wear states can be used for developing on-line drill wear model, i.e. spindle motor cutting current signal increases as drill wear increases, with an almost linear incremental relationship. Based on the drill wear states the tool replacement control decision can be effectively made in automated manufacturing environment.

1.7 DRILL WEAR MONITORING

The manufacturing community is always striving to reduce operating costs while trying to improve product quality and meeting or exceeding customer satisfaction. These goals are behind the drive towards automation and the use of high production and unmanned equipment. In order
to achieve improved productivity and better quality of the product in drilling operation, the online monitoring and prediction of drill wear is an important issue, since drill wear affects the hole quality and tool life of the drill (Jantunen 2002). This project describes a new inspiration for developing on-line model through cutting current signals having an effect of drill wear under varying cutting conditions using LabVIEW in the application of virtual instrumentation. The developed drill wear model is effectively employed for both high speed machining (vertical machining centre) users and conventional machining (radial drilling machine) users.

1.7.1 Drill Wear Monitoring Methods

Drill wear monitoring methods can be classified into two categories, namely, direct and indirect methods. With direct methods it is possible to determine the tool wear directly, which means that these methods really measure the tool wear as such. In spite of many attempts, direct methods, such as visual inspection or computer vision etc. are not effective either economically or technically. In indirect monitoring methods, the wear is identified by measuring the parameters, such as torque, force, vibration, sound, cutting current signals and power etc (Jantunen 2002). In this work cutting current signals were chosen for developing on-line drill wear model under varying cutting conditions.

1.8 EFFECT OF CUTTING CURRENT SIGNALS IN DRILLWEAR MONITORING

Producing a hole by drilling requires certain amount of energy. Cutting forces act on the drill; penetrates through the workpiece by removing the metal and generates certain amount of power (i.e cutting current signals). The current consumption required for drilling varies with the type of workpiece material. It is generally observed that the current amplitude
increases as the drill wear increases, with an almost linear incremental relationship. In this work the cutting current signals were measured for online drill wear monitoring. The major advantage of using the measurement of motor current signals to detect any malfunction in the cutting process is that the measuring apparatus does not disturb the machining process. Moreover, it can be applied in the manufacturing environment at almost no extra cost (Mannan and Nilsson 1997).

1.9 DRILL WEAR MODEL

A mathematical drill wear model is developed based on cutting current signals with varying cutting parameters using nonlinear adaptive control theory. First, the model tends to separate the effect of different variables involved in the process (inputs as well as different wear states) by relying on a process. Second, it tends to be more dependent on on-line testing by using on-line determination of equation parameters (Xiaoli 2001). It has been recognized widely that tool life can be divided into three states, characterized by three different flank wear: (i) normal wear, (ii) moderate wear and (iii) ultimate or severe wear. The sudden rise in wear rate observed during the ultimate tool wear state (state iii) is of interest here as an indication of the need for tool replacement. The model is effectively implemented under LabVIEW environment.

The proposed approach is based on a model which is adjusted on-line (by the on-line parameter determination). It can be applied to various kinds of manufacturing processes and types of tool wear (with the appropriate model) and it is inexpensive and does not require any modifications in the process components.
1.10 VIRTUAL INSTRUMENTATION

Virtual instrumentation is defined as a combination of hardware and software with industry standard computer technologies to create user-defined instrumentation solutions. It specializes in developing plug in hardware and driver software for DAQ. The driver software is the programming interface to the hardware and is consistent across a wide range of platforms. Application software such as LabVIEW, Lab Windows/CVI, Measure and Component Works, deliver the sophisticated display, and analysis capabilities required for virtual instrumentation. Each virtual instrumentation contains three main parts: Front Panel (how the user interacts with the virtual instrumentation), Block Diagram (the code that controls the program), and the Icon/Connector (means of connecting one virtual instrumentation with the other virtual instrumentations). The block diagram (back panel) contains the graphical source code of the drill wear model. The front panel objects appear as terminals on the block diagram. LabVIEW is used for developing the drill wear model in the proposed work.

1.11 NEED FOR PRESENT STUDY

Developing of a methodology for process monitoring is now playing an important role in the manufacturing world. The increasing demands such as quality control, cost reduction are driving the performance of modern machine tools and require the improvement of methods for process monitoring and control. Guaranteeing reliable production process and stable product quality is of central importance to industry (Smith 1993). Drill wear detection methods can be direct or indirect. Direct methods such as visual inspection, computer vision etc., can be applied while the tool is not in contact with the work-piece. This drawback prevents these methods to be used for automated manufacturing systems. Indirect methods, in which various sensors signals (such as thrust force, torque, acoustic emission, current, power, vibration) correlating to tool wear have been extensively applied to on-line prediction of tool wear detection (Jantunen 2002).
Xiaoli and Tso (1999) established the correlation between drill wear and motor current at different cutting conditions. Fuzzy classification of drill wear states was applied successfully for on-line wear monitoring using spindle motor and feed motor current signals. Xiaoli (1999) applied wavelet transform on motor current signals to detect the breakage of a small diameter drill. Though the detection of breakage was successful, the analysis failed to predict the drill breakage in advance. Karali et al (2007) modeled the drilling process by a multilayer feed forward neural network with a back propagation learning algorithm. Drill wear has been predicted successfully through the neural network, which was trained with the RMS value of current signal and the cutting conditions (drill diameter, feed-rate, and spindle speed).

Motor currents measurement was used as an indirect method to measure cutting forces. Thrust force can be estimated using the RMS of the feed motor current (z-axis), and cutting torque can be estimated using the RMS of the spindle motor current. The characteristic parameters of drill failure CPDFs are used as inputs to the neural network. The output of the neural network is defined as the DSI (Young et al 2008).

Spindle motor current enlightens as to how much power is used in the cutting process and it advises about the dynamics of cutting. Measuring the spindle motor current is the easiest among other methods and therefore, the measurement of the current has been widely tested and used (Jantunen and Jokinen 1996). The favorable role of feed and spindle motor current in predicting the wear values during the machining process, using fuzzy logic technique has been recently reported (Salimi et al 2012). A review of the literature suggests that current signal provides several benefits in drill wear monitoring. Recently, many researchers have carried out the experimental investigation of drill wear by using current signals with fixed cutting conditions in practical applications.
On-line drill wear monitoring using cutting current signals with various methods like fuzzy logic, neural network, and other signal analysis techniques has been executed in different ways in the application of machining like drilling, boring, turning, milling etc. In this research work, a new on-line drill wear monitoring method has been developed based on cutting current signals with the effect of drill wear under varying cutting conditions using virtual instrumentation.

1.12 SCOPE OF THE PRESENT STUDY

In the present research work, an on-line drill wear state monitoring and effective tool replacement technique was developed based on cutting current signals and the various cutting parameters (cutting speed, feed, and drill diameter) in drilling. In this work, standard data acquisition software LabVIEW in the application of virtual instrumentation was studied and applied to establish effective drill wear models and to predict the drill wear states by on-line.

The new combination of spindle motor cutting current signals and computer based on-line wear monitoring using LabVIEW in drilling was implemented effectively. The effects of on-line drill wear state monitoring on high speed machining (vertical machining centre) in the drilling of AISI 1018 steel, AISI 1040 steel and the jute fiber reinforced composite laminates and conventional machining (radial drilling machine) in the drilling of AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates by High Speed Steel (HSS) drill bit with varying cutting conditions were investigated. All the experiments were carried out under wet conditions i.e. with the use of coolant.

A lot of emphasis was given to the consideration of how the drill wear monitoring and diagnosis could be made easy, automatic in practice
even though there are so many factors that influence the monitoring, i.e. the workpiece material and cutting process parameters such as diameter of the drill, cutting speed and feed. For this purpose virtual instrumentation techniques were studied. The results of cutting current signals on drill wear under varying cutting conditions were analysed for various workpiece materials in both high speed machining and conventional machining.

The established on-line drill wear state model was used for the continuous monitoring of the cutting tool status and to exhibit the drill wear states as a percentage of the maximum permissible wear. The purpose of the developed approach is to detect whether the drill starts to get worn, and needs replaced at proper time.

1.13 PROBLEM DEFINITION

Drill wear influences the quality of the surface finish and the dimensions of the parts that are manufactured. Hence, drill wear monitoring has created quite a lot of interest among researchers and has consequently been studied in a number of research projects by a number of research organizations. The researchers reported in the literature have indicated that many of the approaches that have been developed for drill wear monitoring are indirect monitoring methods (force, vibration and sound, acoustic emission, and cutting current). Some of the deficient characteristics prevailing in the various indirect monitoring methods are listed briefly:

The measurement of cutting forces is not easily arranged between the tool, tool holder, and spindle. Vibration and sound has not been so pronounced in drill wear monitoring due to the amount of noise in a typical cutting process. Acoustic emission is seen to suffer from severe attenuation and multi-path distortion caused by bolted joints commonly found in machine tool structures and restricting the mounting location of the AE transducer to
somewhere very near the tool or workpiece. Yet the concerning observation is that several deficient characteristics of indirect monitoring methods are commonly visible in most of the monitoring methods. Thus the cutting current signals acquired from spindle motor have been chosen for drill wear monitoring with the advantages discussed from the literature arena. As to measurement of motor current signals to detect any malfunction in the cutting process, the measuring apparatus does not disturb the machining process. Moreover, it can be applied in the manufacturing environment at almost no extra cost.

Many of the approaches that have been developed for tool wear diagnosis and are reported in the literature rely on training and a definition phase in order to work properly. In normal production, the need for training and the definition phase might be very problematic if a great number of tools are used in different machining conditions with varying workpiece materials. The review of the literature suggests that LabVIEW in the application of virtual instrumentation provides several benefits in drill wear monitoring. Based on the existing literature studies, it has been concluded that on-line drill wear model based on varying cutting conditions through spindle motor cutting current signals using virtual instrumentation is a different and new approach. Therefore, the drill wear model needs to be implemented for acquiring competitive strengths by overcoming the deficiencies in the methods discussed so far.

### 1.14 OBJECTIVES OF THE PRESENT WORK

The present work investigates the influence on drill wear by spindle motor cutting current signals in the drilling of AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates by a HSS drill bit under
varying cutting conditions and analyzes the effectiveness of developed on-line drill wear model for both high speed machining and conventional machining. The objectives of the present work are:

1. To develop an on-line drill wear model for the drilling process. For this purpose a number of sub-goals have to be fulfilled. It is necessary to study and discover which indirect monitoring methods are best for drill wear. It is also necessary to identify which signal analysis techniques work best for this purpose. A method for handling the varying process conditions also needs to be developed. Finally the goal is to be able to detect and display the wear of the drill in order to enable tool replacement at the proper time.

2. To develop the on-line drill wear model using nonlinear adaptive control theory under LabVIEW environment. This model needs to measure the on-line process signals (e.g. cutting current signals) during drilling and to identify the process features from the measured process data.

3. To carry out the drilling experiments for both high speed machining (vertical machining centre) and conventional (radial drilling machine) over a wide range of varying cutting conditions, and study the drill wear performance on the drilling of AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates with the HSS drill bit.

4. To acquire the cutting current signals using CT under varying cutting conditions, to analyze and identify the status of the wear based on the drill wear model and to identify the defective tool
replacement at the proper time in automated manufacturing environment. To draw the inferences from the implementation experiences. To refine the model, if required, according to the implementation experiences.

1.15 METHODOLOGY

In this research work, the machining experiments were carried out in high speed machining and conventional machining under varying cutting conditions. The on-line drill wear monitoring methodology used for the high speed machining of the AISI 1018 steel, AISI 1040 steel, and the Jute fiber reinforced composite laminates by a HSS drill bit is shown in Figure 1.3. The on-line drill wear monitoring methodology used for the conventional machining of the AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates by a HSS drill bit is shown in Figure 1.4. Figure 1.5 shows the methodology for performance analysis of on-line drill wear model.

1.16 OUTLINE OF THE THESIS

This research deals with the developing of on-line drill wear model and effective tool replacement technique in drilling process on vertical machining centre and radial drilling machine. In this work, standard data acquisition software LabVIEW in the application of virtual instrumentation has been applied to predict the drill wear states of HSS drill bit, drilling on a AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates workpiece. This thesis can be divided into three main parts. The first part deals with the system setup for on-line drill wear model.
Figure 1.3  Methodology for drill wear performance analysis in vertical machining centre
Methodology for on-line drill wear state monitoring in radial drilling machine

Development of new on-line drill wear model using virtual instrumentation

Drilling process under varying cutting conditions
(Cutting speed, feed and drill diameter)

Cutting current signals

Drill wear model

On-line drill wear state monitoring using LabVIEW

Drill wear
(by on-line drill wear model)

Drill wear
(by tool maker’s microscope)

Performance analysis (drill wear state prediction)

Tool replacement at proper time

Figure 1.4 Methodology for drill wear performance analysis in radial drilling machine
Figure 1.5 Methodology for performance analysis of on-line drill wear model

The second part deals the development of effective drill wear model based on the relationship between the spindle motor cutting current signals and the various cutting parameters (cutting speed, feed, and drill diameter), using LabVIEW. The third part deals with the performance evaluation of the drill wear studies of the AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates under wet cutting environments.
Chapters 1 and 2 present the introduction to this work and the literature review relevant to this study. These chapters give the overall view of the recent trend of research works being carried out on drill wear model. Chapter 3 outlines the first part of this research work, i.e., the system setup of the on-line drill wear model on vertical machining centre and radial drilling machine. Chapter 4 present the second part of this research work, i.e., the development of the drill wear model using nonlinear adaptive control theory under virtual instrumentation. Chapters 5 and 6 are devoted to the third part of this work, i.e., performance evaluation in the drill wear states of the AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates under wet cutting environments. Chapter 7 sums up and lists the conclusions of this research work and suggestions for further study.

Chapter 1: This chapter deals with the forces acting in the drilling process, the effect of drill wear in spindle motor cutting current signals besides explaining the need for drill wear model in automated manufacturing environment. The main objectives of the present study are to experimentally investigate the influence of cutting current signals with varying cutting conditions.

Chapter 2: In this chapter, the recent literatures about the drawbacks in fixed cutting conditions are reviewed. Different direct monitoring methods and different indirect monitoring methods are studied. The drawbacks in automatic fault diagnosis system are analyzed. The machining studies conducted on various work materials like steel, stainless steel, and composite materials are also reviewed. The recently developed on-line drill wear monitoring approaches are also discussed elaborately. The application of virtual instrumentation in different machining process is also studied.
Chapter 3: In this chapter, the experimental methods used in the drill wear studies on the AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates using the HSS drill bit under varying cutting conditions are explained. The details about the workpiece materials and various industry applications are presented in this chapter. The construction and working principle of the newly developed on-line drill wear model is also presented here.

Chapter 4: In this chapter, the design and development of on-line drill wear model under varying cutting conditions (feed, cutting speed, drill diameter, and workpiece materials) through cutting current signals using nonlinear adaptive control theory under LabVIEW environment are presented. The details about constructions of front panel and block diagram used in the drill wear model are also presented.

Chapter 5: This chapter deals with drill wear performance analysis in vertical machining centre. The results and discussion of the drill wear state prediction and tool replacement control on AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, using the HSS drill bit under varying cutting conditions are analyzed with regards to different drill wear states and tool replacement at proper time in vertical machining centre.

Chapter 6: This chapter deals with drill wear performance analysis in radial drilling machine. The results and discussion of the drill wear state prediction and tool replacement control on AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, Jute and Coir (Hybrid) fiber reinforced composite laminates using the HSS drill bit under varying cutting conditions are analyzed with regards to different drill wear states and tool replacement at proper time in radial drilling machine.
Chapter 7: The conclusions on the drill wear studies under varying cutting conditions, of the AISI 1018 steel, AISI 1040 steel, Jute fiber reinforced composite laminates, AISI 304 stainless steel, Jute and Hay (Hybrid) fiber reinforced composite laminates, and Jute and Coir (Hybrid) fiber reinforced composite laminates are presented in this chapter. Suggestions for further study on this work are also highlighted in this chapter.