CHAPTER 1
INTRODUCTION AND REVIEW OF THE LITERATURE

The manufacturing industry has realized the importance of automations due to increased global competition and the potential economic benefits over the past three decades [1]. Consequently, a substantial amount of research has gone in the field of control on manufacturing process. Ulsoy et al., provided a detailed description on the state-of-art-in machine tool automations during 1970’s and 1990’s respectively [2]. To summarize, the accomplishments during 1970’s has not solved the problems, but clearly indicated the complexity of the manufacturing systems including the non-linear, non-stationary and multivariate nature of the process to be controlled. As a result, the 1990’s saw increased research in the use of advanced methods for automation, monitoring and controlling of manufacturing process. In contrast to the automation, the emphasis on past work, it is our objective to set the stage for the next decades of progress by developing advanced techniques which enhance machine operators’ skill.

The research of the metal cutting process control laboratory is focused on developing and applying an advanced control based approach for enhancing metal cutting process capabilities. This includes an integrated effort of physical modeling and control development. The design of both system and control structure needs to be conducted with an understanding of the dominant process physics. Thus, much of the
research in the process control laboratory involves modeling of Non-linear cutting process system which provided insight on the dominant process dynamics. A control perspective, however, provides the basis for determining, why modeling is important. The research projects typically conducted with industry partners. Spans a range of important applications in various areas like enhanced non-linear metal cutting process for optical and opto-electrical applications, advanced engines, power systems and cutting tools.

In this chapter comprehensive introduction to the modeling and advanced control techniques are applied to metal cutting process and it has been enumerated in detail.

1.1 MODELLING TECHNIQUES FOR METAL CUTTING PROCESS

The term modeling in general refers to the description of the system by a set of mathematical equation. A mathematical model of the system is based on physical principles or empirical relations. Mathematical models of industrial process and control of system operations, but for many of the industrial process it is difficult to obtain mathematical models because of their complex behavior, in flowing characteristics and operating conditions. However, the modeling techniques are uses following non-conventional approaches.
1.2 ARTIFICIAL NEURAL NETWORK

Artificial neural networks are the results of academic investigations that are used in mathematical formulation of model nervous system operations. The resulting techniques are being successfully applied in a mixture of everyday non-linear system applications.

Neural networks (NN) represent a meaningfully different approach to using computers in the work place. A neural network is used to learn patterns, recognition and relationships in data. The data may be the result of market research efforts, a production process given in the varying operational conditions. The development of artificial neural networks started 50 years ago. Artificial Neural Networks (ANN) are gross implications of real (biological) networks of neurons. Due to the complexity and incomplete understanding of biological neurons, various architectures of artificial neural networks have been reported in the literature. Most of the ANN structures are used commonly in many non-linear system or in complex problems often consider the behavior of a single neuron as the basic computing unit for describing neural information processing operations. They perform the operations in similar to that of the human brain. Hence it is reasonable to expect a rapid increase in our understanding of artificial neural networks leading to improved network paradigms and the host of application opportunities [3].
1.3 FUZZY LOGIC CONTROLLER

Most industrial applications of modeling and control rely on intuition, sound engineering judgment, past experience, and historic procedures. Fuzzy Logic Controller are excellent at developing human-made systems that can perform the same type of information processing, as if our brain performs. Fuzzy Logic systems, their decisions on inputs in the form of membership functions which formulae are used to determine the fuzzy set and a value belongs to the degree of membership in that set.

The variables are then matched with preconditions of linguistic IF-THEN rules (Fuzzy Logic rules) and the response of each rule is obtained through fuzzy implication. To perform compositional rule of inference, the response of each rule is weighted according to the confidence or degree of membership of its inputs, and the centroid of the response is calculated to generate the appropriate output, for the design of fuzzy logic systems. The most straightforward approach is to define membership functions or rules subjectively by studying an existing controller in manufacturing process of metal cutting industry and then testing the design for the proper output. The membership functions or rules should be adjusted if the design fails, when the plant is highly non-linear, it is easier to design and implement a Fuzzy rule that will control a complex plant [4].
1.4 MANUFACTURING OF NON-LINEAR METAL CUTTING PROCESS

MANUFACTURING is “a set of correlated operations and activities, which includes product design, material selection, planning, production, inspection, management, and marketing of the product, for the manufacturing industry”. Computers are commonly used in modern manufacturing process practice. In the late 1960s, computers were first used for the direct control of groups of machine tools. In the 1970s, the concept of Flexible Manufacturing System (FMS) was introduced. An FMS is “a computer-controlled grouping of semi-independent work stations linked by automated material handling systems”. Systems of this type are capable of producing a variety of products automatically. They are now widely used in the manufacturing industries. Currently, the development of computer-aided manufacturing systems is advanced to the stage where Computer Integrated Manufacturing (CIM) systems are in a rapid and world-wide proliferation [1]. A CIM system results when the design effort includes the use of computers to achieve an integrated flow of manufacturing activities based on integrated information flow that links together all organizational activities. Thus the next stage results in the Intelligent Manufacturing Systems (IMS).

The systems which belong to this stage can be characterized by their ability to solve problems without either a detailed, explicit algorithm
available for each solution procedure or all the facts, mathematical relationships and models are available in perfect arrangement and complete form for a deterministic (and unique) answer to be found. Since the decision-making process in an advanced manufacturing system, environment is become increasingly difficult and overwhelming to humans, control strategies are widely adopted to assist human efforts. Control strategies for non-linear system are an unfortunate choice of title for an ill-defined technology that may be in the long run the single most important and most pervasive ingredient for the realization of true Computer Integrated Manufacturing (CIM).

The control strategies have provided several techniques with applications in manufacturing. Knowledge based expert systems were most popular control techniques in the 1980s. Recently, there has been an explosion of interest in applying artificial neural networks to manufacturing process. Artificial neural networks are a type of neuro-control that have the potential of increasing the product quality, reducing the reaction time of a manufacturing system, improving system reliability and enhancing its intelligence. Since the late 1990s, hundreds of papers have been published pertaining to neural network applications in manufacturing process. Most of them are widely scattered over many different disciplines and publications. One of the emerging technologies which is highly desired to the metal cutting process of non-linear system [5] is neuro-PID controller.
1.5 MOTIVATION

Due to the convolution of machine tool structure and the manufacture metal cutting process, the dynamics of manufacture non-linear cutting process has not yet been understood completely. This is especially true for manufacturing metal cutting processes involving high temperature and speed. To model and control these complex processes, new approaches which can represent complex phenomenon combined with learning ability is needed [2].

The motivation of present work is to develop a model to predict the flank wear of manufacturing process of on-line cutting process chip formation and compare it with the experimental results. First step is assumption of empirical models for flank wear in terms of cutting parameters and cutting forces. The term modeling of non-linear flank wear sub-system in general refers to the description of the system by a set of mathematical equations based on experimental results. Next step is experimentation. Flank wear is obtained as a function of cutting speed, feed, depth of cut and cutting forces. The proposed dynamic model contains certain constants. Evaluation of constants for the proposed dynamic model has been done. The simulation and control of non-linear flank wear system and comparison of the approaches of tuning PID
Controller techniques for automation industrial processes of the manufacturing metal cutting process has been performed [3].

1.6 SCOPE AND OBJECTIVES OF RESEARCH WORK

1. To determine tool wear (flank wear) and their different cutting conditions for conducting experiment of metal cutting process.

2. Development of mathematical dynamic metal cutting model by flank wear.

3. Design and control of metal cutting process by flank wear using PI controller.

4. Design the tuning of PID controller using neural network and fuzzy logic controller for flank wear model.

5. Calculations of performance criteria Like ISE & IAE for flank wear model.

6. Comparison of performances of new approach controllers of dynamic models for flank wear model.
1.7 ORGANISATION OF THESIS

Chapter-1 gives a brief introduction to the non-linear system of manufacturing of metal cutting processing and approach control strategies are presented, and a detailed survey of literature is carried out on various control strategies for tool wear mechanisms of cutting conditions and deals with the current research with previous research of tuning of PID Controller for metal cutting process.
Chapter-2 deals with problem description and formulation of dynamic mathematical model for metal cutting process by flank wear model based on tool wear mechanism and this chapter presents the simulation studies based on experimental mathematical dynamic modeling and control techniques applied to metal cutting processing by flank wear.

Chapter-3 describes the development of Conventional controller of metal cutting process sub system for the simulation of dynamic characteristics of non-linear system and subsequent performance evaluation. The best choices of mathematical model for sub system of manufacturing of metal cutting process are based on the flank wear modeling parameters.

Chapter-4 presents the development of non-Conventional controller like Neuro-PID and Fuzzy Logic Controller function based on PID Controller of sub system for the simulation of dynamic characteristics of non-linear metal cutting process and subsequent performance evaluation. The theory developed in this chapter is used for simulation of different control strategies for non-linear metal cutting process by flank wear. Simulation results for various cutting conditions is evaluated. The results obtained are very useful for the automation of manufacturing metal cutting process by flank wear.
Chapter-1
- Introduction
- Non-Linear System for manufacturing of material processing
- Focus out line of research work methodology & Organization of Thesis
- Literature survey for requirement for manufacturing of material processing by tool wear
- Distinguish of dynamic model for tool wear based on previous and current research work

Chapter-2
- Description of the metal cutting process by flank wear model based on tool wear mechanism.
- Development of dynamic model basis on experimental tool wear mechanism of flank wear.

Chapter-3
- Description of Conventional controller for tool wear mechanism
- Design the tuning of PI Controller using Synthesis method of flank wear model

Chapter-4
- Development of tuning of PID Controller for non-linear flank wear system
- Automation of flank wear for various cutting conditions of ANN & FLC with PID

Chapter-5
- The Simulation studies of PI & Neuro-PID & Fuzzy Logic Controllers
- Evaluate and comparison of PI, Neuro-PID and Fuzzy Logic Controllers for dynamic model of metal cutting process by flank wear

Results and Discussions
Path of Further Feature Scope of Research work.

Fig. 1.2 ORGANISATION OF THESIS CHART
Chapter-5 deals with the evaluation and comparison of PI, Neuro-PID and Fuzzy Logic Controllers for dynamic model of metal cutting process by flank wear that are developed in chapters 3 & 4.

The PI controller settings the parameters Proportional gain \((K_p)\) and Integral Time \((T_i)\) are designed using Synthesis method tuning technique by applying the step input to the sub-system model. The mathematical model for metal cutting process by flank wear is also obtained. The optimal settings are then found by finding the minimum values of Integral Square Error \((ISE)\) and Integral Absolute Error \((IAE)\). Typical Proportional Integral \((PI)\) control is designed by the synthesis method. A fuzzy or PI controller is designed and simulations tests are conducted. It is observed that the centre of gravity method yields better results for the case study considered [6] among the existing defuzzification.

The neuro controller developed in this work use a multilayer feed forward network which is on-line trained using back propagation algorithm. Bipolar sigmoidal activation function is chosen for the hidden layer and linear activation function is used for the output layer. The closed loop responses of the various flank wear of non-linear cutting process with PI, Fuzzy and neural networks based PID controllers are presented and evaluated.

SUMMARY AND CONCLUSION summarizes main conclusions and path for future scope of the Research work.
1.8 REVIEW OF THE LITERATURE

The dynamics of this Non-linear process are still not completely understood due to the complexity of machine tool structure and the manufacture process. This is especially true for manufacturing processes involving high temperature and speed. To model and control these complex processes, new approaches which can represent complex phenomenon combined with learning ability are needed. A brief review of literature in modeling and control of metal cutting processes are presented.

Studies on control strategies of automation for metal cutting process has been reported by many researchers but to achieve fast dynamic response, there are two possible routes. The first way is to develop a more accurate non-linear model of the metal cutting process based on which the controller is designed as suggested by Tse and Adams. The other method is the artificial intelligence way of using human experience in decision-making [7-13]. Such an advanced controller can work well even for a system with an approximate model.
The technique by So et al., fuzzifies the error and change in error of the output like surface roughness of flank wear mechanism, and the Sugeno type fuzzy system gives the change in output. Bor-Ren Lin and Hua used the mamdani fuzzy system and compared its performance with different mode controller and fixed tolerance method.

1.8.1 Previous Research

Research and development efforts for Control system of machine tools have been underway since the early 1960’s. These research efforts were primarily concentrated in the U.S., West Germany, Italy, and more recently Japan and Israel [14-21]. These efforts began bearing fruits in late 1960’s and early 1980’s with the development of several commercial systems.

![Fig. 1.3 Typical Hardware configuration](image-url)
These early Control Systems were used primarily in grinding, drilling and milling operations; demonstrated significant increment in productivity, there lay many practical problems which discouraged industrial users. In particular, reliability problems, especially with cutting force sensors. Further, in any control application a good understanding of the controlled system is essential, Colwell and his colleagues point out that there is a lack of basic understanding of the cutting process [22, 23]. Recent advances in this area are reported in, particularly with regard to tool wear. Attempts to mathematically define and economic performance index, and to optimize the machining process on-line met with limited success. In light of the difficulties in formulating an index of performance and measuring all the required variables, including dimensional correction loops based on inspection of the finished part and systems for controlling the tool wear rate, minimizing tool work piece impact, and detecting and correcting for chatter, etc.

With the widespread acceptance of CNC-Lathe systems during the past decade, the implementation of control systems has become more reliable and economical. For CNC-Lathe drilling or milling systems of the implementation of control systems require only a torque or cutting force sensor and additional software. The low cost and reliability of microprocessors and advances in sensing technology in recent years has made these systems much more attractive. It is desirable that CNC
machine tools are designed to accommodate the possibility of adding sensors and modifying software for control systems. Variations in the process parameters can lead to poor performance or even instability. This problem is discussed further in the next section.

There is currently renewed interest in more complex control systems using a hierarchical computer control structure. This trend is in deepening with the general goals of integrating and automating design and manufacturing through the use of computer systems. One can envision a computer controlled machine tool in the future with several levels of control, including the position and velocity control loops; control loops which maintain cutting forces and torque at desired levels; and additional control loops for tool wear rates, dimensional corrections, chatter, etc. Such complex hierarchical computer control systems can be implemented in a modular manner as our basic understanding of the machining process improves on basis of tuning the control system parameters. These systems will be part of an even more complex automated system, which will included tool changing, parts handling, and inspection, etc [24].

1.8.2 Tuning of Control System Parameters

Feed back control systems are intended to eliminate the effects of external disturbances acting on the controlled system or process. The term “tuning of parameters control” in the control literature refers to the
systems that attempt to eliminate the effects of changes in the controlled system itself, in addition to the effects of changes in the controlled system itself, in addition to the effects external disturbances acting on the system. Tuning parameters of control system modifies the parameters of the controller, or generates an auxiliary control signal[25], in order to maintain some index of performance at a desired level despite of changes in the controlled system. In the literature, the term “tuning of control parameter” is used in general context to describe open loop control system, which may not have automatic tuning mechanism. Feedback control system as a part of the computer system is called an advanced control system[26] which is used to converts non-linear model to linear by tuning the control parameter like $k_C, k_I, k_D$. In Fig1.4 various automatic due tuning methods are described. Groover has discussed the differences between feedback control systems and tuning of parameters control systems by non-conventional methods and proposed a classification scheme for machine tool control systems [27].

Many researchers have recognized the need for parameters of tuning control systems, in order to achieve stability and good performance over a wide range of operating conditions. Gieseke reported a control system with a PI controller where the P and I action gains are functions of the spindle speed for the sake of wear rate. Weck described as control systems which uses digital logic to switch the controller gain adjustment. One uses a cutting process model to estimate the process
gain and adjust the controller gain accordingly. However, all represent preliminary attempts at a practical solution and not a theoretically based design [16, 17].

Fig. 1.4 Structure of a variable-gain control system

The most advanced work to date on tuning parameter by advanced control system for machine tools has been conducted by gain control system for turning based on cutting force measurement and manipulation of the feed rate. Fig. 1.4 shows the structure to that shown in Fig. 1.3 for a conventional control system, we note that a parameter estimation block provides estimates of the cutting process parameters which vary with depth-of-cut and spindle speed and also based on cutting speed. The controller adaptation block uses the estimated desired constant value of the open-loop gain is maintained. Masory and koren have theoretically and experimentally (using a 70HP CNC/AC, lathe) verified the feasibility of a variable-gain control system for turning.
However, their work has also indicated the need for further studies. Specifically research is needed to:

1) Determine the best strategies and structure for tuning parameter of control system by non-conventional controller methods like Neuro Control and Fuzzy Logic system.

2) Develop practical methods for the selection of tuning parameters and sampling periods.

3) Evaluate selected designs through actual machining tests with different controller parameter tuning methods and by non-conventional methods.

1.8.3 Current Research

Present research concentrates on the first task which requires the investigation of controller algorithms, parameter estimation algorithms, and controller by tuning parameters with different non-conventional methods for a variable-gain system such as shown in Fig.1.4. Furthermore, other structures for parameter tuning of controller, such as the advance model, following Control System by non-conventional control method with adaptation algorithm shown in Fig.1.5, will also be investigated. Control systems do not require explicit parameter estimation and use a reference model to specify the desired closed loop system characteristics. Such systems have been successfully applied to
certain industrial problems and extensive theoretical developments are available [22-25].

![Diagram of an adaptive model following control system](image)

*Fig. 1.5 Structure of an adaptive model following control system*

The comparison of different controller strategies of structures and algorithms for the selection of tuning parameters and the sampling period are the best achieved through digital simulation and analytical methods. We are currently carrying out digital simulation studies of the variable-gain system in Fig. 1.4. Digital simulation and analytical studies will then be extended to other studies, the most promising structures and strategies will be selected and studied in further detail. Finally, machining tests on an NC lathe and a CNC milling machine will be conducted for final evaluation of the selected design. These tests will utilize cutting force measurements and manipulation of the wear rates [27, 28].
Digital simulation studies for the structure shown in Fig. 1.4 have shown an excellent qualitative agreement with the experimental results in. Thus, these studies can be expected to provide useful information for evaluation and design. These simulations are based on the tool wear mechanism for mathematical modeling of the metal cutting process by flank wear model.

The next chapter explains the theory of tool wear mechanism which helps to describe the problem statement of current research work and modeling of the Non-linear flank wear model.