CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Choosing the right cutting parameters is a vital step in machining because the cutting parameters influence on the output characteristics of the machined products like surface finish, the tooling cost by influencing the tool wear and finally the safety of the machine tool by influencing the cutting force. Optimizing the cutting parameters is difficult in conventional machines. However, it is easy to control the parameters precisely in case of CNC machines. In using CNC machines the advantage is that the part program can be modified even before it is loaded on to the machine i.e. the parameters can be optimized offline. Though there are facilities to have online optimization techniques like adaptive control they work out to be costly solutions. Though there are many parameters that influence the output characteristics it is found from literature that cutting speed, feed rate and depth of cut are the major parameters that have to be optimized. In order to understand and access the current status of research in the optimization of machining parameters, an extensive literature review has been carried out. The selected literature reviews for the present investigations are given in the following sections.
2.2 TAGUCHI METHOD – AN OVERVIEW

The Taguchi method of experimental design is one of the conventional approaches for producing high quality products at low cost. It is an efficient and effective method of designing experiments and a fast way of identifying the parameters which influence the processes. It is a modified method in design and analysis compared to traditional design and is widely used in making quality improvements by developing Orthogonal Array (OA) and simplifying the Analysis of Variance (ANOVA). This approach is used to determine the feasible combination of design parameters that reduces variability in product responses.

Taguchi has developed a methodology for the application of factorial designed experiments. His contributions have also made the practitioner’s work simpler by advocating the use of fewer experimental designs, and providing a clear understanding of the nature of variation and the economic consequences of quality engineering in the world of manufacturing (Yang et al. 1998; Bhattacharya et al. 2009).

The Taguchi method is widely used to find an optimum setting of manufacturing process parameters. It is one of the most important statistical tools of TQM for designing high-quality systems at reduced cost. The main thrust of the Taguchi techniques is the use of parameter design, which is an engineering method for product or process design. The objective of parameter design is to optimize the settings of the process parameter values for improving the performance characteristics and to identify the product parameter values (Montgomery 1997; Ahmet Hascalik et al. 2008). In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environment.
conditions and other noise factors. Therefore, the parameter design is the key step in the Taguchi method to achieve high quality without increasing cost (Taguchi et al 1989).

Basically, classical parameter design, developed by Fisher (1925), is complex and not easy to use. Especially, a larger number of experiments have to be carried out when the number of process parameters increase. In contrast, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only.

Paulo Davim (2003) studied the influence of cutting conditions and cutting time on turning Metal Matrix Composites (MMC). A plan of experiments, based on the techniques of Taguchi, was performed. An orthogonal array and the analysis of variance were employed to investigate the cutting characteristics of MMC using PCD tools.

Aman Aggarwal et al (2005) and Indrajit Mukherjee et al (2006) reported a review of literature on optimization of machining techniques. This review shows that techniques like fuzzy logic, genetic algorithm, scatter search, Taguchi technique and response surface methodology are the latest optimization techniques that are being applied successfully in industrial applications for optimal selection of process variables in the area of machining. A review of literature on optimization techniques has revealed that there are, in particular, successful industrial applications of design of experiment-based approaches for optimal settings of process variables.

Palanikumar (2008) studied the use of Taguchi and response surface methodologies for minimizing the surface roughness in machining Glass Fiber Reinforced Plastics (GFRP) with a Polycrystalline Diamond (PCD) tool. The experiments were conducted using Taguchi’s experimental design
technique. The cutting parameters used were cutting speed, feed and depth of cut. The effect of cutting parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. The experimental results revealed that the most significant machining parameter for surface roughness is feed followed by cutting speed.

Gul Tosun (2011) reported a statistical analysis of process parameters for surface roughness in drilling of Al/SiCp metal matrix composite. The experimental studies were conducted under varying spindle speed, feed rate, drill type, point angle of drill, and heat treatment. The settings of drilling parameters were determined by using Taguchi experimental design method. The level of importance of the drilling parameters was determined by using analysis of variance. The optimum drilling parameters were obtained by using the analysis of signal-to-noise ratio. Confirmation tests verified that the selected optimal combination of process parameters through Taguchi design was able to achieve the desired surface roughness.

Harilal Singh et al (2010) reported the utilization of robust design-based Taguchi method for optimization of Abrasive Flow Machining (AFM) parameters. Here, AFM was used to finish conventionally machined cylindrical surface of Al/15 wt% SiCp-MMC workpiece. The influence of AFM process parameters on surface finish and material removal was analyzed. Taguchi experimental design concept, L18 ($6^1 \times 3^2$) mixed orthogonal array was used to determine the S/N ratio and optimize the AFM process parameters. Analysis of variance and F-test values also indicate the significant AFM parameters affecting the performance.
2.3 EFFECT ON SURFACE QUALITY

The quality of the machined surface is one of the most important concerns which affect the functionality of the machined surface. In a machining operation surface quality depends more on the process variables rather than characteristic features of the material itself. Hence, estimation of surface roughness and minimization of the same has become essential. Surface finish is important for surface sensitive parts subjected to fatigue. Hence, understanding of surface roughness provides many opportunities to avoid failures and enhance component integrity and reduce overall cost (Chandrasekaran et al 1997).

Hasan Oktem et al (2006) developed an approach for determining the best cutting parameters which can produce minimum surface roughness in end milling mould surfaces of an ortez part used in biomedical applications by combining neural network and genetic algorithm. They developed a simulation model for the component of ortez part to determine the critical regions to be used in roughness measurements and to produce a plastic product.

Bharathi et al (2012) have used particle swarm optimization technique to achieve desired surface roughness in minimum machining time. They carried out experimental investigations on aluminium material to study the effect of machining parameters such as cutting speed, feed, and depth of cut on the surface roughness and to obtain the desired surface roughness on face milling process. They developed a mathematical model for surface roughness prediction using Particle Swarm Optimization (PSO) on the basis of experimental results. The model developed for optimization was validated by confirmation experiments.
Ghani et al (2004) used Taguchi optimization methodology to optimize the cutting parameters in end milling operations. They evaluated cutting speed, feed rate and depth of cut as milling parameters while machining hardened steel AISI H13 with TiN coated P10 carbide insert tool under semi-finishing and finishing conditions of high speed cutting. An orthogonal array, Signal-to-Noise (S/N) ratio and Pareto Analysis of Variance (ANOVA) were employed to analyze the effect of these milling parameters. The analysis of the result showed that the optimal combination for low resultant cutting force and good surface finish are high cutting speed, low feed rate and low depth of cut.

Dimitros Vakondios et al (2012) studied the influence of milling strategy on the surface roughness in ball end milling. They chose Al7075-T6 alloy as the material various cutting parameters like axial and radial depth of cut, feed rate, inclination angles $\varphi$ and $\omega$ were selected to perform 96 experiments and the results were analyzed using regression analysis and analysis of variance. They used all possible milling strategies viz., vertical, push, pull, oblique, oblique push and oblique pull. For each strategy a mathematical model of the surface roughness was established, considering both the down and up milling.

Azlan Mohd Zain et al (2010) have used Genetic Algorithm (GA) to optimize the cutting conditions to minimize the surface roughness in end milling. They studied the optimal effect of the radial rake angle of the tool, combined with speed and feed rate cutting conditions in influencing the surface roughness. By referring to the real machining case study, they developed a regression model. The best regression model is determined to formulate the fitness function of the GA. The analysis of this study has proven that the GA technique is capable of estimating the optimal cutting conditions that yield the minimum surface roughness value.
Eyup Sabri Topal (2009) has made an attempt to study the role of step over in predicting the surface roughness in flat end milling. They performed machining experiments under various cutting conditions. Two ANN structures, one considering step over ratio, and the second without considering it were created. The artificial neural networks were trained and tested by using the measured data for predicting the surface roughness. Average RMS error of the ANN model considering step over ratio was 0.04 and without considering step over ratio was 0.26. The first model proved capable of predicting the average surface roughness (R_a) with a good accuracy.

Cevdet Gologlu et al (2008) felt that apart from the influence of the cutting parameters the cutter path also might have an influence on the surface roughness in pocket milling. They used Taguchi method for their study. Their first aim was to investigate optimum cutting characteristics of DIN 1.2738 mould steel using high-speed steel end mills. The cutting parameters considered were cutting velocity, feed rate, depth of cut and step over. The second aim was to identify the effects of cutter path in pocket milling. They found that one direction and back and forth cutter path strategies were better than predicted results.

Li et al (2008) made an attempt in studying off-line optimization on NC machining. Implementing an on-line optimization technique involves high cost and complex system. With virtual machining gaining popularity off-line optimization technique is simple and cost-effective. Reliability verification, cutting parameter optimization and error compensation can be integrated into one system to improve machining processes comprehensively. The optimization is realized via modifying NC programs.

Han UI Lee et al (2003) have proposed an off-line feed rate scheduling system based on an improved cutting force model that could
predict cutting forces accurately in end milling operations. They divided the original blocks of NC code into smaller ones with the optimized feed rates to adjust the peak value of cutting forces to a constant value. They considered the acceleration and deceleration characteristics for a given machine tool for realistic feed rate scheduling. The pocket milling experiments showed that the proposed method is accurate and efficient in maintaining the cutting force at a desired level.


Shi Hyoung Ryu et al (2006) observed that tool deflection due to cutting forces affects the surface texture and the surface flatness. Tool run-out and tool setting error including tool tilting and eccentricity between tool center and spindle rotation center were considered together with tool deflection caused by cutting forces. They used RMS deviation, skewness and kurtosis for evaluating the generated surface texture characteristics.

Surface roughness is an indication of the machining performance, which has to be minimized. To predict the minimum $R_a$ value a standard mathematical model was developed using regression and ANN by Azlan Mohd Zain et al (2012).

Babur Ozcelik et al (2006) developed a statistical model of surface roughness in high-speed flat end milling. Statistical models are helpful in predicting the surface roughness. They used the machining variables such as spindle speed, feed rate, depth of cut, and step over under wet cutting conditions. First and second order models were developed using experimental results of a rotatable central composite design, and were assessed by means of various statistical tests.

Dutta et al (2013) made an attempt to study the correlation between the tool flank wear with the machined surface texture in end milling operations. Micro and nano-particles are being widely applied in industrial applications. In such cases the particle size plays a major role.

Aykut Canakci et al (2013) studied the effect of milling parameters on the particle size. They have tried to optimize the milling parameters to improve the efficiency of the milling process and thereby achieve the required particle size.

Ramesh et al (2012) conducted experiments under varying cutting conditions like different cutting speed, feed and depth of cut to study the effect on the surface roughness in the turning of titanium alloy. When materials are used in corrosive environments the surface finish plays a crucial role. Titanium alloy is one such material used in aerospace and biomedical applications. They used response surface methodology to optimize the cutting parameters.

Various approaches like CAD-based, Operations Research (OR) and Artificial Intelligence (AI) are used to optimise the cutting parameters in CNC machining. Kyung Sam Park & Soung Hie Kim (1998) have given the overview of the various approaches and have reviewed the AI based technique in achieving on-line adaptive control.
2.4 EFFECT ON TOOL FLANK WEAR

Tool wear is an important criterion as it influences the productivity, surface finish and the product cost. When the tooling costs go high the cost of production also goes up and finally the product cost is escalated. With CNC machines the cost of the cutting tools is high. Flank wear is mainly attributed to the rubbing action of the tool on the machined surface. Crater wear happens at higher cutting speeds and feeds. Since flank wear is prominent the life of the tool depends on the amount of flank wear.

Dutta et al (2013) studied the correlation between the tool flank wear and the texture of the machined surface. The end-milled surface images were analyzed using image texture analysis method. They applied Gray Level Co-occurrence Matrix (GLCM) and Run Length Statistical (RLS) techniques on the pre-processed images.

Liew et al (2008) analyzed the wear of PVD-coated carbide and uncoated carbide tools in milling of modified AISI 420 stainless steel at low speeds. They studied the effect of cutting speed and the work piece hardness on the tool flank wear. They also found that the use of cutting fluid considerably reduced the sudden tool failure.

Zuperl Uros et al (2009) applied a neural-fuzzy scheme to predict the flank wear from cutting force signals. Machining experiments were conducted using the proposed method and they found that by using appropriate maximum force signals, the flank wear can be predicted within 4% of the actual wear in end-milling operations.

A neural network-based sensor fusion model was developed by Ghosh et al (2007) for Tool Condition Monitoring (TCM). Signals for cutting
forces, spindle vibration, spindle current, and sound pressure level were fused to estimate the average flank wear of the main cutting edge.

Li et al (2006) performed an experimental study of the tool wear propagation and cutting force variations in the end milling of Inconel 718 with coated carbide inserts. They found that the peak force variation in a single cut pass was due to thermal effects and the gradual increase of the mean peak force in successive cuts was due to the tool wear propagation.

Krain et al (2007) in their experimental work evaluated the effect of feed rate, radial depth of cut, and tool material and tool geometry on the tool life and tool wear during end milling of Inconel 718. In their first phase they used a fixed tool material and geometry to examine the effects of various feed rates and radial depths of cut. In their second phase, they examined a reduced number of parameters but various different tool materials and geometries were utilized.

Pinaki Chakraborty et al (2008) used PVD coated carbide inserts under semi-dry and dry cutting conditions and proposed a mixed effects model for the analysis. They found that this modeling approach considered unobserved heterogeneity during machining and proposed a tool wear progression model that can better detect effects of significant factors than traditional regression models.

Bulent Kaya et al (2011) trained ANN based decision making model using the acquired cutting force and torque signals along with cutting conditions and time. They also developed an online Tool Condition Monitoring (TCM) system for milling of Inconel 718 super alloy.

Jacob C. Chen & Joseph C. Chen (2005) proposed an Artificial-Neural-Networks-based In-process Tool Wear Prediction
(ANN-ITWP) system. They took the feed rate and depth of cut from the cutting parameters and the average peak force in the $y$-direction collected online using a dynamometer as input variables for the proposed ANN-ITWP system.

Kang-Jae Lee et al (2007) studied the influence of force components from different parameters on the measured spindle current and employed a hybrid approach to regulate the cutting force for tool wear signal extraction from the spindle current.

Palanisamy et al (2008) studied the effect of cutting speed, feed and depth of cut on the tool wear. They used two modeling techniques, regression mathematical model and Artificial Neural Network (ANN) model for predicting tool wear. The Design of Experiments (DoE) technique was used to conduct experiments with three factors at five levels. The experimental data was used to train the feed forward back propagation Artificial Neural Network (ANN) for prediction of tool wear.

Aldo Braghini Junior et al (2009) studied the effect of cooling and lubrication on the tool wear while machining precipitation-hardened martensitic stainless steel and found that tool lubrication was effective in preventing tool damage due to tool temperature variations.

An attempt was made by Chen Zhang et al (2013) to measure tool wear in milling operation using carbide tools. A model based procedure for predicting tool-wear progression by using machining simulation was attempted by Chen Zhang et al (2013). They developed a NC milling machining process simulation software NCToolWearSim by using Visual C++ and OpenGL. The developed process simulation software was used to simulate the cutting process.
Guofeng Wang et al (2013) have used Gaussian Mixture Regression (GMR) model to predict continuous tool wear based on features extracted from cutting force signal. Experiments were conducted on titanium alloy milling to test the effectiveness of the proposed method. They also used multiple linear regression, radius basis function, and back propagation neural network to make a comparison with the GMR model. It was found that GMR-based method was the most accurate among these methods.

Rapid tool wear becomes the limiting factor in maintaining consistent machining quality of the composite materials. Azmi et al (2013) used Multiple Regression Analysis (MRA) and neuro-fuzzy modeling to predict and monitor the wear on carbide tool in end milling of Glass Fibre-Reinforced Polymer (GFRP) composites.

A tool wear model which includes abrasive, adhesion and diffusion wear implemented in a commercial Finite Element (FE) code to predict tool wear in machining hydrogenated titanium alloy Ti-6Al-4V with uncoated carbide tools has been developed by Shubao Yang et al (2013). Digital image processing technique was used to analyze the images of worn cutting tools to assess the amount of wear and thereby predict the remaining useful life of the tool was used by David Kerr et al (2006).

Tsao (2009) adopted Grey-Taguchi method to optimize the milling parameters to machine A6061P-T651 aluminum alloy. He used the grey relational grade obtained as the performance characteristic in the Taguchi method. Then, the optimal milling parameters were determined using the parameter design proposed by the Taguchi method.

Jurkovic et al (2005), using a CCD camera and laser diode with linear projector determined the profile deepness on a tool surface which gives
a 3D image of relief surface. This gives an accurate idea about the tool condition.

Nouari & Ginting (2006) studied the performance of alloyed carbide tools during dry machining of titanium alloy Ti-6242S. The tools were analyzed in terms of tool life and surface finish. Experiments were conducted using uncoated carbide tool and multi-layer CVD coated tool. Tool failure modes and wear mechanisms for both tools were examined at various cutting conditions. The localized flank wear ($V_b$) was found to be the predominant tool wear for both the tools.

Flank wear of cutting tools is often selected as the tool life criterion because it determines the diametric accuracy of machining, its stability and reliability. Viktor P. Astakhov (2004) analyzed the flank-work piece contact interface through the experimental assessment of the contact stresses and found that the minimum tool wear occurs at the optimum cutting speed.

Chen Zhang et al (2011) proposed a new approach based on shape mapping to acquire tool wear in order to establish an off-line tool wear predicting model for assessing the degree of wear and remaining useful life. After finishing each of the machining experiments the tool is used to make a milling hole in a material which has less influence on the tool wear. The characteristic parameters of these holes are measured using a Co-ordinate Measuring Machine (CMM) to correlate the shape with the tool wear.

2.5 EFFECT ON CUTTING FORCE

Cutting force prediction is important for the planning and optimization of machining process.
Seok-Hying Bae et al (2003) developed a cutting force model with two independent variables, a geometric measure called chip-load and feed rate. Based on 2D chip-load analysis for the concave line-line segment of NC tool path, the feed rate is calculated automatically using the simplified-cutting force model (SCFM) obtained by the cutting experiment with a tool dynamometer.

Choy & Chan (2003) developed an improved NC tool path pattern for pocket milling. While milling around corners, cutting resistance rises momentarily due to an increase of cutter path length. Bow-like tool path segments are appended to the basic tool path at the corner positions. In corners the cutter loops around the appended tool path segments so that corner material is removed progressively in several passes.

Tae-Yong Kim & Jongwon Kim (1996) developed an adaptive cutting force controller for milling processes. The cutting forces of x, y and z axes are measured indirectly from the use of currents drawn by a.c. feed-drive servo motors. The pulsating milling forces were measured indirectly within the bandwidth of the current feedback control loop of the feed-drive system. The indirectly measured cutting force signals can be used in the adaptive controller for cutting force regulation.

Various cutting parameters like spindle speed, feed rate, depth of cut influence the cutting force. Li et al (2006) have analysed the cutting force variation along with the tool wear propagation. They found that the thermal effects could be a significant cause for the peak force variation within a single cutting pass.

Abou-El-Hossein et al (2007) studied the effect of cutting speed, feed rate, radial depth and axial depth of cut on the cutting force and
developed first and second order models for predicting the cutting force produced in end-milling operation of modified AISI P20 tool steel.

Lei Zhang & Li Zheng (2005) analysed the effect of the variable radial depth of cut, which is generally encountered as the end mill enters and exits the corner, on the cutting forces which further affects the contour accuracy of the milled pockets. They have developed an analytical model of cutting forces for steady state machining condition.

Zhao-cheng Wei et al (2010) developed a new approach to predict the cutting forces for the whole finishing process of generalized pocket machining. They discretized the pocket into a series of small processes and each of the small processes was transformed into a steady-state machining using a new approximation method. The cutting geometries of each discrete process, i.e., feed direction, equivalent feedrate per tooth, entry angle, and exit angle are calculated based on the information refined from NC code.

Hyun-Chul Kim (2011) optimized the generated tool path to maintain a constant MRR and thereby to achieve a constant cutting force and avoid chatter. He used pixel-based simulation technique to generate additional tool path segments.

Sung-Joon Kim et al (2006) developed an algorithm, for indexable end mills, that calculates tool geometry data at an arbitrary axial position. They developed a cutting force model which uses cutting-condition-independent cutting force coefficients which considers run out, cutter deflection, geometry variation and size effect for accurate cutting force prediction.

Han-Ul Lee & Dong-Woo Cho (2007) developed a new method to obtain the most appropriate reference cutting force for rough milling. The
reference cutting force was determined by considering the transverse rupture strength of the tool material and the area of the rupture surface. They used finite element method to accurately calculate the area of rupture surface.

Adetoro & Wen (2010) used Finite Element Analysis (FEA) as a numerical tool to simulate the cutting process and determine both the average and instantaneous cutting force coefficients. They used Arbitrary Lagrangian and Eulerian (ALE) Formulation in FEM simulations. The cutting force coefficients were obtained using the least squares method.

Palanisamy et al (2006) developed a dynamic cutting force model for end milling to predict the tangential cutting force and thrust force. Also they have used Oxley’s energy partition function and Rapier’s equation to study the thermal effect on the cutting force.

Devi Kalla et al (2010) utilized mechanistic modelling techniques for simulating the cutting of Carbon Fibre-Reinforced Polymers (CFRP) with a helical end mill. They have developed a methodology to predict the cutting forces by transforming specific cutting energies from orthogonal cutting to oblique cutting.

Radhakrishnan & Uday Nandan (2005) attempted to develop an empirical relationship between the cutting force in an end milling operation and the cutting parameters such as cutting speed, feedrate and depth of cut, by using both multiple regression and neural network modeling. Regression model was used to fit the experimentally collected data and filter out any abnormal data points. The final set of filtered data was analysed using neural networks to yield a final model.

Kaymakci et al (2012) developed a unified cutting mechanics model to predict cutting forces in milling, boring, turning and drilling
operations. The process models combine the material properties, cutting mechanics, tool geometry, process kinematics and structural dynamics and are used to predict force, torque, power, form errors and vibrations during metal cutting operations.

Omar et al (2007) introduced a generic and improved model to simultaneously predict the conventional cutting forces along with 3D surface topography during side milling operation. Their model incorporates the effects of tool runout, tool deflection, system dynamics, flank face wear, and the tool tilting on the surface roughness.

Li et al (2008) in their work used an extended octree method to represent the work piece and tool swept volume to acquire the cutting depth and cutting width with high precision so that cutting forces can be predicted precisely. They have developed a framework of cutting force prediction based on virtual machining.

Jian-Wei Dang et al (2010) proposed a mechanistic cutting force model which considers the overall cutting forces contributed by both the flank edge and the bottom edge cuttings simultaneously. They found that the bottom edge cutting has a remarkable effect on the total cutting forces, when the axial depth of cut is relatively small.

The selection of cutting tools and machining strategy and parameters, which have a significant impact on overall machining efficiency and process reliability, still depends on the experience of the machinist or the NC programmer. Zeki Yazar et al (1994) developed a method for estimating the cutting forces in 3-axis milling of sculptured surface. The NC programmer can optimize the machining parameters especially the feed rate based on the predicted cutting force.
Optimization based on physical simulation can give a better control of a machining process, especially to a variant cutting process, where the cutting parameters, such as cutting depth and width, change with cutter positions. Li et al (2004) have used heuristic methods for feed rate optimization based on cutting force prediction. Each cutting path segment is divided into micro-segments. Feed rates at several segments are determined together to make milling force satisfy various practical constraints of milling.

Jeong Hoon Ko et al (2003) developed a virtual machining system which can simulate real machining for a given set of NC codes. They have formulated an analytical model for off-line feed rate scheduling to regulate the cutting force and thereby improve the productivity and machining accuracy.

Kline et al (1982) developed a model which is based on chip load, cut geometry and the relationship between cutting forces and chip load. Both instantaneous and average force system are described as a function of cut geometry and feed rate. Force characteristics during cornering cuts are predicted by the model and are examined as a function of axial depth of cut and feed rate.

2.6 MODELING USING RESPONSE SURFACE METHODOLOGY (RSM)

The factors that are considered as most important are used to build a polynomial model in which the independent variable is the experiment’s response. Mathematical models have been developed using RSM technique to predict the output characteristics of any machining process. Some of the works done by various investigators who have used RSM technique for modeling are presented in this section.
Alauddin et al (1996) developed mathematical models for surface roughness with respect to cutting speed and feed rate by response surface methodology to optimize the surface finish in end milling of Inconel 718 using uncoated carbide inserts under dry machining conditions.

Bhattacharya & Sorkhel (1999) attempted to develop a comprehensive mathematical model to correlate the influences of various machining parameters on the dominant machining criteria like material removal rate and over cut phenomena through RSM. They used the experimental data for modeling.

Sahin et al (2005) developed a surface roughness prediction model for machining mild steel with TiN coated tungsten carbide cutting tools using response surface methodology. A second order mathematical model, in terms of cutting parameters was developed by them.

Suresh et al (2002) tried to prove that it is necessary to use theoretical models to know the experiment's response in advance. The models make it feasible to do prediction in function of operation conditions.

Polynomial models are widely used as approximating functions and normally a second order polynomial is used to form mathematical models. Palanisamy et al (2008) used regression analysis to develop a second-order polynomial model to predict the tool wear in end milling operations. The input parameters used for conducting experiments were cutting speed, feed rate and depth of cut.

Palanikumar (2008) established a second-order model with cutting parameters, viz., cutting speed, feed rate and depth of cut and surface roughness as the output parameter. They developed the model using RSM while machining glass fiber-reinforced plastics with a polycrystalline
diamond tool. RSM and ANOVA were used to evaluate the composite machining process to perform the optimization for investigating the parametric influence of machining parameters on surface finish.

Abou-El-Hossein et al (2007) developed first and second order models for predicting the cutting force produced in end-milling operation of modified AISI P20 tool steel. The first and second order cutting force equations were developed using the Response Surface Methodology (RSM) to study the effect of four input cutting parameters, cutting speed, feed rate, radial depth and axial depth of cut, on cutting force.

2.7 MODELING USING ARTIFICIAL NEURAL NETWORK (ANN)

Muthukrishnan et al (2008) developed two modeling techniques to predict the surface roughness namely ANOVA and ANN. In ANOVA, it is revealed that the feed rate has the highest physical as well as statistical influence on the surface roughness right after the depth of cut and the cutting speed. ANN methodology consumes lesser time and gives better accuracy. The authors concluded that optimization using ANN is the most effective method compared with ANOVA.

Basheer et al (2008) developed an ANN based model to predict surface roughness of machined surface of Al/SiCp composites. The predicted roughness of machined surfaces was found to be in very good agreement with the unexposed experimental data set.

Surface roughness is an indication of the machining performance, which has to be minimized. To predict the minimum $R_a$ value a standard mathematical model was developed using regression and ANN by Azlan Mohd Zain et al (2012).
2.8 OPTIMIZATION USING GREY RELATIONAL ANALYSIS

The proposed models are subjected to optimization techniques to find out the cutting conditions for economical machining. Taguchi method is one of the techniques used for optimizing a single performance characteristic. The optimization of the multiple characteristics with Taguchi method requires further research. For machining of any metal, the surface roughness, tool wear and cutting force of lowest values will have the best fit characteristic and the material removal rate of highest value will have the best characteristic. As a result, an improvement in one performance characteristic may require the degradation of another performance characteristic. Hence, multiple performance characteristics are much more complicated than optimization of single performance characteristic. The orthogonal array with grey relational analysis can be effectively used for optimizing multiple performance characteristics (Lin et al. 2002).

The grey theory, first proposed by Deng (1989), avoids the inherent defects of conventional, statistical methods and requires only a limited amount of data to estimate the behavior of an uncertain system. During the past two decades, the grey theory has been successfully applied to research in industry, social systems, ecological systems, economy, geography, traffic management, education, environment, etc. Grey relational analysis is based on geometrical mathematics in compliance with the principles of normality, symmetry, entirety, and proximity. Fung (2003) has further applied grey relational analysis to the manufacturing process optimization for wear property of fiber-reinforced polybutylene terephthalate composites.

The application of this technique converts the multi response variable into a single response grey relational grade and therefore, simplifies the optimization procedure. An integrated Neural Network-Grey Relational Analysis-Genetic Algorithm (NN-GRA-GA) system has been developed by
Fengguo Cao & Qinjian Zhang (2004) for successful determination of the optimal process parameter. Narender Singh et al (2004) have used grey relational method for optimizing the Electro Discharge Machining (EDM) process parameter on machining Al/SiCp composites. The Grey-Taguchi method has been applied to optimize multiple performance responses of arc welding, drilling, electro discharge machining (Lin et al 2005) and flank milling process (Kopac & Krajnik 2007). Recently, Lung Kwang Pan et al (2007) has applied and demonstrated the effectiveness of optimizing multiple quality characteristics of Nd:YAG laser-welded titanium alloy plates via Taguchi method based grey analysis. In the present work, grey relational analysis has been applied to optimize the machining parameters during the machining of AISI 1045 steel.

2.9 SUMMARY

It is easier to optimize the machining parameters with a CNC machine than with conventional machines. Many researchers have taken cutting speed, feed rate and axial depth of cut as the machining parameters and have made attempts to create various statistical and mathematical models to predict the output responses like surface roughness, tool wear, cutting force and Material Removal Rate (MRR). A few researchers have used grey relational analysis for multi-performance optimization.

Except for in the case of adaptive control system in most of the machining experiments the feed rate is kept constant, at least for a given cut-segment. In this context the author has made an attempt to introduce a new feed rate method, named as ‘Progressive Feed Rate’ method wherein at the start of any cut-segment the feed rate is increased gradually rather than using a constant feed rate. To the best of the author’s knowledge based on the extensive literature survey conducted no one has made a similar attempt.
This investigation has proposed to conduct machining experiments with both the existing ‘Constant Feed Rate’ and the proposed ‘Progressive Feed Rate’ methods. The output parameters, surface roughness, tool wear, cutting force and material removal rate in both the methods will be compared to find the effectiveness of the proposed method. The experimental data obtained from the proposed method will be analyzed and mathematical models using response surface methodology and ANN will be developed.

2.10 SCOPE AND OBJECTIVES

Virtual machining and off-line optimization are gaining importance especially with respect to CNC machining. They avoid catastrophic failures while doing actual machining. CNC machines are primarily employed wherever the characteristics of the output responses are critical. Since, only a limited research has been done focusing mainly on the feed rate, this research gains significance. It is necessary to optimize the machining parameters in order to improve the MRR, tool life, surface finish in the work piece, and to reduce the cutting forces. Multi-performance optimization will give an overall improved machining. Based on the above facts, objectives of the investigation are set out as follows:

- To investigate the effectiveness of the proposed progressive feed rate method
- To conduct experiments for both the existing constant feed rate and the proposed progressive feed rate method
- To compare the output responses, surface roughness, tool flank wear and the cutting force between the existing and the proposed method
• To study machining characteristics using PVD and CVD coated carbide inserts and Uncoated carbide inserts for comparison

• To use Response surface methodology (RSM) to create regression mathematical models for predicting surface roughness, tool flank wear and cutting force

• To use ANOVA to verify the validity of the regression model and to identify the significance of the individual input parameters on the output response

• To create Artificial Neural Network (ANN) model to model the output responses and to further validate the regression models

• To carry out multiple performance optimization using Grey Relational Analysis (GRA) to optimize the machining parameters for better output responses such as surface roughness, tool flank wear and cutting force.

The scheme of this research is given in Figure 2.1.
Performance studies on the effect of progressive feed rate in CNC machining

Milling

Work Piece Material

AISI 1045 Steel

Cutting Tool Inserts

• PVD Coated Carbide Insert
• CVD Coated Carbide Insert
• Uncoated Carbide Insert

Machine Tool

3-Axis VMC CNC Machining Center

Observations

Surface Roughness

Tool Flank Wear

Cutting Force

Modelling

• Response Surface Methodology (RSM)
• Artificial Neural Network (ANN)
• Grey Relational

Conclusion

Figure 2.1 Scheme of the Research