CHAPTER 3

LITERATURE REVIEW

Detailed survey on the research works recently published in the eminent journals was studied in-depth to acquire best knowledge and understand the constraints of the study.

3.1 REVIEW OF LITERATURE

For several years, rigorous research has been conducted in the area of CNC milling from diverse perspectives (Raksin and parnnichkun, 2004; Siller et al., 2006; Omiru and Nearchou, 2009; Rahnama et al., 2009). Some investigators seem to contribute to the expansion of the frontier of CNC milling knowledge by focusing on system performance improvement tools such as sensors (Ertekin et al., 2003), neural and adaptive networks as well as fuzzy controllers (Chen and Men 2000; Liang et al., 2002 Uros et.al., 2009; Zuper et al., 2011; Kim and Jeon, 2011). Others applied optimization techniques to achieve their goals in CNC milling research (Ghani et al., 2004; Yang et al., 2009). Still, others have focused on different aspects such as hardenability (El-bestawi et al., 1997), nano surface generation (Cheng et al., 2008), new material study (Sharman et al., 2001), free-from surface studies (Terrier et al., 2004), carbon steels (Kumar et al., 2012) and tool life (Vojciechowski and Twardowski, 2012), thus the paragraphs follow contain a comprehensive review of existing studies in the literature in its divisive modes, covering the various contributions of the authors till date.

The research paper by Moshat et. al. (2010) studied optimization of CNC milling process parameters using PCA-based Taguchi method that had
served the purpose of optimization but not simultaneous optimization of surface roughness and the material removal rate in the study. Routara et. al. (2010) had given the outline of the soft material milling parameters in their study on optimization of CNC end-milling of UNS C34000 medium-lead brass with multiple-surface roughness characteristics. A single-response study provided base in determining the parameters that were studied. The case studies conducted at the laboratory have prompted for the real-time studies and to find the solution for the manufacturing firms around the place. Mustafa and Ali (2006) analyzed the effect of the length and diameter of work piece, depth-of-cut and feed while the cutting speed, which is an important machining parameter, was kept constant. Taguchi method was used in this work in order to obtain more reliable and optimum results.

Cusa et. al. (2011) criticized the excessive use of high-speed milling for precision machining of aluminium and magnesium and more frequently used results in high quality of the surface and shorter machining times by omitting grinding. Kadirgama and Noor et. al. (2008) highlighted the optimization of the surface roughness when milling aluminium alloys (AA6061-T6) with carbide coated inserts using response surface method (RSM) and Radian Basis Function Network (RBFN) to predict thrust force and surface roughness. Kechagias (2011) brought out the influence of cutter geometry and cutting parameters during end-milling on the surface texture of aluminium alloy 5083 that was experimentally investigated using Taguchi L18 standard orthogonal array. Fang et. al. (2007) presented the fact that the extensive research has been conducted in the past on tool flank wear and crater wear in high-speed machining by investigating the effect of tool edge wear on the cutting forces and vibrations in 3D high-speed finish turning of nickel-based super alloy Inconel 718. Abele and Frolich (2008) compiled the case study of high-speed milling of titanium alloys and provided base for different metallurgical and machining conditions to be taken into account for
the study. The case study of titanium based alloys were conducted for the high-speed milling process for sets of input parameters with moderate cutting speeds and feed rate to get better material removal of aircraft materials.

Aggarwal and Singh (2005) reviewed various linear and non-linear optimization techniques in detail and the relative advantages are also discussed and inferred for the non-linear optimization methods, the most suited for the optimization of machining processes. The suggestion of the authors is to follow appropriate set of optimization methods based on the problem on hand and also to use a base statistical method to obtain the initial basic feasible solution and a non-linear methodology like genetic algorithm, according to the respective problem and solution requirements. The real frame work was developed by the study conducted by Yih-Fong and Chen (2005) on two-phased parametric optimization for better accuracy by Taguchi’s robust design method, which prompted the two-phase analytical technique with Taguchi’s DOE and simultaneous optimization procedure to give away the various parameters on surface roughness requirements followed by a case study. Sai and Bouzid (2005) developed the simulation models and analysis of the chip formation and the surface roughness for up face milling process conducted to get the optimal parameters and suggested to consider the more number of parameters with higher levels of analysis to get the best set of parameters including the cutting force, tool wear rate and wet or dry process. Fidan and Elsawy highlighted (2002) the knowledge based solution using various cutting conditions for optimizing the milling process and found out software solution to get the optimal parameters with machining involving large numbers of varying parameters.

Mike Lou et al. (1999) developed the prediction technique for the surface roughness of the CNC end-milling process but focused only on the roughness average but not at the material removal rate. The above literature
analysis had given us an opportunity to know the state of the art and the need of the hour for the small and medium type companies, where the experiments were conducted for the case study.

This work focuses on comprehensive solution to the optimal output of the lowest average surface roughness with optimally high rate of material removal for the finish operation of the aluminium 6061 and stainless steel 304 with high speed machining operation. The above literature study also revealed that the controlling parameters are the speed of the spindle, feed rate of the cutting tool, depth-of-cut, material hardness and the type of insert used for machining (Moshat et al. 2010). The literatures have generally discussed the factors and parameters with single objective and the same have given us the base idea of the various factors involved and the parameters to be studied with this case study (Kechagias et al. 2011). The improvements and strides of the earlier researchers are taken as benchmark for the start up of the work, and one of the relevant areas of improvement at simultaneous optimization of the parameters is studied in this paper. The need for optimized parameter set for best roughness measures with improved metal removal rate by controlling the relevant parameters (Kadirgama et al. 2008) was realized. This study excludes and fixes less influencing tool wear, cooling method, Cutting force, tool geometry and tool metallurgy and many other factors as they were discussed in detail by the researchers and got optimized earlier (Routara et al., 2010; Mustafa and Ali 2011), hence the contributions by the researchers are considered as best suited, kept as constant and referred as least influencing factors for the simultaneous optimization.

Palanikumar et al. (2011) studied the machining parameters, including cutting speed, feed and depth-of-cut, which were considered for experiments and mathematical modeling, developed using RSM and optimization of process parameters is carried out using desirability function-
based approach but failed to recognize the importance of the response MRR for productivity.

Babu et al. (2010) concluded that feed rate is the predominant contributor to better surface finish, followed by the spindle speed and depth-of-cut. The study indicated that when the feed rate is 0.1mm/rev, cutting speed is 111.5 m/min and depth-of-cut of 0.2 mm, the lowest surface finish is attained for CNC turning process.

Alao and Konneh (2011) reported the effectiveness of the use of Taguchi and Box-Behnken designs for minimizing surface roughness in precision grinding of silicon using resin-bonded diamond-mounted wheels. Taguchi method was used to study the effect and optimisation of grinding parameters while Box-Behnken method was utilised to develop a mathematical model relating the average surface roughness to the grinding parameters, depth-of-cut, feed rate and spindle speed.

Mee (2009) in his thesis reported on the sequential nature of response surface methods and proposed a class of three-level designs and an analysis that will address these shortcomings and aid the user in being appropriately advised as to factor importance.

Khidhir and Mohamed (2010) reported that the chip burr has a significant effect on tool damage, starting in the line of depth-of-cut. For the coated insert tips, the burr disappears when the speed increases to above 150 m/min with the improvement of surface roughness; increasing the speed above the same limit for uncoated insert tips increases the chip burr size and showed that the surface finish of nickel-based alloy is highly affected by the insert type with respect to cutting speed changes and its effect on chip burr formation and tool failure.
Raksiri and Parnichkun (2004) tried new off-line error-compensation model by taking into account the geometric and cutting force-induced errors in a 3-axis CNC milling machine. The geometric and cutting force-induced errors in flat end-mill of slot cutting, which were estimated and found to be highly non-linear.

Natarajan et al. (2011) reported that the behavior of response is non-linear and non-predictive as surface roughness decreases for increased spindle speed and lowered feed rates, but for higher feed rates, the depth-of-cut influences the surface roughness considerably. For a given feed rate, the increase in feed rate causes the surface roughness to increase and then decreases.

Arif et al. (2010) developed an analytical model based on Griffith’s energy-balance criterion for brittle fracture to predict the critical chip thickness for ductile–brittle transition in micro-cutting of tungsten carbide by end-milling and established that ductile-mode machining of tungsten carbide can be performed efficiently by end-milling process within certain critical limits of cutting conditions governed mainly by the material properties and tool geometry.

Mahdavineja and Saeedy (2011) have reported the effect of process parameters of cutting speed and feed on the quality of turning of AISI 304 stainless steel machining and tool flank wear is closely related to the cutting speed, so that it decreases significantly by increasing the cutting speed. Surface roughness is mostly affected by the feed rate, so that the surface finish can be improved by decreasing the feed rate as well as increasing the cutting speed. Since, at higher speeds and lower feed rates built-up edge decreases, so do the cutting forces and machine vibrations.
Tzeng and Jean (2005) presented a Taguchi dynamic approach which was integrated with ideal function model. The methodology was employed in evolving an optimal high-speed CNC milling process of high-dimensional quality. It was reported that the experimental results show that dimensional accuracy of the machined product significantly improved with the use of the optimal conditions produced by the Taguchi approach.

In another work, Lo (2000) examined a CNC machine tool interpolator for generating the cutter path for ball-end milling of a free–from surface whose surface interpolator comprises of on-line algorithms cutter-contact (cc) path scheduling, path scheduling, CC path interpolation, and tool offsetting. The work further developed interpolator algorithms for iso-parametric, iso-scarellop and iso-planar machining methods. It was concluded that the surface interpolator method minimized the data loaded to the CNC machine tool and maintained the desired feed rate and position accuracy along the CC path.

Shokrani et al. (2012) focused on the cryogenic CNC end-milling of the Inconel 718 nickel based alloy using TiAIN coated solid carbide tools. The study concluded that cryogenic cooling potentially improves surface roughness of machined parts relative to the dry machining. This advantage was achieved with insignificant power consumption of the machine tool.

Yet in another study, El-Mounayri et al. (2005) dealt with an integrated product development system for optimized CNC ball-end milling. The work was an improvement of earlier submissions, which now contains technical detail extensions from flat end-milling to ball-end milling from 2D (speed and feed) to 3(1/2) D (speed, feed, radial and axial depth of cut) and the modeling as well as simulation of the flat-end milling that included more input variables. The work was formed, through verification and validation to be in good agreement between predicted and experimental measured parameters.
A practical approach to generating accurate iso-cusped tool path in the process planning of sculptured surface parts was contributed by Chen and Song (2006). The authors noted that the approach has implementation feasibility in manufacturing industry where it could be integrated into the computer-aided manufacturing software systems, which will ultimately promote the usage iso-cusped tool paths.

Dotcheva and Milward (2005) reported a theoretical and experimental methodology for the efficient planning of finishing end-milling operation for machining a pocket-type contour. The focus was to overcome human error in the system, thus generating better cutting conditions for given tool path. With the development of geometric relationship among the cutting tool, corner-milling operation and machine surface, a mathematical model that described the cutting phases during the corner cutting was developed, optimized and experimentally verified. It was concluded that the optimized model was efficient, exhibiting “in-tolerance” accuracy and surface roughness.

Osornio-Rios et al. (2008) examined the application of reconfigurable logic to high-speed CNC digital controllers in a situation that the high processing speed at the servo loop update time is critical. The conclusion is that the PID system is functional and has been synthesized into a low-cost reconfigurable device like field programmable gate array, which was applied to a high-speed CNC milling machine.

In Benardos and Vosniakos (2002), a neural network modeling approach to the prediction of surface roughness in CNC face milling was contributed. Experimental validation of the model was made using data obtained a system based on the following factors: depth-of-cut, the feed-rate-per-tooth, cutting speed, the cutting tool wear, its engagement, the use of cutting fluid and the three components of the cutting force. The data obtained were processed under Taguchi methodic application and then used for training.
and monitoring the networks performance. The surface roughness was predicted with a mean squared error of 1.86%.

Tzeng (2007) presented the application of Taguchi methods integrated with principal component analysis for process optimization of the high-speed CNC milling tool steels SKD-11 and SKD-61 using a set of optimal process conditions for obtaining the best-rate precession, accuracy surface roughness and tool wear. Based on experimental results the optimal process conditions for the high-speed CNC milling process was determined as $A_1$ (down-milling), $B_1$ (cutting speed, 150 m/min), $C_2$ (feed per tooth, 0.04 mm/tooth), $D_3$ (film material, TiAIN), $E_2$ (tool material, k20), $F_3$ (number of teeth, 4) $G_1$ (rake angle, 4°) and $H$ (helix angle, 30°). It was concluded that the optimal process shows that the multiple performance characteristics were optimized for the best levels of results achievement.

Kwon et al. (2006) investigated the closed-loop measurement error in CNC milling in relationship with different inspection techniques. Verification of the approach was done through empirical means with the conduct of three cutting experiments and the use of design of experimental methodology with three levels and three factors on a CNC machine centre. The result of cutting condition simulation using three material types and parameter setting showed potentiality of improvements in production efficiency and improvements in production efficiency and improved part quality.

Dweiri et al. (2003) developed a down-milling machining process of alumic-79 with the use of adaptive neuro-fuzzy inference system as a tool to predict the effect of machining variables (spindle speed, feed rate, depth-of-cut, and number of flutes) on the surface finish of alumic-79 for the purpose of improving and increasing its range of application. It was concluded that for the two flutes, the minimum surface roughness of 0.327mm was achieved at
the spindle speed of 2000 rpm, feed rate of 0.05mm/tooth and a depth-of-cut of 2mm.

Ozcelik and Bayramoglu (2006) dealt with a statistical model for estimating the surface roughness in high-speed flute end-milling process considering wet conditions of cutting. The variables of interest in the work are spindle speed, feed rate, depth-of-cut and step-over. The authors developed first and second-order models from experimental results of a notable central composite design while the assessment was done by statistical tests. It was reported that the highest coefficient of correlation ($R_{adj}^2$) (88%) and order of significance of the main variables is as $x_5 > x_3 > x_4 > x_1 > x_2$, where $x_i$ represents the variables of interests and are total machining time, depth-of-cut, step-over, spindle speed and feed rate respectively.

Gordon and Hillery (2005) analysed how a low-cost, high–speed cutting machine was built using linear motors so as to conduct machining tests using a composite material. The configuration of the machine was a gantry $x/y$ motion system with a mounting of a high-speed electro-spindle and inter-faced with a stand-alone CNC controller for which a C$^H$ Microsoft Windows programme was written. The CNC machine is capable of a table speed of over 40m/min and a spindle speed of 30,000 rpm.

Colak et.al (2007) claimed to have used gene expression programming method to predict the surface roughness of milling surface with related cutting parameters (i.e. cutting speed, feed and depth-of-cut of end-milling operations). The work concluded that the linear equation developed suitably predicted the surface roughness of the work piece from experimental study.

Hatna et al. (1998) reported a literature survey that captured the important area of pocket machining, which includes the machining of mechanical parts, dies and moulds. They examined the relationship among shape, cutter, machine tool and cutting conditions in the optimization process
of cost and lead time of pocket milling. The results of their review showed the geometric aspects of pocket extraction and tool path generation with the optimization of cutting conditions as an impact to the process planning of the CNC machining of pockets.

Mecomber et al. (2005) dealt with an approach to the generation of aluminium masters used in the replication of polymer-based microfluidic devices by CNC milling. To overcome previous limitations of CNC milling, several novel advancements were made. First, external calibration and measurement of the milling process was made to achieve micro features with tolerance up to a factor of ten better than what is expected from the CNC mill used. Second, 102mm diameter high-density microgram carbon end-mills were used with all mining steps externally calibrated and measured in order to reduce the unwanted volume occurring from two intersecting features. Third, keyway slots were milled into the master in order to accommodate various sizes of molding master keys as a means of generating masters with abutting features of different widths.

Beczea et al (2000) carried out an investigation on high-speed five-axis milling of hardened D2 tool steel (hardness HRC 63) by developing a five-axis analytical force model that takes care of the cutter location data file for computing the chip load. Multiple machine issues such as chip morphology, cutting forces, tool wear mechanisms, tool life and surface integrity were considered and the effects of complex tool paths on these issues together with that of instantaneous tilt angle variation on the forces were studied. It was conclude that the application of the model was feasible through a verification exercise.

Fontaine et al. (2007b) investigated the effect of tool-surface inclination on cutting forces in ball end–milling using a predictive milling force model based on a thermo-mechanical modeling of oblique cutting. The
method was claimed to be efficient in predicting accurately the cutting force
distribution on the helical ball end–mill flutes from the condition of tool
genometry, pre form surface, tool–path, cutting material behavior and friction
at the tool-chip interface with the application of the model to ball end-milling
with straight tool-paths having tool-surface inclinations, the results were
compared with data obtained from ball–ending experiments performed on a
three-axis CNC equipped with a Kistler dynamometer.

An optimal tool orientation control for 5-axis CNC milling with ball
end cutters was recently proposed by Farouki and Li (2013). The authors
illustrated the method using closed form solutions for simple analytic
surfaces. It was concluded that the real-time implementation of the proposed
methodology was within the scope of modern CNC system.

Kaya et al. (2011) initiated an effective and efficient strategy based on
artificial neural network to estimate tool flank wear. The ANN model was
trained with the use of real time acquired three-axis ($F_x, F_y, F_z$) cutting force
and torque ($M_z$) signals as well as with cutting conditions and time. It was
concluded that the statistical performance of the ANN model was very good,
having a high correlation and low error ratio between the actual and predicted
values of flank wear.

The discussion by Preiss and Kaplansky (1985) centered on a part
program for milling using artificial intelligence techniques. The approach and
details of implementation were reported in the work. The input to the program
is the graphic representation of the part (a drawing), user defined items (tool
details, material type, etc). The author claimed that the program solves the
problem of achieving the goal state from the initial state with the use of
machining moves, and the part program. It was later stated that the
implementation produced a part program for a 2-part on a 3-axis CNC milling
machine.
Wojciechowski and Twardowski (2012) experimented to compare the tool life of sintered carbide (with TiAN coating) and cubic boron nitride ball end-mills by using hardened steel x 155CrVMo12-1 plate as the work piece during the milling process. The plate had a constant surface inclination angle, variable cutting speeds and feeds. The experiments involved the measurement of cutting forces and specific cutting pressures as functions of tool wear. The values obtained were applied to cutting force formulation; which has tool wear as one of its components. It was concluded that in a certain range of cutting speed, the total life acquired for sintered carbide can be higher than that obtained for cubic boron nitride tool. Furthermore, for cubic boron nitride cutter, abrasive wear was primarily independent of cutting speed.

Yang and Golub (1994) developed an approach, a CNC trajectory generation approach, which improved the cutter path tracking of high-precision milling of spatial contours and sculptured surfaces. The trajectory commands were obtained by solving the inverse dynamic problem enhanced with a cutter load predictor. The proposed algorithm utilized efficient machine dynamics formulation in a parameterized space. It was concluded that superior tracking performance over a wide range of operational speeds, i.e. low, medium and high was possible. Fontaine et al. (2007a) discussed the influence of tool-work-piece inclination on cutting forces in ball end-milling and calculated a thermo-mechanical modeling results based on a previous work with a comparison with experimental results. The model of the ball end-milling was applied to machining operations with straight tool paths and various tool-surfaces inclinations, including ramping and contouring configurations. The authors concluded with a discussion on the influences of cutting conditions, radial run-out and ploughing on cutting forces as well as cutting stability.

From the perspective of achieving maximum production rate and allowing for a wide range of machine tool and component surface roughness
constraints, Wang (1998) discussed the concept of optimization analysis, strategy and Cam software for single pass end-milling on CNC machine tools. The author claimed that the deterministic optimization approach involving mathematical analysis of constrained economic trends and associated graphical representation of the feed-speed domain provides a deeper understanding of the influences of constraints and guarantees global optimization attainment. The author reported on the superiority of the proposed approach over handbook recommendations.

Chang and Hong (2005) proposed a buffered digital differential analyzer algorithm, which performs milling electric discharge machining of a curve constructed from a sequence of segments using a traditional computer-aided manufacturing system interlinked to the computerized numerical controller. The authors demonstrated that the algorithm interpolates more than one segment in a sampling interval and supports the effective machining of a parametric curve on the condition that electrode crosses the connection between the shut segments.

Zuperl et al (2011) developed an application of neural adaptive control strategy to the problem of control of cutting force in high-speed milling operations. The work presented a framework for integrating adaptive control and a standard CNC for optimizing a metal cutting process. The architecture was confirmed as efficient through the conduct of numerical simulations and experimentations.

Wu et al (2002) used the principle of torque (force) balance of the ram components, the expressions of compensation forces (compensation torques) as well as the stroke distance of the ram for the theoretical analysis and structural characterization of super-heavy duty CNC floor type boring and milling machine of TK6932, rods compensation, hydrostatic pressure compensation and wire rope compensation measures to compensate the
deformation error of ram. The results obtained through experiments and computer simulation shows that straightness of the ram at its overhanging end meets industrial standards.

Dumitrache and Borangiu (2012) presented a NC tool-path generation strategy having a tool engagement control system that reduces machining time and tool wear suitably fit for use in high-speed machining. The system was designed for arbitrary complex discrete part geometry. The authors developed the tool-path computation based on image models for design part, raw stock and cutting tool. It also involves pixel-base simulation of the milling process. They claimed to have compared the method with existing ones successfully.

Topal (2009) extended previous works on surface roughness prediction to incorporate the step over ratio integrated with cutting speed, speed rate and depth-of-cut. The study focused on the role of the step over ratio in surface roughness prediction studies in flat end-milling operations. With experimental data collected from the study, ANN was applied with its structures trained and tested by using the measured data for predicting the surface roughness. It was concluded that the model, which incorporated step over ratio was capable of predicting the average surface roughness ($R_a$) with a good accuracy.

Solis et al. (2004) utilized chatter’s analytical prediction method, which was integrated with experimental multi degree-of-freedom systems model analysis. The focus was on attaining stability information for some vibration modes that could be used for graphing the stability lobes for high-speed milling, and in the selection of parameters for chatter free operations.

Lopez de Lacallea et al. (2002) proposed optimization tools for high speed milling (HSM) of GG25 grey iron castings and GGG701 ductile iron casting stamping dies from the point of view of their geometry, base material and coating. Experimental tests were carried out for validation purpose using coated carbide tools and PCBN (Polycrystalline cubic boron nitride) tools.
Ng et al (2000) presented a comprehensive review of literature on high-speed machining; specifically end-milling and ball end cutting for the machining of complex 3D aerofoil surface in titanium alloys and nickel-based super alloys. The work presented a review of published data on the effect of cutting/work piece orientation (i.e. engagement or tilt angle, on tool performance). Experimental work was done on the effect of cutter orientation on tool life, cutting forces, chip formation, specific force, and work piece surface roughness when high-speed ball end-milling Inconel 718™ under grey cutting condition using 8 angle of 45° from the cutter axis. A horizontal downward (BEN) cutting orientation provided the best tool life with cut length %0% longer than for all other directions (+βF, βF, and −βF).

In a further work, Ng et al. (2000b) experimented with determining the effect of cutter orientation, tool coating and cutting environment on tool life, tool wear mechanisms, when high speed ball nose and milling Inconel 718™, considered temperature measurements from the implanted thermocouple technique, which indicated that high pressure. Cutting fluid application substantially reduced work piece temperature from 320°C when cutting dry to 175°C.

Salami et al. (2007) optimized feed rate using two programs: “ACIS” (with scheme language) and “Visual Basic”. Scheme program was used for modeling the work piece, tool, cutting edge, and calculating maximum cutting force and the Visual Basic program was utilized to control all the activities linked to the ACIS program for estimating optimized feed values. Verification of the model and programs were made using laboratory tests and an insert-type one-flute ball-end cutter on a CK45 carbon steel work piece with no coolant used throughout the experimental works. It was concluded that significant increases in productivity was achieved by using the optimized feed rate method.
Kopac and Kampus (2005) presented the process controlled by CNC milling machine-tool together with CAD/CAM master Cam system and a smooth forming tool. They defined experimental testing and measurement with without a full-size model.

Monreal and Rodriguez (2003) discussed the influence of the tool path strategy on the cycle time of high-speed milling operations. Experiments were conducted and predictions made, focusing on pocketing operations with a zigzag tool path, quantifying the significant discrepancy between the programmed feed rate and the actual average feed rate. The work followed a mechanistic approach for cycle time evaluation. The mechanistic model construction is based on the experimental measurement of the machine tool acceleration and specific geometric assumptions regarding tool motion. The authors claimed that the approach is capable of capturing the influence of the zigzag tool path orientation on the machining cycle time.

Ning and Veldhuis (2006) analyzed a mechanistic approach for the simulation of ball-end milling, which incorporates tool wear that considers realistic cutting forces experienced during the full operation. The authors considered the total cutting force as the summation of the forces from the rake face, cutting edge, and flank face. The flank force was defined as a function of flank wear. The empirical tool wear model proposed is based on wear measurement at one-degree increments around the ball of the cutting-edge angle within the in-cut region of the tool. The model was declared as valid with a finishing operation on hardened HB die steel with uncoated tungsten carbide inserts.

Oktem et al. (2006) reported an approach to determining the best cutting parameters, leading to minimum surface roughness in end-milling mould surfaces of an Ortiz part, which is commonly used in biomedical applications by coupling neural network and genetic algorithm. These two
artificial intelligence techniques were then fused to design of experiments for optimization purposes. Experimental data and more extensive data were utilized to validate the work. It was concluded by the authors that experimental data predicted values agreed.

Gologlui and Sakarya (2008) investigated optimum cutting characteristics of DIN 1.2738 mould steel using high-speed steel and mills. The cutting parameters investigated are cutting velocity, feed rate, depth-of-cut and step-over. The effect of cutting path strategies when employing pocket milling was then investigated. These two issues were addressed with the use of Taguchi method.

Heo et al. (2011) presented a methodology that partitions a pocket machining area and identify machining features used for planning of high speed pocket machining, incorporating a machining volume slicing method based on geometric features of the pocket. The validation exercise was done by applying the partitioning algorithm in simple and complex shapes to a case in pocket milling.

Imani et al. (2012) developed a method for the prediction of cutting forces and surface texture in end-milling operation based on time series analysis. First, an equivalent damping ratio was defined for the cutting zone with the damping ratio of the non-cutting zone determined by experimental force signals. The model used for simulation incorporated time finite element analysis used for predicting the dynamics of the milling system. It was concluded that the implemented model accurately predicted cutting forces and a 3D surface texture for low radial immersion cutting.

Kious et al. (2010) established a relationship between the acquired signals variation and the tool wear in high speed milling process using an experiment as a variation tool. The cutting forces were measured in an off-line perspective and cutting force signatures analyzed during the milling
operation for the life cycle of the tool. It was concluded that the variation of
the variance and the first harmonic amplitudes were linked to the flank wear
evolution.

Hanwu and Yueming (2009) proposed a virtual operating system, which was applied to operation training of manufacturing facility and
manufacturing process simulation. The framework of the work is VRML and
browser/server structure i.e it could run with a free plug-in and run package
via Microsoft Internet Explorer. It was concluded that the approach was
feasible using the CNC milling machine.

Yang and Lee (2002) developed an algorithm based on hybrid adaptive
control system that regulates the spindle current in a CNC end-milling system
through the control of the federate. The composite elements of the algorithm
developed include adjustable proportional feedback control, fine control, and
entry federate control. Through experimental investigations, the steady state
spindle current, time constant and time delay were varied and results observed
under diverse cutting conditions. It was concluded that the algorithm
developed demonstrated global stability and also showed satisfactory
applicability behavior.

Fontaine et al. (2006) presented a predictive force model, which was
developed based on thermo-mechanical modeling of oblique cutting for ball-
end-milling. The proposed method was claimed to accurately predict the
cutting force distribution on the helical ball-end flutes from the tool geometry,
the perform surface, the tool path as well as the cutting conditions. Others are
the material behavior and the friction at the tool-chip interface. The
conclusion from the study was that the results obtained from the theoretical
modeling compared well with experimental results from the application of the
model to ball-end milling test data, the validation exercise was also
successful.
Franco et al. (2008) studied the influence of back cutting on the surface finish obtained by face milling operations. The surface roughness was modeled from the perspective of tool run outs and height deviations which affects the surface marks provoked by back cutting. Milling experiments were carried out for a spindle speed of 750 rpm, depth-in-cut of 0.5mm and feeds from 0.4 to 1.0mm/rev. The author claimed to obtain good results when experimental observations were compared with the theoretical model predictions.

Tang et al. (2009) proposed an analytical stability prediction method. The model has multi-degree-of-freedom system model analysis. The model allows consideration of the effects of multi-mode dynamics of the system, higher excited frequency and wider spindle speed range on stability limits in high-speed milling. The model helped in the selection of milling parameters for a maximum material removal rates in real operations without chatter. The quality of the method was satisfactory using a number of tests.

Zaghbani and Songmene (2008) focused on dry milling by developing an analytical cutting force model for dry high-speed milling of aluminium alloys which utilizes work piece properties and cutting conditions in the estimation of cutting force and temperatures during end-milling processes. The work considered transformation from orthogonal-to-oblique cutting and the incorporation of Needleman-Lemonds constitutive equation into the model to simultaneously determine the average shear stress and the cutting temperature in the primary and secondary shear zones. It was observed that a good agreement exists for both force and temperature results for the investigated cutting conditions from the perspectives of the theoretical models to experimental results.

Lou and Chen (1997) developed an in-process surface recognition system that measures surface roughness during end-milling. The framework
of the system is based on an intelligent hybrid software-fuzzy-nets as well as an hardware components consisting of a sensor tested, which assesses the real-time surface of a work piece with which information on the achievement of quality standard could be met.

Kasim et al. (2013) worked on ball-nose end-milling process with a study on tool wear which examines the tool life and wear mechanism during the machining of Inconel 718 having a physical vapour deposition-coated carbide tool and varying the cutting parameters. The study identified large radial depth-of-cut the major factor influencing the tool wear. A mathematical model was developed to predict the locating of the pitting (responsible for notching and flaking), which aided in determining the location associated with the maximum load exerted during cutting. It was concluded that the error between the predicted model of pitting and the actual notching/flaking was less than 6%.

Schmitz et al. (2001) studied the production of functional prototypes, which are monolithic and metallic in nature using the CNC milling machine. The focus was on process time and the following fundamentals were required; (i) high speed/high power spindles (ii) proper spindle speed selection (iii) machining parameter definition (iv) high feed/high acceleration machine drives (v) intelligent path generation and (vi) pre-process verification of arbitrary three-dimensional CNC part paths.

Frank et al. (2004) described the use of CNC milling machine in the rapid machining of diverse parts allowing minimum human intervention. The methodology is based on layer-based approach for the rapid, semi-automatic machining of parts geometries in diverse materials. The methodology was illustrated by examples from the viewpoint of parts machined.

Omirou and Barouni (2005) developed machine codes for integrating advanced programming capabilities in the framework of a PC-based milling
machine controller. The characteristics integrated into the system of a CNC milling machine are the tool motion along space curves, cutter offsetting for free-form curves and two machining cycles for revolved (external or internal) surfaces with free-form profiles.

Kuram and Ozcelik (2013) studied the micro-milling of aluminium materials with ball-nose end-mill from a four-stage perspective of experimental work, modeling, mono and multi-objective optimization. The experiment utilized Taguchi method to find out the effects of spindle speed, feed per tooth and dept-of-cut on tool wear, force and surface roughness. It was observed that work-piece surfaces had accumulations of plastically deformed work-piece material in view of the high ductility of aluminium. For the modeling aspect of the work, the data generated through experimental means were used to formulate first-order models for predicting responses in micro-milling of aluminium with minor errors. The optimization model was used to minimize all responses via Taguchi’s signal-to-noise ratio. The responses were then optimized simultaneously using grey relational analysis.

3.2 LITERATURE FINDINGS

Considering the above efforts by researchers, the concentration is on the only objective is to optimize the single response of surface roughness as the desired quality of the customer. The objective of this research is to provide the effective solution to the small- and medium-scale industries, which are really striving for the quality and productivity using the CNC machining for completing precision component manufacturing orders. These job-order type companies are primarily thrive for reputation by way of providing better quality of surface finish with better utilization of the capacity to improve the productivity of more efficient production in shorter period by continuous improvement. Hence the objective of achieving the dual goal in single stroke is performed on the high speed CNC milling machine used for
precision component manufacturing as the model machine compatible with the results of the study to all the machines under study and to their capacities.

3.3 NEED FOR FURTHER RESEARCH

The companies involved in precision components manufacturing were taken for case study on their machining standards, production and suppliers in search of solution to their problem that could be addressed by the research. The companies involved are mainly of precision components manufacturers and job-order type companies supplying inland Germany and Japan. Their operating standards are at the levels of 3ppm, when manufactured goods are out to the market. Loss in quality is directly attributed to the profit loss of these companies, whereas the small continuous improvement is gain in multiple folds, as the rejections are less quality, standards goodwill are at high. They used to obtain more rejections because of the order requirements of closer tolerances of $R_a$. When forced for the lowest of $R_a$ for the precision finish milling operation, the operator generally resorts to mid-point strategy. Generally the cutting tool manufacturer gives the range of operating parameter under assurance that the tool wear rate would not affect the $R_a$ values while machining after their in house research and findings, up to a specific time period (90mins) of operation.

3.4 MOTIVATION FOR THE RESEARCH

The VMC operator chooses the mid-point of the ranges of parameter in the catalogue of the Cutting tool manufacturer. The thump-rule of selecting the mid-point is in general practice for a given material also according to the VMC machine tool manufacturers hand book. At the end of case study, it is found that due to selection of parametric value the overall efficiency is compromised and needed to be reduced. Detailed research is
required to reduce such losses to improve the efficiency and productivity of the operation. The plan is to obtain better values of $R_a$ by while increasing the material removal rate and productivity of the operation by suitably fixing right values for input parameters. Based on our case study experience with the companies, they are desirous for us to obtain solution to their problem of scientific selection of process parameters; they are not interested in just as an academic endeavor which will only confirm to similar issues which were already addressed well in depth by the cutting tool manufactures and machine tool manufacturing companies. The need for the solution has led to multi-objective problem, which has not been reported in any of the literature to simultaneously addresses in detail to the real time needs of the SMEs, who participated in the case study. Generally the research and studies in this area considers this problem as one of the requirement to optimize the surface roughness characteristics of machining process. The only research considered similar issues of multi-objective problem comprising of the same set of responses converted (Moshat et al. 2010) as equated weightage problem in principal component analysis, instead of considering multi-objective optimization problem with equal priorities. The other important work in this direction has converted the issue as two-phased optimization (Yih-Fong and Chen 2005), which has not yielded best possible results. Hence, it is planned in the study to give scientific selection of process parameters by giving equal priority weightage to all the factors involved in the precision manufacturing with a multi-objective optimization based on response surface methodology devised by George Box and Donald Behnken (1960).