A QUALITATIVE STUDY OF ESSENTIAL VARIATIONS IN THE CUTTING TOOL DIMENSIONAL FEATURES AND END MILL DEFLECTION AND THEIR EFFECTS ON MACHINING ACCURACY IN CNC MILLING MACHINE

A dissertation Submitted
in partial fulfillment of the requirements
for the degree of

MASTER OF TECHNOLOGY

In

MECHANICAL ENGINEERING

With specialization

In

“Production and Industrial engineering”

Submitted By

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CERTIFICATE

This is to certify that Ms. Farheen Mirza (Enrollment. No.1600100920) has carried out the research work presented in the dissertation title “A qualitative study of essential variations in the cutting tool dimensional features and end mill deflection and their effects on machining accuracy in CNC machine.” submitted for partial fulfillment for the award of the Masters of Technology in “Production and Industrial Engineering” from Integral University, Lucknow under my supervision.

It is also certified that:

(i) This dissertation embodies the original work of the candidate and has not been earlier submitted elsewhere for the award of any degree/diploma/certificate.

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DECLARATION

I hereby declare that the thesis titled “A qualitative study of essential variations in the cutting tool dimensional features and end mill deflection and their effects on machining accuracy in CNC machine.” is an authentic record of the research work carried out by me under the supervision of Dr. Mohd Reyaz-ur-Rahim Department of Mechanical Engineering for the period from Jan 2022 to at June 2022, Integral University, Lucknow.

I declare that I have faithfully acknowledged and referred to the works of other researchers wherever their published works have been cited in the thesis. I further certify that I have not willfully taken other's work, para, text, data, results, tables, figures etc. reported in the journals, books, magazines, reports, dissertations, theses, etc., or available at web-sites without their permission, and have not included those in this thesis citing as my own work.

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ACKNOWLEDGEMENT

At this moment of accomplishment, I wish to pay my heartfelt gratitude and sincerest thanks homage to my guide, Dr.Mohd.Reyaz-Ur-Rahim (Assistant Professor), department of mechanical engineering, Integral University, Lucknow. This work would not have been possible without his able guidance, support and encouragement under his guidance, I have successfully overcome many difficulties and learned a lot. He used to review my work progress, give his valuable suggestions and made correction. His unflinching courage and conviction will always inspire me, and I hope to continue to work on his noble thought.

I am also extremely indebted to Dr. P.K.Bharti, HOD, Mechanical Engineering Department, Integral University, Lucknow for providing necessary infrastructure and resources to accomplish my research work. I warmly thank to Er. Faizan Hasan, Dr. Mohd. Anas and Er. Abhishek Dwivedi for their valuable advice and encouraging me at regular interval. I would also like to thank Mr. Thomas, workshop instructor for his support during my entire work.

Lastly it goes without saying that I am indebted to a my friends and well-wisher specially who cooperated and helped me during the work.

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ABSTRACT

The main purpose of this dissertation is to study the mechanism of deflection error and find the optimum condition for the cutting process to minimize deflection error. Basically, this dissertation is for finding the reasons of the abnormal machining accuracies and try to solve the problem in it.

The two main topics to review during this are; analysis of various varieties of variations in cutting implement dimensional options and their impacts on machining accuracy & The effect of finish mill deflection on machining accuracy. Tool deflection takes place once the cutting force overcomes the tool stiffness, inflicting the tool to bend.

The tool won't perceptibly bend throughout the operation, but the proof is at intervals the ultimate measurements. Accuracy and precision are necessary in CNC machined components, accuracy refers to the closeness of the measured result to a selected price. However, we regularly encounter the fault of CNC machines tools causes abnormal machining accuracy, the error is sometimes hidden and troublesome to diagnose.

There are a unit specific reasons for the abnormal machining accuracy within the CNC machining like, the modification of parameters, mechanical faults, point error and improvement of electrical parameters. Machining of steel inherently generate high cutting temperature, that not solely reduces tool life however conjointly impairs the merchandise quality. typical cutting fluids area unit unsuccessful in managing the high cutting temperature and swift tool scratch. any they conjointly deteriorate the operating atmosphere and cause general environmental pollution.

CHAPTER 1

1.1 INTRODUCTION

CNC {Computer numerical control} machining is the most widely used subtractive manufacturing technology. In CNC, material is far away from a solid block employing a form of cutting tools to provide a locality supported a CAD model. Each metal and plastics are often machined with CNC. Accuracy and preciseness are 2 necessary ideas in measurement of CNC machined elements, accuracy refers to the closeness of the measured result to a selected price. However, we regularly encounter the fault of CNC machines tools causes abnormal machining accuracy, the error is sometimes hidden and troublesome to diagnose. There are specific reasons for the abnormal machining accuracy in the CNC machining like, the change of parameters, mechanical faults, positional error and optimization of electrical parameters.

- Steel machining naturally produces high cutting temperatures, which not only shorten tool life but also degrade the quality of the finished product.
- Standard cutting fluids are inadequate for controlling high cutting temperatures and rapid tool wear. Additionally, they harm the working environment and contribute to environmental contamination in general.

The recent challenge of machining industries is principally centered through the action of prime quality, Accuracy and precision are two important concepts in measuring of CNC machined parts, the word accuracy refers to the closeness of the measured result to a specific value. We generally encounter the fault of CNC machines tools which causes machining accuracy to differentiate, the error in the machine accuracy is generally hidden and difficult to find out.

There are specific reasons for the abnormal machining accuracy in the CNC machining like, the change of parameters, mechanical faults, positional error and optimization of electrical parameters.

High cutting temperatures are produced during the machining of steel, which also shortens tool life and lowers product quality. Standard cutting fluids can't control the high cutting temperature and quick tool wear. They also worsen the working environment and cause general environmental contamination.

Deflection in machining has a big impact on the dimensions and math, especially when using tools with different types of shape like long end edge tools to apply cumulative cutting forces. By carefully choosing an appropriate lubrication mode and controlling the cutting parameters, this type of end edge mistake may even be effectively reduced. The goal of this analysis is to examine the deflection error mechanism and comprehend the ideal situation for the cutting methodology to reduce deflection error.

The basic goal of this study is to review the total deflection error mechanism and comprehend the ideal circumstances for the cutting methodology to reduce deflection error. The main goal of this thesis is to identify causes of anomalous machining accuracy and attempt to find a solution to the problem. The two primary areas to examine during this thesis are listed below;

- An analysis of different types of variations in cutting tool dimensional features and their effects on machining accuracy.
- The effect of end mill deflection on machining accuracy.

A machine or metal cutting implement is employed to manufacture metal elements of machines through machining, a method whereby metal is by selection removed to form a desired form.

1.2 Tool deflection happens when the cutting force exceeds the tool's stiffness, causing the tool to bend. The instrument must remain rigid throughout the process, but the final measurements reveal the precise outcomes.

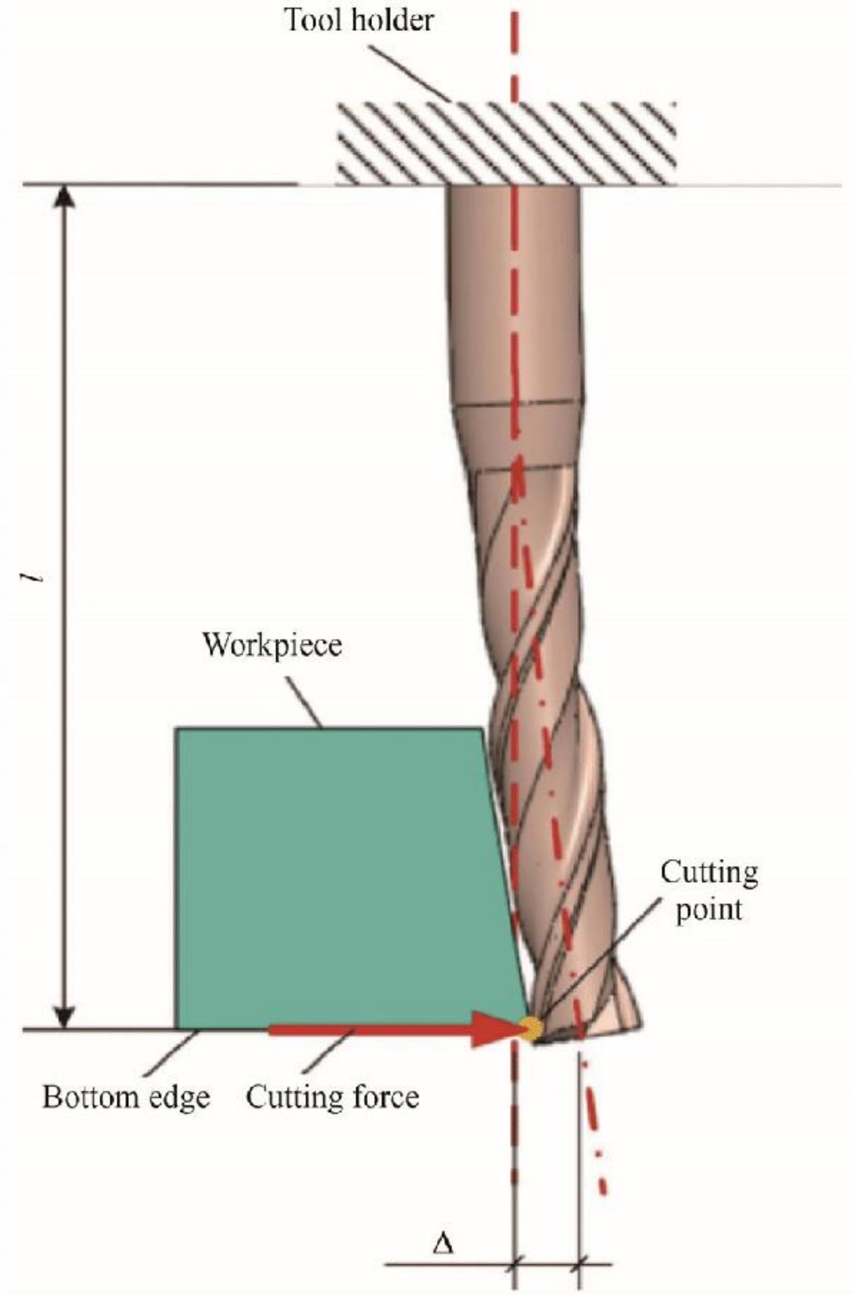


FIGURE 1.1 TOOL DELECTION

Reduce the length of the cantilevered element to lessen tool deflection. The smallest number of tools necessary to complete the cut must be forced to hang out of the chuck.

Tool deflection is reduced by making numerous passes and small cuts. In this analysis, one of four factors—lubrication mode, least amount lubrication, dry cutting and nano lubrication—that are important to deflection error in flood lubrication, end-edge tool machining, is taken into account.

AL 6061-T6 was employed as the work material for this analysis, and the tool was an HSS end Aspect edge is the chosen mode since it has an edge with a four mm diameter. The Taguchi methodology is intended for the experiment, which consists of sixteen samples.

S/N response analysis and analysis of variance were used to examine the cutting fore and deflection error on a piece (using social scientist ANOVA). The findings show that roughly 95% of deflection error is influenced by radial depth of cut. The alternative factors' effects are not significant.

The secondary level of depth of cut (10 mm) and smallest Quality of Lubrication yields the best deflection error (31.22 m) at very low levels of radial depth of the cut (0.32 mm) and feed of cut (250 mm/minute)

Comparatively speaking, this can explain the end edge deflection process far better than ordinary cutting force theories. It demonstrates that the two parameters affecting deflection error are the distance between the tool holder and the cutting purpose. Cutting force adds a somewhat more important outcome between these two components. Additionally, it has been demonstrated that cutting force and deflection error have a strong linear relationship.

1.3 TAGUCHI Technique-The Taguchi method is one of the best experimental approaches for determining the bare minimum of trials to run within the range of factors and levels that are allowed. Taguchi strategies are applied math techniques, also referred to as "sturdy style techniques," created by Genichi Taguchi to raise the caliber of manufactured goods, and more recently,

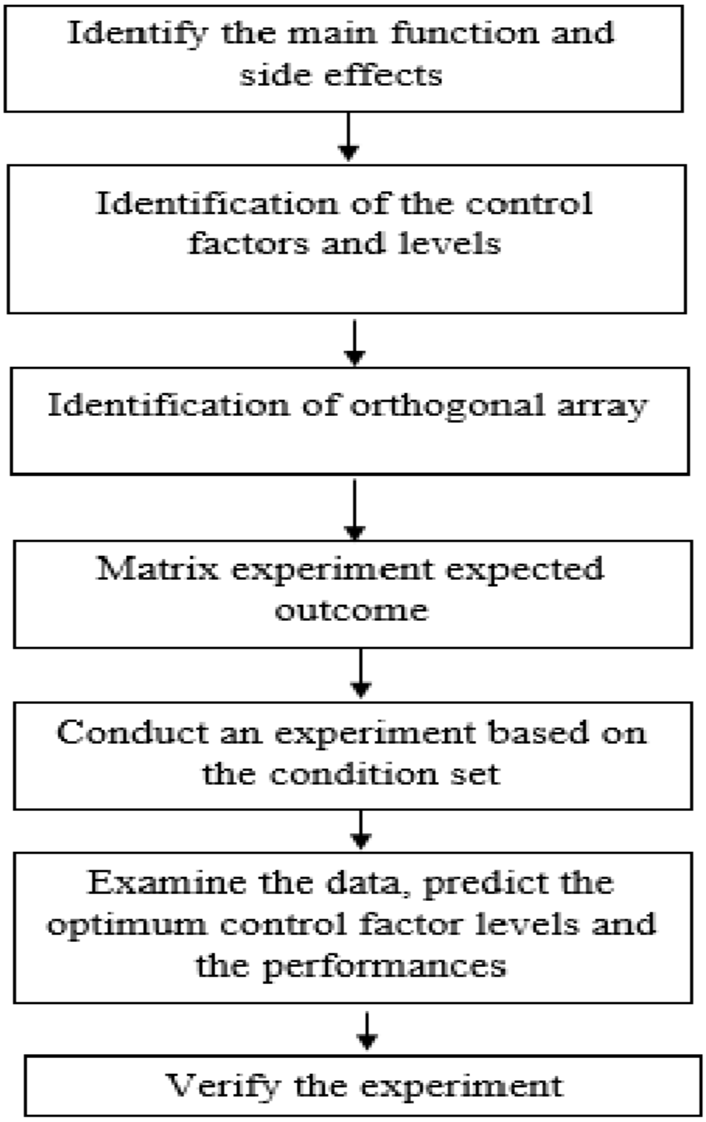


FIGURE 1.2 IMPLEMENTATION OF TAGUCHI METHOD

The required halves for the subsequent assembly, as well as the attained requisite geometrical shapes and dimensional tolerances, are provided by the machining parameters and process of composite materials. Advanced features of composite halves are frequently manufactured using standard machining techniques such grinding, drilling, turning, and abrasive cutting.

Commonly, it is accomplished by removing components in the form of chips. The kinematic connection between the cutter and work is closely related to the shape and size of the chip eliminated, the rate of material removal, and the beautiful surface finish. In order to achieve the desired geometric form, dimensional tolerances, and premium finish, the producer can utilize the edge approach to remove the unneeded material. In composite manufacturing, the edge operation is used as a corrective machining technique to generate smooth, high-quality surfaces. The type of fiber used in composites has a greater impact on the machining parameters and tool selection.

It is essential to confirm that the machining method and tool elite are suitable for the material. To maximize the machinability of the edge, the information on the cutting mechanism is crucial. Surface roughness has a significant impact on dimensional accuracy, mechanical item performance, and production costs. Due to these factors, the manufacturer is required to optimize the cutting conditions in order to achieve the desired surface roughness.

Because it has an impact on the product's appearance, functionality, and dependability, the surface condition of factory-made products receives special attention in the demand for premium quality and fully machine-controlled production. It is also crucial to maintain consistency in tolerance and surface finish. The diagnosis of the stability of the machining process is also influenced by surface roughness, where a decrease in surface quality may indicate non-homogeneity in the material of the workpiece, increasing tool wear, chatter from the cutting tools, etc.

1.4 PROBLEM STATEMENT-

In the literature very limited number of published works was found on machining accuracy. Those authors who have studied about machining accuracy, have concentrated on specific aspect(s) of machining accuracy and factor(s) affecting these aspect(s). For example, Arai et al [16], Sata et al [53] and Rahman [54], all have studied machining accuracy of an NC lathe. But in their respective accuracy analysis, Arai et al considered diameter variation of the workpiece, Sata et al monitored the length variation of the workpiece and Rahman examined out of roundness error of the workpiece.

These studies are useful; but in reality, all these errors occur simultaneously due to combined effect of all the error components. It seems that nobody has studied the combined effect of all* (at least the dominant ones) factors affecting machining accuracy considered from different accuracy aspects such as dimension, form, surface texture, etc. In this thesis an attempt will be made to study different aspects of accuracy of a typical component machined on a 3-axis machining centre and then to trace back the factors causing these errors with a view to presenting a more realistic and "total effect".

We have noticed that, several studies have been reported on machine accuracy. Different models are also available to calculate the machine error, in particular the geometric errors of machine tools. There are two basic approaches for accuracy improvements, viz., error avoidance and error compensation. We also note that where the error compensation method is divided into many branches and sub-branches, while the error avoidance method is untouched. Although error avoidance should be the first step of accuracy control, in the literature we find almost all researchers have used some form of error compensation technique for reducing both the machine and machining error. While discussing about their error model and its effectiveness, some of the authors like Eman et al [23], Nijs et al [104] suggested that their model could offer more benefits if it was considered at design stage of the machine invariably "touching on" the need for error avoidance.

Researches have applied different compensation techniques for machine and machining accuracy enhancement. Most popular among those techniques is ACS (Adaptive Control Systems). Although ACO (Adaptive Control with Optimization) and ACC (Adaptive Control with Constraints) were tried, however, this area has been only an area of academic research with no significant industrial application being reported. The problem with ACO is that it needs a huge database, which is practically impossible to store in the computer for all types of work and tool materials and for different cutting conditions.

The main problem associated with ACC is, how to justify its objective or criterion of control strategy. Performance index can be maximum productivity, minimum cost, higher accuracy, better surface finish, or a compromise-combination of some of these objectives. In ACS where maximum productivity is used as performance index PI, Equation (2.2) is used to calculate PI. But in Equation (2.2) it is assumed that all cutting tools wear out identically under nominally identical work conditions.

This is not true and there arises a need for on-line tool wear monitoring. Lack of on-line tool wear sensors is another obstacle in developing industrial ACS for CNC machining operations. This does not necessarily mean that ACS cannot be implemented to solve industrial problems. ACS can be applied to solve the problem part by part, but would not give a universal solution for the "total problem".

In the literature survey "Studies on Co-ordinate Measuring Machine" is included; because, first, due to similarity in configuration of 3-axis machine tools and 3-axis coordinate measuring machines, some authors like Knapp [24], Belforte [102], etc have studied geometric accuracy of both of these machines together; second, perhaps more important is the fact that measured accuracy of the machined components depends on the accuracy of the measuring machine (CMM), we have also noticed that Koval et al [49] in their list of components of machining accuracy, have included the workpiece inspection error.

We have seen that; many authors have studied machine accuracy and have developed different models for error calculations. But no one seems to have analysed the effect of machine accuracy on machining accuracy. Using existing mathematical models, volumetric accuracy of any point within the machine space, can be calculated. But actual inaccuracy of the machined component will depend not only on the accuracy of the machine tool, but also on the volume of the workpiece (in other words amount of inaccuracy will depend on dimensions of the workpiece). *

In machining, only a small part of machine space is generally used and in that case the error component of machining accuracy inherited from machine accuracy may not be as large as thought to be. Further investigations on the effects of machine accuracy on machining accuracy is therefore deemed necessary.

It seems that hardly anyone has studied the "error avoidance" method for accuracy control of CNC machining operations, although many researchers felt the need for it. At this stage the potential benefits of this method need to be established to generate adequate research interest. In the literature we also find that some authors, while advocating the error compensation method, have criticized the error avoidance method.

For example, Lee and Barash [30] wrote, "While the former (error avoidance) has been by no means completely achievable, the latter (error compensation) has been preferred as a convenient means to reduce the error". It is apparent that no method is capable of producing errorfree-machining. Sensor-based adaptive control methods appear to be providing a reasonable compromise for reducing the errors that are resulting from the process of manufacture.

Considering the need for "total quality" in manufacture, when viewed in its integral role, representing the entire process of converting the raw materials into finished products, it seems reasonable to assume that error avoidance must play a significant role in the whole process. Thus, the core of future work must be aimed at achieving a partial solution to quality enhancement in manufactured products, by a thorough investigation into the dimensional and geometric accuracy features of a typical machined component.

1.5 Concluding Remarks-

From the summary of the literature survey presented in this section the following general remarks are drawn:

1. Very little research has been done on the machining accuracy of CNC machining operations.

2. The causes of the poor accuracy levels produced in CNC machining operations are not well established and there exist significantly large differences of opinions among the researchers about the likely causes of errors and their levels of influence.

3. Adaptive control systems have been developed and tested by many researchers; but most of these researchers were concerned more about the productivity and in many cases the accuracy was sacrificed to increase the productivity.

4. The potentials for research into error avoidance methods are still ripe and would play a major role in quality enhancement of the manufactured product in CIM environment. It is the firm opinion of the author of this thesis that "prevention" is always better than the "cure".

1.6 CNC Milling:

CNC milling, also known as computer numerical control milling, is a kind of machining that removes material from a piece of work and produces a part or product with a unique design using computerised controls and spinning multi-point cutting tools.

The most frequent operations performed on CNC milling machines are listed below: Examples of milling operations include face milling, plain milling, angular milling, and form milling

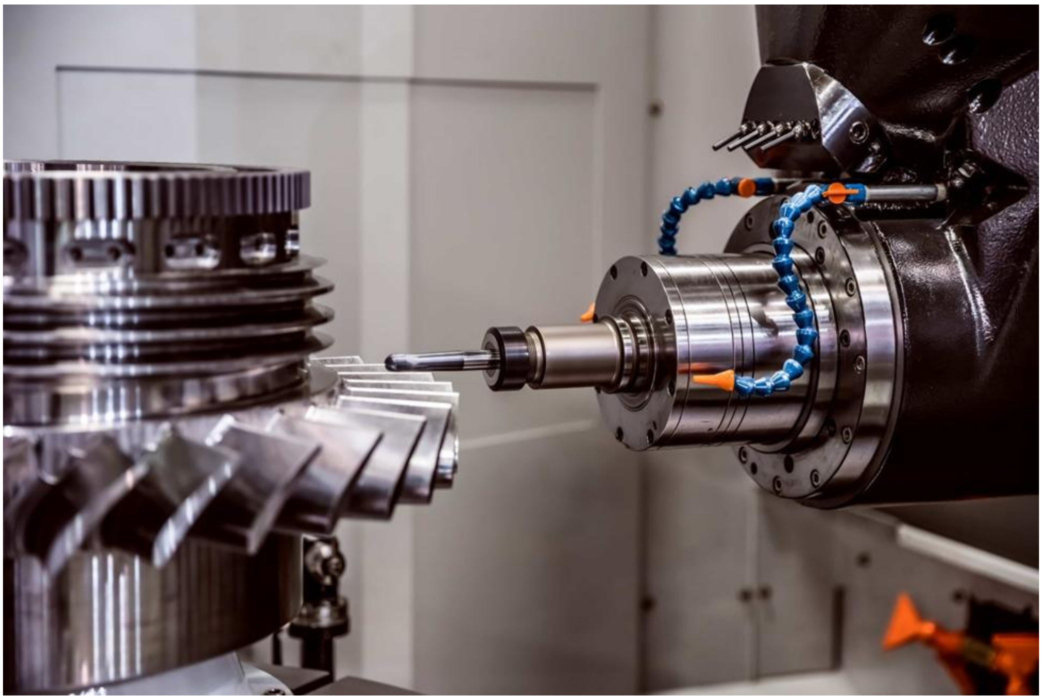


FIGURE 1.3 CNC MILLING MACHINE TOOL

1.6.1 Machine Components used in the CNC Milling Machine;

Despite the huge range of milling machines that are available, most of them share a lot of fundamental parts. Shared components include: the machine interface; the column; the knee; the saddle; the worktable; the spindle; the arbor; and the ram.

1.6.2 Material Considerations; Although the CNC milling method is ideally suited as a secondary machining process to offer finishing characteristics to a custom-designed item, it may also be utilized to generate different kinds of designs and parts entirely from scratch. Using CNC milling technology, it is possible to create parts from a number of materials, such as: • Metals (including alloy, exotic, heavy duty, etc.)

• Elastomers • Ceramics • Composites • Plastics (including thermosets and thermoplastics)

1.6.3 Main functions of the CNC Machine

- Machine Tool Control
- In-process compensation
- Improved programming and operating features
- Diagnostic

FIGURE 1.4 MILLING MACHINE

1.6.4 Milling technological parameters include: • rotational speed [rpm]; • tool diameter [mm]; and • cutting speed [m / min].

feed rate [mm/min]

• feed per revolution [mm / rev];

• cut width and depth [mm]

1.6.5 Adjustable process parameters:

Cutting Velocity (V): It is defined as the cutter's peripheral speed in metres per minute.

V= DN/1000 is the cutting speed equation.

where N = cutting speed/rotational speed and D = cutter diameter (mm) (rpm)

The material of the work piece, the cutter's diameter and tooth count, the feed and depth of cut, the cutter's width, and the use of coolant are the main factors that affect a milling machine's cutting speed.

Feed(f): The term "feed" refers to both the movement of work in relation to the cutter's axis and the pace at which it is fed.

The feed is expressed in three ways during the milling process:

Feeding per tooth (fz) Feeding per revolution (frev) Feeding per minute (fm)

The three feeds mentioned above are linked in the following way:

N*frev = fz*Z*N = fm

where Z represents the cutter's tooth count.

N = Rotational speed / Cutter speed (rpm)

1.7 The following is the methodology for studying the mechanism of maximum surface error:

1. 1. Design a sequence of experiments to provide a sufficient and accurate measurement of the desired response. calculating the depth of the cut and the federate to arrive at the average surface error %.
2. Finding the value of damping coefficients of the tool at different torque values with medium variations.
3. The average of the maximum surface error should be less than 5%, this error can be decreased by adjusting the feed rate and the damping coefficients.

1. 8 FACE MILLING- The most frequent milling process, face milling, can be carried out using a variety of instruments. The most popular types of cutters are those having a 45o getting into angle, however in some cases, spherical insert cutters, square shoulder cutters, and aspect and face mills are also utilized. Select the right cutter for the job to maximum productivity.

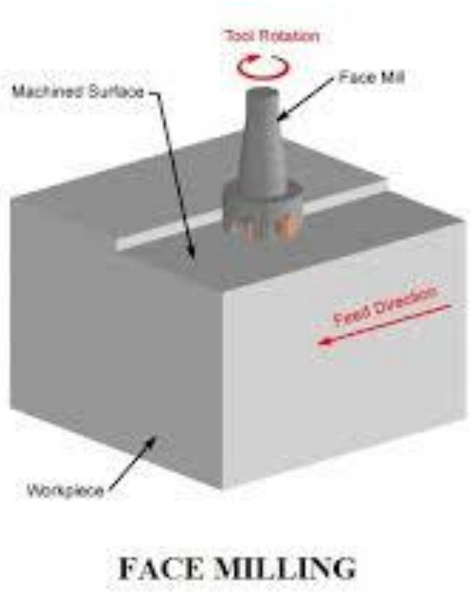


FIGURE 1.5 FACE MILLING

General face milling, high feed milling, heavy duty face milling, and wiper insert finishing are some face milling activities.

1.9 PLAIN MILLING: Plain milling is the most typical milling machine operation. • A flat, horizontal surface parallel to a milling cutter's axis is produced by plain milling.

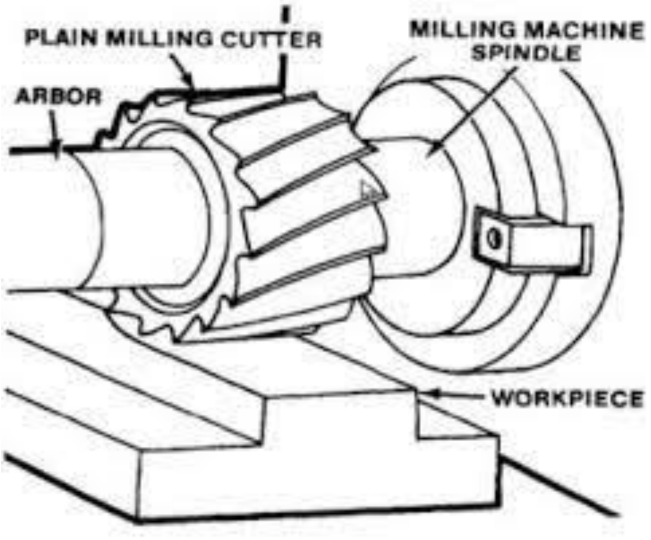


FIGURE 1.6 PLAIN MILLING

The cutter used in plain milling is primarily used for milling of flat surfaces parallel to the cutter's axis. A helical-shaped teeth cutter is used when a large amount of product must be removed. The helical angle allows several teeth to cut at the same time, resulting in a smoother cutting action.

1.10 ANGULAR MILLING- The technique of milling flat surfaces that are neither parallel nor perpendicular to the axis of the cutting tool is known as angle milling, sometimes known as angular milling. This implies that the surface to be machined is at an angle to the rotating milling cutter's axis.

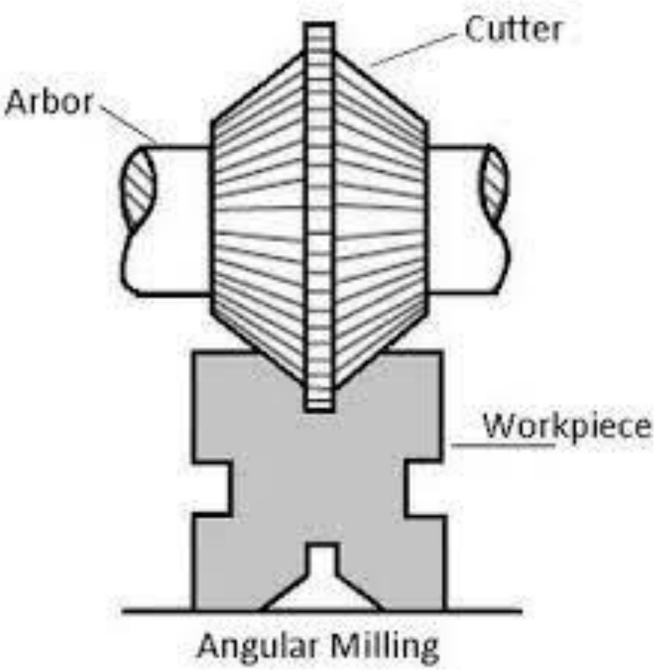


FIGURE 1.7 ANGULAR MILLING

CHAPTER 2

LITERATURE SURVEY

From the recent literature survey it was find that to identify the present knowledge on machining accuracy in CNC machining operations, it has been found that only a very limited number of published work has been reported to date. It appears that this subject has somehow been overlooked by most of the authors, as rightly pointed out by Arai et al , "The authors have made various kinds of research on the turning of NC lathe for several years, but they have not yet tried the research of working accuracy". Due to the vastness of the problem, many of the researchers have concentrated on specific factors affecting the machining accuracy of CNC machining operations.

- These authors consider the problem only from their own point of view totally ignoring the combined effect of all factors that are likely to influence the process. Basically, the problem is far more complex than it is shown.

  - The study of machining accuracy necessitates a broad understanding and greater information in a wide range of fields. Deflection in machining has a significant impact on size and pure mathematics, especially when using exaggerated cutting forces and complex-shape tools like long finish edge tools. This type of finish edge error can also be reduced quickly by controlling the cutting parameters and selecting an appropriate lubrication mode.

Linyan Liu et al. (2014) A data-centric method management system for CNC machine design and development (D&D) that integrates method and knowledge is presented by Linyan Liu et al. (2014). The character of the machine style applied determines all of the needs for the framework. Modules for method simulation, method execution, and information object management are included in the suggested framework. Each of those modules is carefully designed to support the management of the knowledge-centric machine development technique. The author also helps to construct the epitome. The study's findings make it easier to integrate information into CNC machine design and development, enhancing machine capabilities and lowering the cost and length of the development cycle. This increases efficiency and ensures magnificent machine development.

Venkata Krishna Pabolu et al. (2010) discuss the design and implementation of a low-cost 3D processed numerical system (CNC) for industrial use. During the course of this paper, an Embedded CNC machine was prototyped. There is a detailed description of various modules such as software system development and electronic/electrical development, as well as technical details of their implementation.

Druv Patel et al. (2014) investigated the effects of various parameters such as tool speed, tool feed, and depth of cut on CNC routers and discovered that the proportion contribution of feed rate is the greatest, implying that feed rate is the most dominant issue for modelling surface end. Kurbanoglub et al. distribute edge surface roughness prediction methods based on biological process programming. CNC edge has evolved into one of the most capable, productive, and versatile manufacturing methods for elegant or sculptured surfaces. Their expected producing output is a minimum of useful in order to style, optimise, and engineer up to stylish, multi-axis edge centresOrganic phenomenon programming technique is used in this study to predict surface roughness of edge surface with associated cutting parameters. Surface roughness is predicted using cutting speed, feed, and depth of cut from finish edge operations.

Julie et al. (2013) Using the Taguchi style technique, Julie et al. (2013) made a discovery about surface roughness optimization in a finish edge procedure. In an exceedingly CNC face edge operation, this article analyses the Taguchi style application for improving surface quality.

It could be necessary to incur higher production costs or productivity losses to maintain acceptable surface quality. In addition to noise considerations including in-operation chamber temperature and the use of several tool inserts within the same specification, this study considered management parameters that affected tool condition and dimensional variability, such as feed rate, spindle speed, and depth of cut. ANOVA analyses were conducted using an orthogonal array of L9(34) to find the many variables impacting surface roughness and to determine the best cutting combination.

CHAPTER 3

DESIGN OF EXPERIMENT AND EXPERIMENTAL WORK

3.1 MACHINE ACCURACY- Researchers have been concerned about machine accuracy for a long time and several publications have been produced examining this problem. Pioneering work on machine tool accuracy was done by Schlesinger, who has been reported to have started his work on acceptance standards for machine tools in 1901. His famous book "Testing Machine Tools" [17] is still very widely used by machine tool manufacturers, users, inspectors and plant engineers.

In this book 44 inspection charts, a discussion of the basic principles and an explanation of testing procedures are given. In its recent edition a chapter on NC machine tools written by Koenigsberger and Burdekin is included. This book is to be regarded as a reference book due to its diversity of contents. Schlesinger's machine tool accuracy tests include: flatness of tables, straightness of sideways, accuracy of spindle rotation, accuracy of linear motion, lead or pitch error of lead-screws, etc. In his book measurement procedures of these inaccuracies are explained in details. In the test charts tolerances of the inaccuracies are also given.

Tlusty and Koenigsberger [18] pointed out that the classic concept of geometric accuracy which was created by Schlesinger and later accepted by various national and international standards, does not account for a variety of functional effects such as weight deformation, clamping force deformation, thermal effects, dynamic errors in displacement systems, and so on. These inaccuracies are particularly important for CNC machines, because in CNC machining operations normally the operator who can take necessary actions to eliminate most of those effects is not present.

Tlusty and Koenigsberger studied the geometric accuracy of machine tools using a "work zone concept" (where the error is calculated within the whole work zone) and a "master part trace test" (where a master part is used to find error components). Their study also includes spindle rotation accuracy, displacement accuracy, weight and clamping effects, thermal effects, forced vibration and cutting force deformations. Main findings of their study are: • Weight and clamping effects may cause errors many times greater than the basic alignment errors. • On average, the thermally induced error is of equal significance to the positioning error. • Cutting force deformations may entirely be neglected for turning, boring and milling. * Tlusty et al must have been referring to Schlesinger's original work in which some functional effects were not included.

But in the recent edition of Schlesinger's book where a new Chapter is added titled "Recent Developments in Machine Tool Testing", the accuracy of positioning system, cutting tests for accuracy assessment using a standard test piece, weight deformations, indexing table errors, thermal deformations, spindle rotation accuracy, dynamic testing of machine tools, etc. are discussed.

In another paper [19], Tlusty developed the work zone concept for testing the accuracy of NC machine tools. He employed a streamlined method known as "the linear system of accuracy of NC machine tools." The system is called linear because only linear (translative) deviations from the motions of the machine's bodies are considered. In practise, only 9 of the total 21* error components representing the volumetric accuracy of a 3-axis machine tool were taken into account. Tlusty advocated against using a machining test, because (a) it is more expensive and time consuming; and (b) the effects of tool wear and workpiece distortions cannot be distinguished from those of machine inaccuracy. Tlusty used a graphical template as a master part in his work to test the accuracy of NC machine tools.

Tolerances for accuracy tests were developed by him, and they were expressed as linear functions of distances between points in the working zone (another reason for calling the system linear). The angular motions were avoided because they are difficult to measure and there is no data on them. The criterion for finding the angular motion tolerances. However, the effects of angular deviations on linear deviations were indirectly tested by increasing the number of measurements.

Finally, Tlusty gave an example of how to figure out how many linear measurements are necessary to fully convey the impact of errors caused by individual co-ordinate motions on the precision of relative tool-workpiece motions throughout the machine's operating zone. A finite element method was utilised by Cowley and Hinduja [20] to analyse the structural characteristics of machine tools.

The static deformation of tool used in machining structures and structural elements was computed using computer programmes. Machine tool structures were classified into plate-like elements (rectangular, triangular, and so on) and beam-like elements. The deformations of each individual element were calculated and then combined to form the overall structure's resultant deformation.

This approach is very useful for designing machine tool structures and structural elements because deformation, which contributes significantly to machine error, can be minimised. However, as Cowley and Hinduja pointed out, their analysis was based on a very simple structure, and detailed analysis of a complete machine tool using their techniques requires the calculation of a large number of finite elements. Schultschik [21] investigated "volumetric" errors in 3-axis machine tools by combining the components error in the work space of a given machine tool. The machine tool's geometric model was created, and his analysis was based on a diagram.

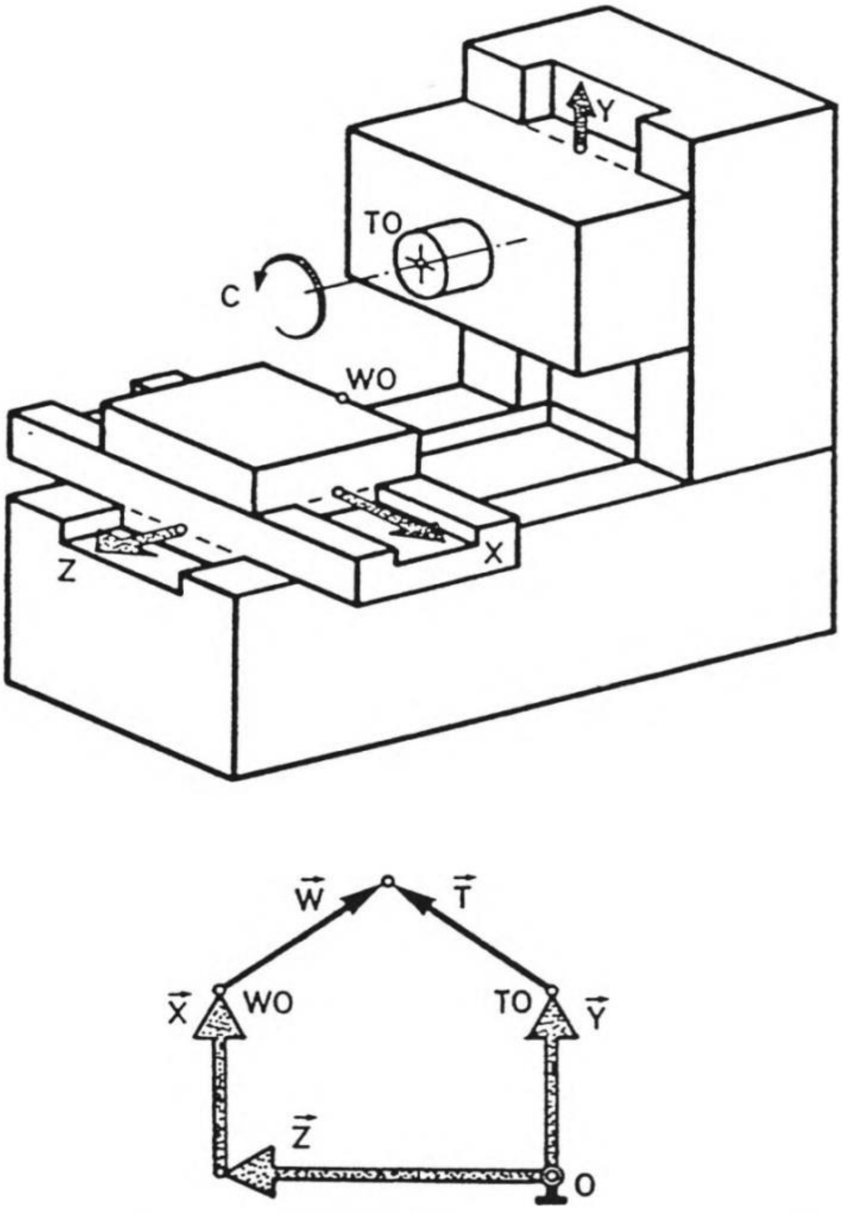
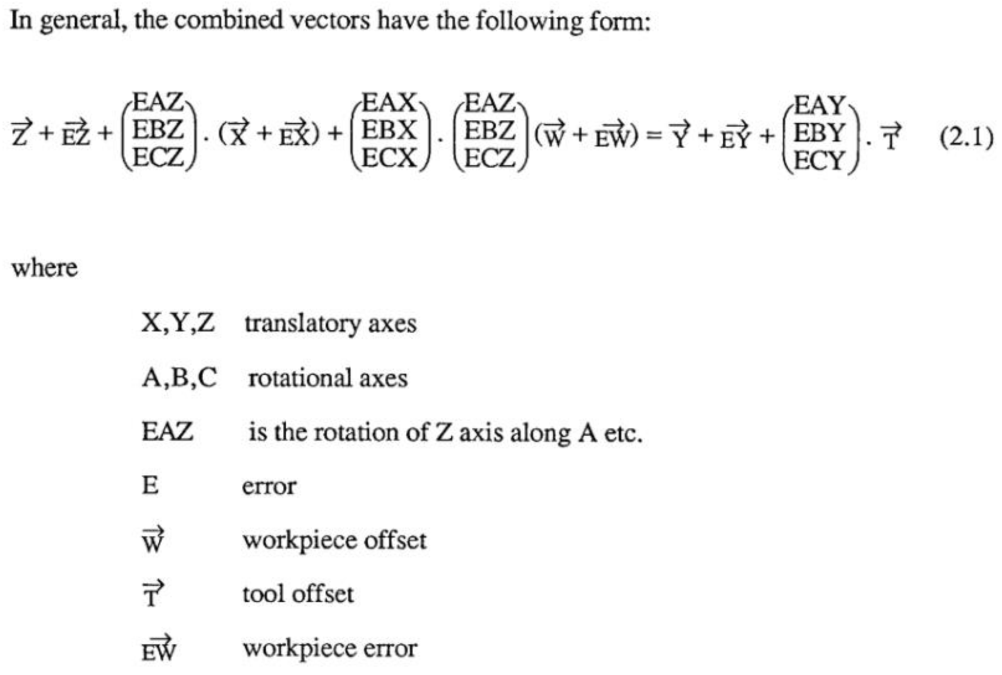


FIGURE 1.8 **A Typical Machine Tool and it's Vector Diagram**



In general, the combined vectors have the following form:

$$\vec{Z} + \vec{EZ} + \begin{pmatrix}EAZ\\EBZ\\ECZ\end{pmatrix} \cdot (\vec{X} + \vec{EX}) + \begin{pmatrix}EAX\\EBX\\ECX\end{pmatrix} \cdot \begin{pmatrix}EAZ\\EBZ\\ECZ\end{pmatrix} (\vec{W} + \vec{EW}) = \vec{Y} + \vec{EY} + \begin{pmatrix}EAY\\EBY\\ECY\end{pmatrix} \cdot \vec{T} \qquad (2.1)$$

where

X,Y,Z	translatory axes
A,B,C	rotational axes
EAZ	is the rotation of Z axis along A etc.
E	error
$\vec{W}$	workpiece offset
$\vec{T}$	tool offset
$\vec{EW}$	workpiece error

FIGURE 1.9 THE VECTOR FORMULA

3.1.1 FACTORS AFFECTING THE MACHINING ACCURACIES-

There are a number of factors which can cause poor accuracy levels in CNC machining operations. One observation shows that over thirty factors directly or indirectly influence milling operations. The following factors have been identified as causing poor machining accuracy by the Lawrence Livermore Laboratory in the United States:

Faults in the geometry and kinematics of the machine tool; errors in the spindle of the machine tool; thermal effects on the machine tool and the workpiece; errors in static and dynamic loading; errors in tool wear; and errors in work holding.

Koval and Igonin [49] made a comparative analysis of machining errors for a heavy NC machine tool. They listed the factors affecting machining accuracy. All those error components for a heavy NC vertical milling machine were calculated analytically. As error components in point-to-point machining and contour machining differ, these two cases were considered separately.

The method of quadratic summation was used to find the resultant error and the error values obtained analytically showed close match with the experimental values.

3.1.2 METHODS OF IMPROVING MACHNING ACCURACIES-

A systematic approach to improve the machining accuracy is shown in the figure below. Two basic methods for the improvement of machining accuracy have been proposed [51]: (a) error avoidance and (b) error compensation (error reduction). Error avoidance entails removing the source of the error through improved design and controlled manufacturing technology. It is sometimes possible to improve a machine's machining accuracy through a series of thoughtful and conscientious design features and by optimising the machining process at no (or very little) extra cost. Error avoidance should therefore be the first step in accuracy control. "A method of negating the effect of the error by forecasting it using a model designed for the 34 purpose," according to [47], is how error compensation is defined. Two types of error compensation exist: active error compensation and pre-calibrated error compensation.

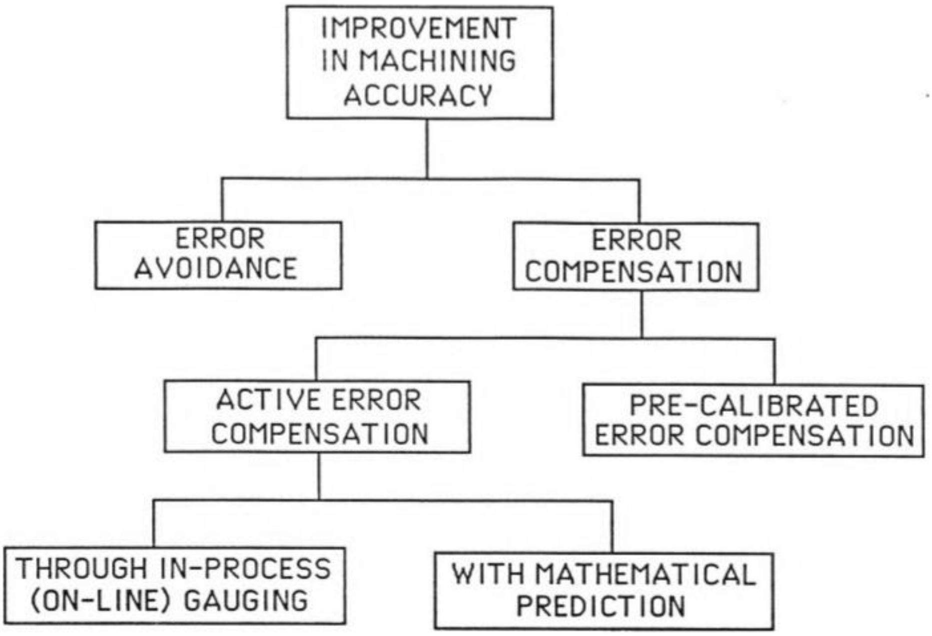


FIGURE 1.10 IMPROVEMENTS IN MACHINING ACCURACY

3.2 EXPERIMENTAL WORK-

AL 6061-T6 was the material used for the study's workpieces. It is used for a variety of things, including furniture, boats, and engineering and structural applications. The mode employed is side milling, and the cutting tool is an HSS end mill with a 16 mm diameter.

FIGURE 1.11 ALUMINIUM 6061-T6 RODS

- Three samples are included in the usage, which was created using the Taguchi approach. Cutting force and deflection error on a workpiece are analysed using S/N response analysis and analysis of variance.

Aluminium 6061-T6 is a non-ferrous metal and a 6000 Series Aluminum Alloy.

3.2.1 Its general characteristics and applications are as follows:

1. Phenomenal joining characteristics
2. Acceptance of applied coatings is high.
3. Combines relative strength
4. Good adaptability
5. High corrosion resistance and widespread availability

TABLE 1.1 6061 T6 Aluminum Bar Physical Composition

Physical Property of the bar	**Value**
Density(g/cm3)	2.70
Melting Point(°C)	582
Thermal Expansion(K)	23.4 x 10^-6
Modulus of Elasticity (Gpa)	69
Thermal Conductivity (W/m K)	170
Electrical Resistivity	%43 IACS

TABLE 1.2 CHEMICAL PROPERTIES OF ALUMINIUM 6061

Chemical Element	**Present %**
Manganese (Mn)	0.0 - 0.15%
Iron (Fe)	0.0 - 0.70%
Magnesium (Mg)	0.80 - 1.20%
Silicon (Si)	0.40 - 0.80%
Copper (Cu)	0.15 - 0.40%
Zinc (Zn)	0.0 - 0.25%
Titanium (Ti)	0.0 - 0.15%
Chromium (Cr)	0.04 - 0.35%
Other (Each)	0.0 - 0.05%
Others (Total)	0.0 - 0.15%
Aluminium (Al)	Balance

The cantilever beam model is used for the static analysis of finish mills since the tool holder is believed to be stiff.

Calculating the deflection on the top mill axis for a given pure mathematical condition and loading is the static analysis' most specific goal.

The top mill used in the model's loading and boundary conditions are shown, with D1 standing for the mill's diameter, D2 for the shank's diameter, L1 for the flute's length, L2 for the overall length, F for the purpose load, I1 for the flute's moment of inertia, and I2 for the flute's half-while-not moment of inertia.

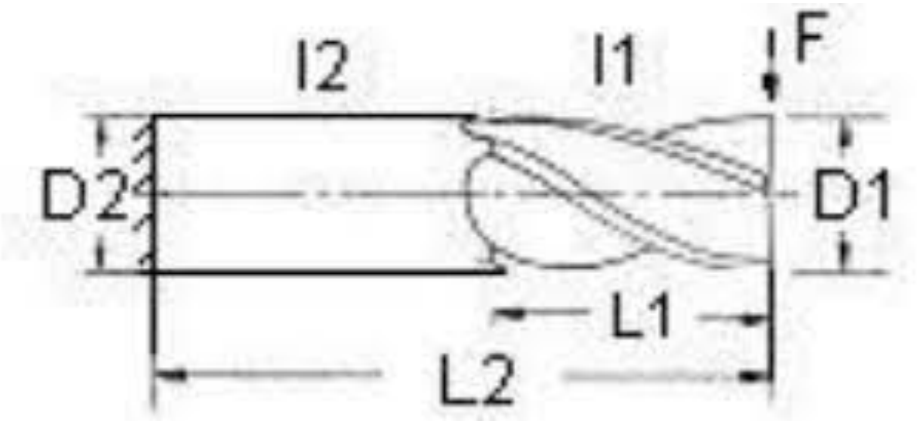


FIGURE 1.12 SPECIFICATION OF THE TOOL

- No of Flutes- 04 Shank length- 30 mm
- Día of Mill- 10 mm Diameter of shank- 10 mm
- Length of flute - 40 mm Total length- 75 mm

3.2.2 The greatest deflection of the cutting tool is calculated using the moment-area theorems.

-

$$Y[max]=FL_1^3/3EI_1+1/6\{FL_1(L_2-L_1)(L_2+2L_1)\}/EI_2+1/6\{FL_2(L_2-L1)(2L_2+L_1)\}/EI_2$$

3.2.3 The analytical model may be used to ascertain the stiffness of an end mill. Tool Deflection and Maximum Surface Error. The stiffness settings are used to calculate the end mill's maximum surface error.

Using milling force modelling, the cutting forces are established for surface error estimation in accordance with the characteristics of the work material, cutting, and tool circumstances.

- The experimental findings are used to validate the findings, and a high-speed steel, 4 flute end mill with a 320° helix angle was employed for comparison. The tool gauge length is 75 mm, and the tool diameter is 10 mm. This tool has a stiffness rating of 12562 N/mm.
- The experimental results and the model output are both accurate. Less than 6% of the greatest surface error (Emax) was incorrectly predicted. The findings of the experimental and computed maximum surface errors are listed in the table below.

TABLE 1.3 RESULTS OF MAXIMUM SURFACE ERROR

Axial depth of cut (mm)	Feedrate (mm/tooth)	Emax (Exp.) (mm)	Emax(Model) (mm)	ERROR (%)
19.05	0.14	0.0944	0.0912	3.38
15.00	0.10	0.0722	0.0677	6.23
15.00	0.06	0.0444	0.0438	1.35

15.00	**0.02**	**0.0178**	**0.0167**	**6.18**
18.00	**0.02**	**0.0166**	**0.0158**	**4.82**

- In one of the experiments, an HSS end mill with a 10 mm diameter, an 86 mm overhang, and four flutes was mounted by a CAT40 tool holder and used on three samples.
- It was determined that the damping ratio and effective end mill diameter were 10 mm and 23 Ns/m.

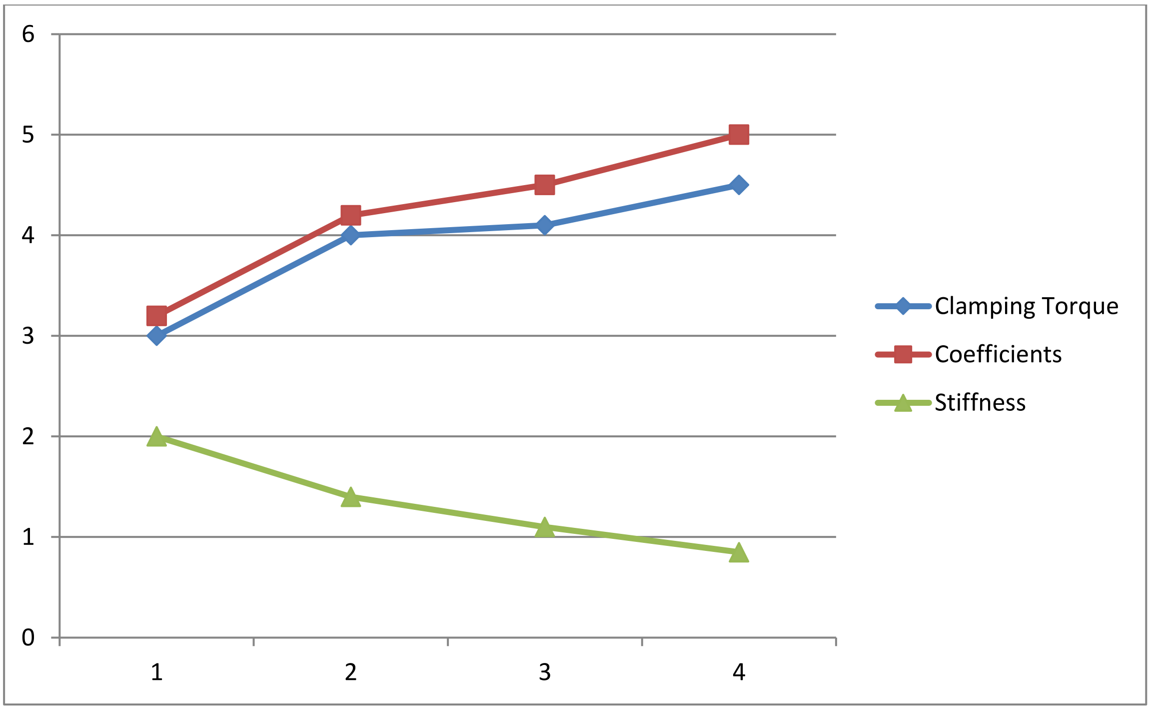


FIGURE 1.13 GRAPH BETWEEN CLAMPING TORQUE, DAMPING COEFFICIENTS AND STIFFNESS

As shown in the graph above, all of the coefficients rise as the torque is applied to the tool holder increases in value. These numbers are all used to determine how the clamping torque affects the stability and rigidity of the tool.

The linear and rotational spring and damping coefficients for the connection between the tool and tool holder/spindle are offered. The agreement between the predicted and actual results is displayed in the table below;

TABLE 1.4 RESULTS OF PREDICTED AND MEASURED COEFFICIENTS

kx (N/m) (linear connection stiffness)	Kq (Nm/rad) (rotation connection stiffness)	cx (Ns/m) (linear connection damping)	cq (Nms/rad) (rotation connection damping)
84.8×10^5	8×10^4	1022	6.3

On the CAT40 holder, different clamping torque values are 25 Nm, 35 Nm, and 45 Nm are used. The effective diameter of the tool is nearly 19.213 mm.

HSS had a damping coefficient of 27 Ns/m. Using the nonlinear least squares method, the stiffness and damping coefficients for HSS and tool holder/spindle combinations are calculated.

As the clamping torque imparted to the tool holder rises, all coefficients rise. These figures will be used to project how clamping torsion will affect the dynamics and stability of the tool.

TABLE 1.5 VALUE OF COEFFICIENTS AT DIFFERENT CLAMPING TORQUE VALUES

HSS	T=25Nm	T=35Nm	T=45Nm
kx (N/m)	**4.4×10^{7}**	**5×10^{7}**	**5.6×10^{6}**
Kq (Nm/rad)	**3.4×10^{4}**	**3.6×10^{4}**	**4×10^{4}**
Cx (Ns/m)	**1400**	**1594**	**1800**
Cq (Nms/rad)	**0.32**	**0.398**	**0.510**

RESULTS- The damping coefficient of a system gauges how soon it comes to rest when the oscillation energy of the frictional force has been released. The force necessary to hold a bolted joint together is known as the clamp force.

The value of damping coefficients at different torque values is to be find with medium variations. The average of the maximum surface error is 4.453%, this error can be decreased by adjusting the feed rate and the damping coefficients.

The tool deflection will minimize by knowing the most distinction between the long flute and therefore the long reach tool. in line with the load stress theory, the shorter overhang length causes the lower effects of bend stress. It suggests that the deflection of the tool is faded by decreasing the overhang length of the tool. The tool deflection in the machining of CNC can reduce by increasing the value of tool stiffness. The machining operations square measure typically expedited by tool steel; however, the tool deflection may end up from the exposure of the high-stress load. One of the high-speed steel tools alternatives is the carbide tools, which are considered three times more rigid than the high-speed tools. The carbide tools have their brittle properties and they can be used to reduce deflection.

CONCLUSION- For precise machining and chatter stability, edge tool dynamic and static qualities are crucial. Accurate information does not take precedence over approximations for the dynamics and stability of the chatter. On the other hand, considering the variety of tool and gear holder combinations, tool pure mathematics, and material in an industrial setting, experimental approaches might be daunting.

Individual tool assembly transfer operate measurements are no longer necessary thanks to the analytical models created throughout this research. The models take into account the intricate geometry of flutes when determining cross sectional characteristics. End mills' geometry is further complicated by the fact that they have both fluted and unfluted parts. In both static and dynamic modelling, this segmental property has also been taken into account.

For the sort of circumstances, static and dynamic predictions are without a doubt accurate. In an exceedingly virtual machining system where the shape mistakes and stability constraints for an edge application are mechanically established, the method given here is incredibly helpful.

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LIST OF PUBLICATIONS

1. **“A qualitative study of essential variations in the cutting tool dimensional features and end mill deflection and their effects on machining accuracy in CNC milling machine”** Farheen Mirza, Dr.Mohd.Reyaz-Ur-Rahim International Journal of Scientific Research in Engineering and Management **(IJSREM)** Volume 06, Issue 05 May 2022.

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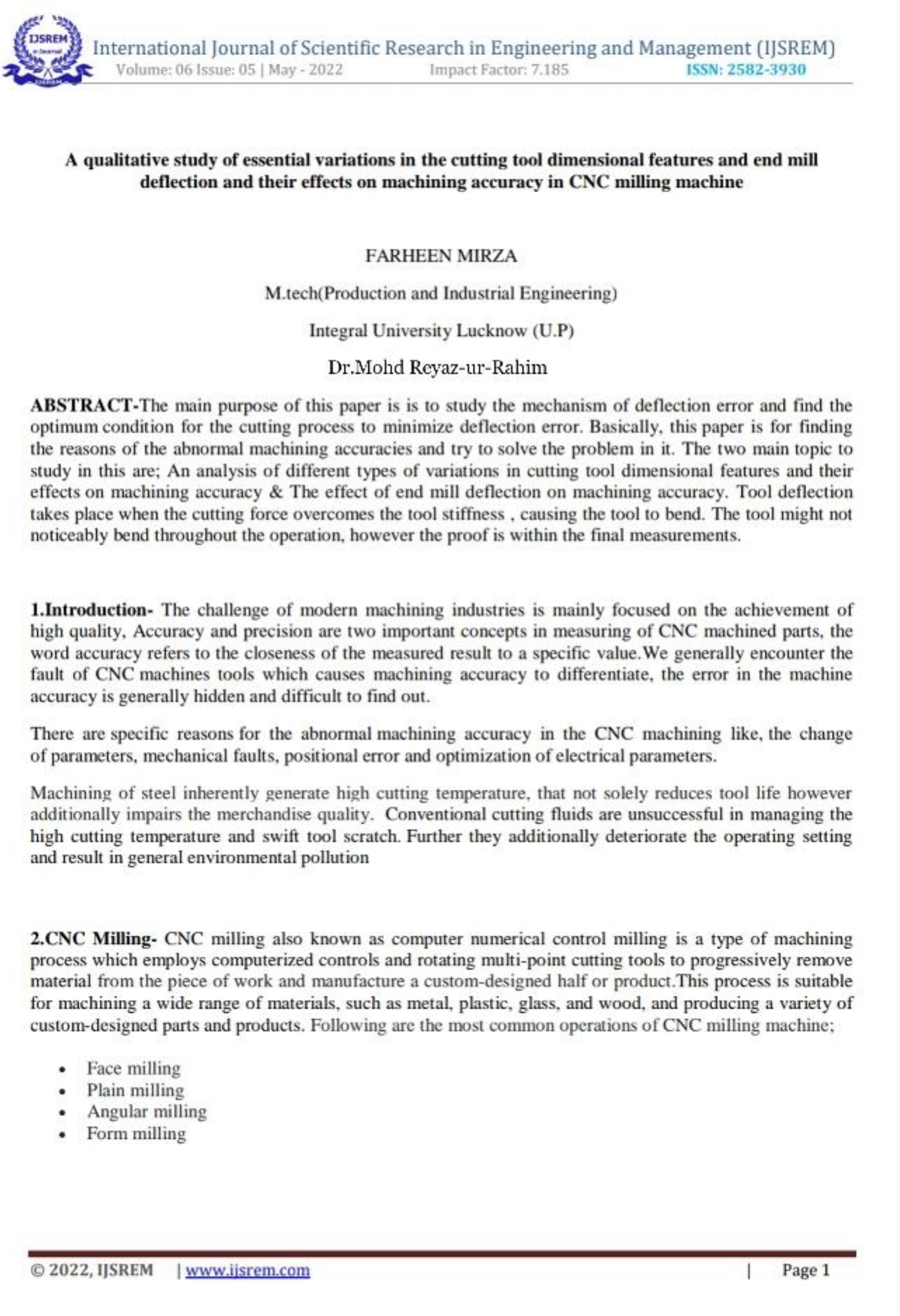
APPENDIX



International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 05 | May - 2022 Impact Factor: 7.185 ISSN: 2582-3930

A qualitative study of essential variations in the cutting tool dimensional features and end mill deflection and their effects on machining accuracy in CNC milling machine

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ABSTRACT-The main purpose of this paper is is to study the mechanism of deflection error and find the optimum condition for the cutting process to minimize deflection error. Basically, this paper is for finding the reasons of the abnormal machining accuracies and try to solve the problem in it. The two main topic to study in this are; An analysis of different types of variations in cutting tool dimensional features and their effects on machining accuracy & The effect of end mill deflection on machining accuracy. Tool deflection takes place when the cutting force overcomes the tool stiffness , causing the tool to bend. The tool might not noticeably bend throughout the operation, however the proof is within the final measurements.

1.Introduction- The challenge of modern machining industries is mainly focused on the achievement of high quality, Accuracy and precision are two important concepts in measuring of CNC machined parts, the word accuracy refers to the closeness of the measured result to a specific value.We generally encounter the fault of CNC machines tools which causes machining accuracy to differentiate, the error in the machine accuracy is generally hidden and difficult to find out.

There are specific reasons for the abnormal machining accuracy in the CNC machining like, the change of parameters, mechanical faults, positional error and optimization of electrical parameters.

Machining of steel inherently generate high cutting temperature, that not solely reduces tool life however additionally impairs the merchandise quality. Conventional cutting fluids are unsuccessful in managing the high cutting temperature and swift tool scratch. Further they additionally deteriorate the operating setting and result in general environmental pollution

2.CNC Milling- CNC milling also known as computer numerical control milling is a type of machining process which employs computerized controls and rotating multi-point cutting tools to progressively remove material from the piece of work and manufacture a custom-designed half or product.This process is suitable for machining a wide range of materials, such as metal, plastic, glass, and wood, and producing a variety of custom-designed parts and products. Following are the most common operations of CNC milling machine;

- Face milling
- Plain milling
- Angular milling
- Form milling

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