Optimization of CNC Face Milling Process Parameters for Inconel 718 by Using Taguchi Method – A Review

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Abstract - *Every day scientists are developing new materials and for each new material, we need economical and efficient machining process. The main objective of industries are producing better quality product at minimum cost and increase productivity. Though, CNC milling is most commonly used in industry and machine shops for machining parts to precise sizes and shapes with desire surface quality and higher productivity within less time and cost.* Face milling is very common method for finishing of new materials and machined materials. *Inconel 718 is one of the most commonly used nickel based super alloy having a high temperature applications such as aerospace industries and gas turbines in aviation. It is known as the most difficult to cut materials due to its high strength even at high temperatures, low thermal conductivity, and rapid work hardening. An experiment will be performed to find out the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR) for the purpose of machining Inconel 718 Super Alloy. Also, To analyze effect of Process parameters on surface roughness (SR) and material removal rate (MRR) by plotting the various graphs. The cutting tool material used for this purpose is Carbide. The experiments are conducted by using Taguchi L9 orthogonal array method. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) is used to analyses the effect of milling parameters on surface roughness and material removal rate.*

Key Words: CNC Milling Machine (VMC), Inconel 718 Super Alloy, Process parameters, Machining characteristics- SR and MRR, Carbide cutting tool, Taguchi method, ANOVA.

1. INTRODUCTION

Milling is the process of removing extra work piece material with a rotating multi-point cutting tool, called milling cutter. The machine tool employed for milling is called milling machine. So, Milling is a multipoint cutting tool machining operation used for removing a layer of material from complete surface of workpiece and also producing slots in the components.

CNC (Computer Numerical Control) is the general term used for a such system which controls the functions of a machine tool using coded instructions which processed by a computer. The application of CNC to a manual machine allows to perform its operation to become fully automated. Combining this, with the use of a part program enhances the ability of the machine to perform repetitive tasks with higher degree of accuracy.

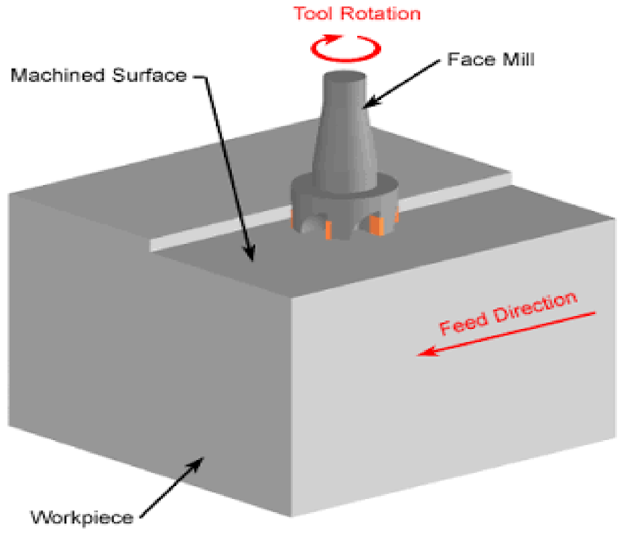

Fig-1: Milling operation

CNC (Computer Numerical Control) is a material removal process used to manufacture components with complicated shapes as well as profiles. In present time, CNC vertical milling machine technology has been improved significantly to meet advance requirements in various manufacturing fields, especially such as in the precision metal cutting industry. This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on surface finish in face milling.

CNC Milling machine is superior to other machines as compared to its accuracy and better surface finish. Every manufacturing industry is trying to achieve the high quality products in a very short period of time with less input. In milling machine, there are many process parameters like spindle speed, feed rate, depth of cut, tool geometry, coolant etc. which affected on required quality parameters. So, selections of such process parameters are the important for any quality parameters.

Milling is basically classified into a three categories:

1. Peripheral Milling:-

It is also known as slab milling. In this, the axis of rotation of the cutter is parallel to the machined surface, and the action is performed achieved by cutting point (edges) on the outer circumference of the cutter.

2. Face Milling:-

In face milling, the cutter is installed on a spindle. The axis of rotation of cutter is perpendicular to the workpiece surface. The diameter of cutter either equal to width of workpiece or greater than width of workpiece which has to be machined.

3. End Milling:-

In this process, the axis of rotation of cutter is perpendicular to the surface of the workpiece which has to be machined. The various operations (profiles) can be produced by milling of flat, irregular and curved sufaces. The cutter which is used in end milling has either straight or tapered shanks for smaller and larger cutter sizes respectively. The cutter, called end mill, has a diameter less than the width of workpiece.

However, Inconel 718 is classified into a "difficult to cut materials" due to its physical properties such as lower thermal conductivity, high affinity for tool materials, and high tendency to work hardening. Inconel 718 super alloy is a high-performance alloy that exhibits several key characteristics, such as Excellent mechanical strength, good surface stability, resistance to thermal creep deformation and resistance to corrosion or oxidation. The crystal structure is typically a face centered cubic austenitic. Super alloys are the alloys which consists a comparatively higher mechanical and thermal strength in comparison with individual metals. These properties of super alloys make them eligible for the purpose, where in high strength to weight ratio of a material is to be expected.

For Ex.:- Aerospace industry, Jet and Rocket engines, Gas turbines, Nuclear and Steam power plants, Submarines, Petrochemical equipments and Other high temperature applications etc.

Surface roughness (SR) is major factor in modern CNC milling industry. Surface finish is one of the prime requirements of customers for machined parts. In most of machining operations the main objective is optimization of surface roughness. The higher value of surface roughness generates on the machining parts and due to rework or scrap results into increase in cost and loss productivity. Surface roughness is major factor in modern CNC milling industry. The purpose of this work is focused on the analysis of optimum cutting conditions to get lowest surface roughness in milling by regression analysis. Also, To investigate the effect of cutting parameter like spindle speed, feed rate and depth of cut on surface finish and material removal rate.

2. CNC MILLING PROCESS PARAMETERS

The process parameters which will influence the experiment of optimizing while machining of the Inconel 718 super alloy are listed below:

1) Cutting speed (rpm):
The cutting speed is the cutting speed of cutter of milling machine, measured in revolution per minute (rev/min). The preferred speed is determined based on the material being cut. Excessive cutting speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct cutting speed for the material and tools will greatly affect tool life and the quality of the surface finish.
2) Feed Rate (mm/min):
It is the velocity at which the cutter is fed, that is, advanced against the work piece. It is expressed in units of distance per time for milling (typically in a millimeters per minute); with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth.
3) Depth of cut (mm):
It refers to the amount of material being taken per pass. This is how deep the tool is under the surface of the material being cut. This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

Although, Face Milling gives good quality surface finish, as a proper execution of the process and control of a number of parameters is maintained for a successful outcome. Recent experimental and computational works have provided insight into how process parameters such as, cutting speed, feed rate, depth of cut are exert significant effects on the surface roughness and material removal rate during machining.

Table-1: Properties of Inconel 718

Workpiece material	Tensile strength (MPa)	Yield strength (MPa)	Melting Temp. (ºC)	Elongation (%)	Hardness (HRC)
Inconel 718	1400	1040-1160	1350	14-16	40-45

Table-2: Chemical composition of Inconel 718 alloy (wt%)

Elements	Fe	Ni	Cr	Nb	Mo	Ti	Al
Percentage	2.8	68.10	21.10	5.07	3.60	1.15	0.65

3. MACHINING CHARACTERISTICS

The most important machining characteristics considered in the present work are:

1) Surface Roughness (R_a): Surface finish is an essential requirement in determining the surface quality of a product. The average surface roughness is the integral absolute value of the height of the roughness profile over the evaluation length (L) and was represented by the equation given below.
Where 'L' is the length taken for the formula,

$$R_a = \frac{1}{L}\int_0^L |Y(x)dx|$$

Observation and 'Y' is the ordinate of the profile curve.
Surface roughness tester (Stylus probe type profilometer) is uses to measure surface roughness of work piece in microns (μm).
2) Material removal rate (MRR): Material removal rate is the volume of material removed per unit time from the work piece surface. We can calculate material removal rate as the volume of material removed divided by the time taken to cut. The volume removed is the initial volume of the work piece minus the final volume. The cutting time is the time needed for the tool to move through the length of the work piece. This parameter strongly influences the finishing grade of the work piece.

$$MRR = [(Wb - Wa)/(t \times q)] \times 1000$$

Where,
Wb = Weight of the workpiece before machining (grams).
Wa = Weight of the workpiece after machining (grams).
t = Machining time period (minutes).
q = Density of work piece material (grams/cm3).

3) Machining Time (min):- L/fN
Where, L=Length of tool travel (mm)
fN=Feed velocity (mm/min)

4) Tool Life (min):- VT^n=C
Where, V=Cutting speed (m/min)
T=Tool life (min.)
n=Taylor's exponent
C=Taylor's constant

4. CUTTING TOOL MATERIALS

Face mill, which includes material selection and geometry, is one of the most important factors that influence surface roughness and the mechanical properties. Tool materials, apart from having to satisfactorily endure the milling operation, affect surface roughness and tool wear. In the context of machining, a cutting tool is any tool that is used to remove material from the workpiece by means of shear deformation. Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the workpiece without the rest of the tool dragging on the workpiece surface.

The desirable cutting tool material used for machining of Inconel 718 has characteristics:

- wear resistance should be good,
- high hot hardness,
- strength and toughness should be high,
- thermal shock properties should be good,
- adequate chemical stability at elevated temperature.

Therefore, the cutting tool material is selected as follows:

1. Carbide cutting tool.

5. RESEARCH ON CNC MILLING OF INCONEL 718 SUPER ALLOY

Mandeep Chahal et al.,[1] in 2013 with the more precise demands of modern engineering products, the control of surface texture has become more important. This investigation outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in end milling operation. The study was conducted in machining operation for hardened die steel H-13. The processing of the job was done by solid carbide four flute end-mill tools under finishing conditions. The input machining parameters like spindle speed, depth of cut, and feed rate were evaluated to study their effect on SR (surface roughness) using L-9 standard orthogonal array. Signal-to-Noise (S/N) ratio, Analysis of Variance (ANOVA) and various plots were generated using MINITAB software. Finally the effect of machining input parameters on SR is studied and reported in this paper.

Lohithaksha M Maiyer et al.,[2] in 2013 studied the optimization of machining parameters for end milling of Inconel 718 super alloy using Taguchi based grey relational analysis. Cutting speed, feed rate and depth of cut ate optimized with, consideration of surface roughness and material removal rate (MRR). Used uncoated tungsten carbide tool of 10mm diameter and 4 flutes. L9 orthogonal array of Taguchi method are applied. Analysis of variance (ANOVA) and grey relational analysis is also applied to get the most significant factor. He found that cutting velocity is most affecting factor and followed by feed rate affecting the multiple performance characteristics.

M. Alauddin et al.,[3] studied the optimization of surface finish in end milling Inconel 718 by using a tungsten carbide insert in dry condition. The nose radius of insert is 0.80 mm. for the analysis of result he has taken two process variables: cutting speed and feed rate. He Used response surface method for experimental design. He found that if feed rate is increased, then the surface roughness is also increased and vice versa. And if cutting speed is increased.

A. Arunkumar et al.,[4] in 2014 suggested in most of machining operations the main objective is optimization of surface roughness. The higher value of surface roughness generates on the machining parts and due to rework or scrap results into increase in cost and loss productivity. To investigate the effect of cutting parameter like spindle speed, feed rate and depth of cut on surface finish on Polyphenylene sulphide with 40% glass fiber (PPS),the experiments have been conducted using L9 orthogonal array in Minitab 16.0 software. Comparison between experimental values and predict values is carried out. The objective was to establish relation between cutting speed, feed rate and depth of cut and optimize the turning conditions based on surface roughness.

Piyush Pandey et al.,[5] in 2013 conducted an experiment was conducted to perform the parametric optimization of CNC end milling machine tool in varying condition. The tool used for experiment was of Solid Carbide and the Mild Steel work piece was used during experiment. The experiment has been taken place efficiently and completes its all objective of optimization. The practical result can be used in industry to get the desirable Surface Roughness and Material Removal Rate for the work piece by using suitable parameter combination.

M. Aruna et al.,[6] in 2012 explained Inconel 718; a nickel based super-alloy is an extensively used alloy, accounting for about 50% by weight of materials used in an aerospace engine, mainly in the gas turbine compartment.. This paper is concerned with optimization of the surface roughness when turning Inconel 718 with cermet inserts. The approach is based on Response Surface Method (RSM). In this work, second-order quadratic models are developed for surface roughness, considering the cutting speed, feed rate and depth of cut as the cutting parameters, using central composite design. The developed models are used to determine the optimum machining parameters. These optimized machining parameters are validated experimentally, and it is observed that the response values are in reasonable agreement with the predicted values.

Amit Joshi et al.,[7] (2012) had taken process parameters like spindle speed, depth of cut, feed rate to investigate to reveal their impact on surface finish using Taguchi Methodology. They had taken L9 orthogonal array to perform experiments. They found the optimal setting for selected process parameters and optimal value of surface finish was obtained at first level of factor A, third level of factor B and second level of factor C. From the ANOVA analysis they were found that feed rate is the most dominating factor for surface finish.

6. RESEARCH GAP, PROBLEM AND CHALLENGE

Generally, Super alloys are machined on the CNC Milling. Inconel 718 super alloy is one such super alloy on which optimization experiment can be performed to find out the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR). Inconel 718 material is the most difficult material to machine. Improper selection of machining parameters causes cutting tool to wear and break quickly as well as economic losses such as damaged work piece and rejected surface quality. Machining parameters and tool geometry are the important parameters which affect the machinability properties. Inconel 718 is Nickel-based alloy difficult-to-machine because of its low thermal diffusive property and high strength at higher temperature. The machinability of Nickel- based alloy Inconel 718 in milling operations has been carried out using multiple inserts under wet conditions on a computer numerical control (CNC) milling machine at different stages of cutting speed.

The objective of this article has been aimed to report work carried out by various researchers in the field of CNC Milling and to bridge gap between the untouched areas. It is analyzed from the literature review that till optimization of Inconel 718 is done by using a single milling cutting tool and single machining parameter. But, still no comparative study is done with multiple machining parameters. So that, An experiment will be performed to analyze effect of process parameters that are influence on surface roughness (SR) and material removal rate (MRR) by plotting various graphs.

Fig-2: Experimental set up for CNC Milling Machine(VMC)

7. CONCLUSION:

This article presents a review of research work carried out in the optimization of the process parameters for CNC Face Milling. In this review article, surface roughness and material removal rate optimization, face milling operation and applications of Inconel 718 have been addressed. Surface roughness (SR) and material removal rate (MRR) are very important factor for determining product quality. Machining parameters like cutting speed, feed rate, depth of cut are crucial to roughness free surface. CNC Face milling gives a good surface finish of Inconel 718. For Experimental design, Taguchi method will be used for optimization process. By using ANOVA (Analysis of variance) Method, find out the significant factor and percentage contribution of each input parameter for obtaining optimal conditions. Using the signal to noise ratio and mean ANOVA calculations, the optimum output characteristics will be predicted by MINITAB software. This review article will covers the effect of process parameters that are influence on surface roughness (SR) and material removal rate (MRR) by plotting the various graphs. Finally from the experimentation, it is found out that the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR) for the purpose of machining Inconel 718 Super Alloy.

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