Optimization of Milling Process Parameter for Surface Roughness of Inconel 718 By Using Taguchi Method

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Abstract— High quality and productivity are two important but major criteria in several machining operations. Vertical End Milling Machining process operated by CNC is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. In the End milling process, the material is removed by parent material from the end mill cutter. The effects of numerous parameters of end milling process like cutting speed (35 to 75), depth of cut (0.12 to 0.21 mm/teeth), feed rate(0.5 to 2.7 mm) have been examined to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by way of Standard Orthogonal Array. The graph of S-N Ratio indicates the superlative setting of the machining parameter which provides the optimum value of surface finish. The superlative set of process parameters has also been predicted to maximize the surface finish. In this project we're describing milling possibilities of nickel alloy Inconel 718. In the beginning is described the application of nickel alloys in industry and also division of nickel alloys. Inconel 718, within this material we make all our own tests of machinability. Cutters with exchangeable sintered carbide blade plates had been used as cutting. Main aim was investigate durability and wear of indexable cutting inserts with regard to different cutting procedures. It is mainly about different combinations regarding used cutting speeds, feed and depth of cut. Three machining process parameter are chosen cutting speed, feed rate and depth of cut. The analysis prepare was created using by Taguchi's L9 Orthogonal Array (OA) and Minitab 17.0 statistical software is employed. Optimal values of process parameter with regard to desired performance characteristic are received by Taguchi design of experiment.

Key words: Optimization, CNC Milling, Taguchi Method, Surface roughness, Inconel 718

I. Introduction

The purpose of this paper is Analysis of machining process and optimization of CNC vertical end milling process by employing Taguchi Method. The focus on this project is to obtain an optimum process parameter consider as cutting speed, feed rate and depth of cut which provides the optimum value{9} of surface finish. The experimentation plan was created using Taguchi's L9 Orthogonal Array (OA) and Minitab 17.0{11} statistical software is employed. Optimal values of process parameter with regard to desired performance characteristic are received by Taguchi design of experiment. Milling is often a versatile in addition to useful machining operation. End milling is the main milling operation which is widely used in a lot of the manufacturing industries automobile capability involving producing complex geometric surfaces with reasonable accuracy in addition to surface finish {2}. However, with the inventions of CNC milling machine {3}, the flexibility may be adopted in addition to versatility within end milling process. It can be found that quite a few research works have been done until now on on-going improvement in the performance involving end milling process. In end milling, surface finish and material removal rate are two important aspects, which require attention both from industry personnel as well as in Research & Development, because these two factors greatly influence machining performances. In modern industry, one of the trends is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems are employed for that purpose. CNC machines are considered most suitable in flexible manufacturing system. Above all, CNC milling machine is very useful for both its flexibility and versatility. These machines are capable of achieving reasonable accuracy and surface finish. Processing time is also very low as compared to some of the conventional machining process. 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 turning 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 turning industry. The purpose of this work is focused on the analysis of optimum cutting conditions to get lowest surface roughness in turning by regression analysis. To investigate the effect of cutting parameter like spindle speed, feed rate and depth of cut on surface finish.

II. Literature review

A.Arun kumar et al 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. Machining was done using diamond insert and measured the surface roughness by using Surfcom 130A. 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. {1}

Vipindas M P et.al.in 2013 analyze that the productivity and quality are two important characteristics those control most of the manufacturing processes. In this paper, quality of machined surfaces in turning operation is optimized through Taguchi method. The comprehensive experimentation and analysis was performed on Al 6061 material based on Taguchi L9 orthogonal array. The commonly used parameters speed, feed and depth of cut were used for this assessment. The roughness values vary between 0.3 and 4.4.A general linear model was employed to evaluate the parametric effects. It was observed that feed is the significant factor at 95% confidence level. Feed has the strongest influence on the quality of machined surfaces in CNC turning. {2}

Prof.V.M.Prajapati et al in 2013 suggested CNC milling is one of the most commonly used in industry and machine shops today for machining parts to precise sizes and shapes. For the analysis input parameters like feed rate, spindle speed and depth of cut selected as a control factors in Taguchi technique of response variable optimization with keeping operating chamber temperature and the usage of different tool inserts constant. And the product quality in terms of Surface roughness and productivity as material removal rate is measured. An orthogonal array of L3 was used and ANAOVA were performed to find out the significance of each of the input parameters on the Surface roughness and material removal rate. {3}

Amit joshi et al in 2013 give survey and says that CNC End milling is a unique adaption of the conventional milling process which uses an end mill tool for the machining process. During the End milling process, the material is removed by the end mill cutter. The effects of various parameters of end milling process like spindle speed, depth of cut, feed rate have been investigated to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by a Standard Orthogonal Array. The results of analysis of variance (ANOVA) indicate that the cutting speed is most influencing factor for modeling surface finish. The graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish. The optimal set of process parameters has also been predicted to maximize the surface finish and concluded that from the graph of S-N ratio. {4}

Piyush pandey* et al 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. {5}

Mandeep Chahal et al 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. {6}

Krishankant et al in 2012 reports on an optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The bars used are of diameter 44mm and length 60mm. There are three machining parameters i.e. Spindle speed, Feed rate, Depth of cut. Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab 15. {7}

Ishan B Shah et al in 2013.This paper discuss of the literature review of Optimization of tool life in milling using Design of experiment implemented to model the end milling process that are using solid carbide flat end mill as the cutting tool and stainless steels s.s-304 as material due to predict the resulting of Tool life. Data is collected from CNC milling machines were run by 8 samples of experiments using DOE approach that generate table design in MINITAB packages. The inputs of the model consist of feed, cutting speed and depth of cut while the output from the model is Tool life calculated by Taylor’s life equation. The optimization of the tool life is studied to compare the relationship of the parameters involve. {8}

Miroslav Janos et al 2012 describing milling possibilities of nickel alloy Inconel 718. It is high-strength, corrosion-resistive, precipitation hardened alloy, being used in the temperature range from -252°C to +700°C Target of this experiment if find the most optimal cutting conditions for planar milling of Inconel 718, experiment was made on stock of size 70 x 115 x 320mm This article shows milling possibilities for nickel alloy Inconel 718 by indexable cutting inserts made by Pramet Tools, s.r.o. from sintered carbide. For inserts SEMT 09T3AFSN were found (from the point of durability) the most optimal cutting parameters vc = 35m.min-1 and feed f_{opt} = 0,12mm. Summarizing all results I can state that if there are used correct cutting parameters, cutting material and geometry of a tool then also machining of alloys as Inconel 718 is economical and effective. {9}

Basim A. Khidhir et al in 2010 suggest a Nickel- based alloy is difficult-to-machine because of its low thermal diffusive property and high strength at higher temperature. The machinability of nickel- based Hastelloy C-276 in turning operations has been carried out using different types of inserts under dry conditions on a computer numerical control (CNC) turning machine at different stages of cutting speed. Conclusion from this study is that the transition from thick continuous chip to wider discontinuous chip is caused by different types of inserts. 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. The results of this study 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. {10}

M. Aruna et al 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. Optimization of turning operation is very useful to reduce cost and time for machining. 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. {11}

Yung-Kuang Yang et al in 2009. This investigation applied the designs of experiments (DOE) approach to optimize parameters of a computer numerical control (CNC) in end milling for high-purity graphite under dry machining. Planning of experiment was based on a Taguchi orthogonal array table. The analysis of variance (ANOVA) was adapted to identify the most influential factors on the CNC end milling process. Simultaneously, applying regression analysis a mathematical predictive model for predictions of the groove difference and the roughness average has been developed in terms of cutting speed, feed rate, and depth of cut. The feed rate is found to be the most significant factor affecting the groove difference. {12}

III. TAGUCHI METHOD

Taguchi methods are statistical methods developed by Genichi Taguchi {5} to improve the quality of manufactured goods and more recently also applied to engineering,biotechnology, marketingand,advertising. Profe ssional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals. The Taguchi method is a commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products through the application of statistical and engineering concepts. It is a method based on Orthogonal Array (OA) {8} experiments, which provides much-reduced variance for the experiment resulting is optimum setting of process control parameters. Orthogonal Array (OA) provides a set of well-balanced experiments (with less number of experimental runs) and Taguchi’s signal-to-noise ratios (S/N), which are logarithmic functions of desired output, serves as objective function in the optimization process. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized.

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment.Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected.

Steps of Taguchi method are as follows:

(1) Identification of main function, side effects and failure mode.
(2) Identification of noise factor, testing condition and quality characteristics.
(3) Identification of the main function to be optimized.
(4) Identification the control factor and their levels.
(5) Selection of orthogonal array and matrix experiment.
(6) Conducting the matrix experiment.
(7) Analyzing the data, prediction of the optimum level and performance.
(8) Performing the verification experiment and planning the future action.

A. Orthogonal Arrays:

Taguchi has developed a system of tabulated designs (arrays) that allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment. Orthogonal arrays are used to systematically vary and test the different levels of each of the control factors. Commonly used OAs includes the L4, L9, L12, L18, and L27. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Typically either 2 or 3 levels are chosen for each factor. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments. If there is an experiment having 3 factors which have three values, then total number of experiment is 27. Then results of all experiment will give 100% accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy.

B. Signal to Noise Ratio and Pareto ANOVA Approach:

The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio {7} takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. There are three standard types of SN ratios depending on the desired performance response.

1) Smaller The Better (For Making The System Response As Small As Possible):

$SN_S = -10 \log (\frac{1}{n}\sum_{i=1}^{n} Y_i^2)$

2) Nominal The Best (For Reducing Variability Around A Target):

$SN_T = 10 \log (Y^2/S^2)$

3) Larger The Better (For Making The System Response As Large As Possible):

$SN_L = -10\log (\frac{1}{n}\sum_{i=1}^{n} 1/Y_i^2)$

"Where n is the number of observations, y is the observed data".

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios are plotted for each factor against each of its levels. Finally, confirmation tests should be run at the "optimal" product settings to verify that the predicted performance is actually realized.

IV. Problem Identification

Inconel 718{10} material is the most difficult material to machine. Improper selection of machining parameters causes cutting tools 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. Nickel- based alloy Inconel 718 is 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 different types of inserts under dry conditions on a computer numerical control (CNC) turning machine at different stages of cutting speed.

A. Milling Possibilities Of Material Inconel 718:

We are describing milling possibilities of nickel alloy Inconel 718{10}. In the beginning it is described use of nickel alloys in industry and division of nickel alloys. Cutters with exchangeable sintered carbide blade plates were used as cutting tools.

B. Typical Properties of Inconel 718:

Property	Metric
Density	8.19g/cm^3
Melting point	1336^{o}c
Modulus of rigidity	77.2kN/mm^2
Co-efficient of expansion	13.0um/m^{0}c

Table 1: Properties of material Inconel 178

Non-magnetic, Good corrosion resistance and oxidation resistance in jet engine and gas turbine applications.

1) Application:

(1) Gas turbine
(2) Rocket motors
(3) Space craft
(4) Nuclear reactors and pumps

Target of this experiment if find the most optimal cutting conditions for milling of Inconel 718, experiment was made on stock of size 70 x 115 x 320mm. Stock was clamped to milling machine type FNG 32 CNC. For machining of Inconel 718 is recommended use of very positive millers.

V. Experiment and Data Collection

A. Experimental Setup:

The material and tool are selected based on the problem identification study.

1) Machine Tool:

CNC Milling Machine

2) Work Material:

Nickel- based alloy Inconel 718

3) Cutting Tool:

Cutters with exchangeable sintered carbide blade

B. For Experimental Work:

The material and tool are selected based on the problem identification study.

- To achieve surface roughness minimize by following parameters
- Cutting speed
- Feed rate
- Depth of cut

C. Planning Phase Input Parameter & There Levels For End Milling:

Parameters of the setting	
Control factor	**Symbol**
Cutting speed	Factor A
Feed rate	Factor B
Depth of cut	Factor C

Table 2: Cutting parameter of the setting

Level	Cutting speed(m/min) V_c	Feed rate(mm/teeth) F	Depth of cut(mm) D
1	35	0.12	0.5
2	55	0.16	1.6
3	75	0.21	2.7

Table 3: Selected input parameter

D. Design Of Experiments (DOE):

For selected input parameters experiments are designed using Taguchi L9 orthogonal standard array. For this purpose software Minitab 17.0 is used.

Level	Cutting speed (v_c) (m/min)	Feed rate (f) (mm/rev)	Depth of cut (d) (mm)
1	35	0.12	0.5
2	35	0.16	1.6
3	35	0.21	2.7
4	45	0.12	1.6
5	45	0.16	2.7
6	45	0.21	0.5

7	55	0.12	2.7
8	55	0.16	0.5
9	55	0.21	1.6

Table 4: Cutting Parameters Are Arranged in orthogonal L9 array

E. *Experimentation:*

After DOE, 9{4} experiments are carried out in CNC vertical End milling {3}. After each experiment Surface Roughness is calculated. A quality characteristic for Surface Roughness is smaller is the better. The signal-to-noise ratios of each experimental run are calculated based on the following equation, which are listed in corresponding tables with the data.

The equation is: - $SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} 1/Y_i^2\right)$

Where

SNi is the signal to noise ratio of ith term,

n = number of measurements in a trial/row, in this case, n=3 and *Yi* is the *i*th measured value in a run/row. Table for response (Surface Roughness) and S-N ratio is shown in Table-5

S. N O.	**(A) Cutting speed (v_c) (m/min)**	**(B) Feed rate (f) (mm/rev)**	**(C) Depth of cut (d) (mm)**	**Response Surface Roughness(µm)**	**S-N Ratio (dpi)**
1	35	0.12	0.5	1.7500	-4.86076
2	35	0.16	1.6	1.1100	-0.90646
3	35	0.21	2.7	0.9500	0.44553
4	55	0.12	1.6	0.8000	1.93820
5	55	0.16	2.7	1.6000	-4.08240
6	55	0.21	0.5	1.1800	-1.43764
7	75	0.12	2.7	1.2000	-1.58362
8	75	0.16	0.5	1.3200	-2.41148
9	75	0.21	1.6	1.8200	-5.10545

Table 5: Table for response (surface roughness) and S-N ratio

VI. RESULT

A. *Response Table For Signal To Noise Ratios Smaller Is Better:*

Level	CS	FR	DOC
1	-1.774	-1.502	-2.903
2	-1.194	-2.467	-1.358
3	-3.034	-2.033	-1.740
Delta	1.840	0.965	1.545
Rank	1	2	3

Table 6: Response Table for Signal to Noise Ratios

B. *Response Table For Means:*

Level	CS	FR	DOC
1	1.270	1.250	1.417
2	1.193	1.343	1.237
3	1.440	1.310	1.250
Delta	0.247	0.093	0.180
Rank	1	2	3

Table 7: Response Table for Means

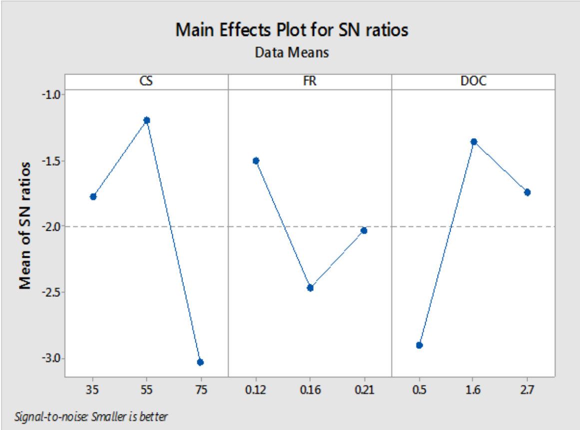

Fig. 1

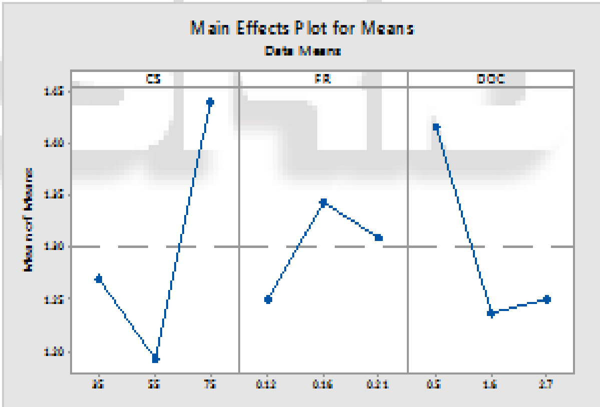

Fig. 2

The figure 1 contains the graph between SN ratio data and input parameter. The figure 2 contain the graph between mean and control factors. The objective of using the SN ratio as a performance measurement is to develop product and processes in sensitive to noise factor. The optimal combination of input machining parameter can be observed from fig 1 i.e. graph between S-N ratio and input parameter, the optimal setting of input parameter is (A_2, B_1, C_2**)**. The process parameter setting with the highest SN ratio always yields the optimum quality with minimum variation.

VII. CONCLUSION

- In this work the effect of machining parameters speed, feed, depth of cut, are studied on surface roughness for milling operation.
- For surface roughness, our observation is based on smaller is better for s/n ratio. Cutting speed has

greater effect than feed and depth of cut, our observation is based on smaller is better for s/n ratio.

- The lowest surface roughness (Ra) of 0.80 µm was achieved corresponding to: f: 0.12 mm/rev, V_c: 55m/min. and d: 1.6 mm.
- From the graph of S-N ratio it can be observed that optimal value of surface finish is obtained at second level of cutting speed, first level of feed rate and second level of depth of cut.
- Taguchi robust design is suitable for modelling surface finish in CNC milling.
- Summarizing all results I can state that if there are used correct cutting parameters, cutting material and geometry of a tool then also machining of alloys as Inconel 718 is economical and effective.

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