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Optimization of Parameters To Reduce The Surface Roughness in Face Milling Operation on Stainless Steel and Mild Steel Work Piece Applying Taguchi Method

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***Abstract* - This experimental study is based on the optimization of milling parameters to reduce the surface roughness in face milling operation using Stainless Steel (SS) and Mild Steel (MS) Work Piece. This experimental study will conduct under the three varying parameters depth of cut, spindle speed and feed rate. The settings of milling parameters will determine by using the Taguchi experimental design of L9 Orthogonal array method. All the nine experiments have conducted using a Stainless Steel and Mild Steel work piece and the roughness was checked using the surface roughness tester. Minitab 19 software has used to find out the combination of the optimum milling parameters by using the analysis of Signal-to-Noise (S/N) ratio. This experimental study will help in decreasing the surface roughness using the optimal combination of the milling parameters.**

***Keywords*- Milling Machine, Surface Roughness, Taguchi Method, S/N ratio, Optimization.**

I. INTRODUCTION

Milling is a metal removal operation. In milling operation metal is removed by a rotating multiple point cutter which is fitted on the arbor of the milling machine. The varieties of features are formed by milling machine on a part by cutting away the unnecessary material. Milling machine is having certain main components, which are its column, saddle, its Base, table, knee, arbor, over-arm and spindle. In milling process, certain aspects plays a very important role such as work-piece, fixture, and cutter which are needed in milling machine.

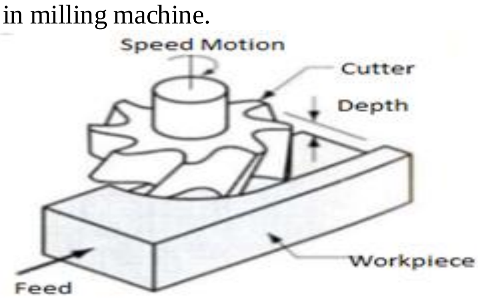

Fig.1 Face Milling Operation.

II. LITERATURE REVIEW

During machining operation it is essential to have proper selection of machining parameters. Now-a-days machining parameters are mainly selected on the basis of previous work experience of the process planner or thumb rule or machining data hand book. All these techniques are time consuming and very tedious. There is a need to develop a model that could able to find the optimal machining parameters for the required surface finish in machining. In this work, the effect of machining parameters is studied to obtain the optimum machining parameters for end milling operations. Many researchers have used the various techniques such as Taguchi method, Genetic Algorithm, Neural Network, ANOVA, Ant Colony Optimization (ACO) and soon have become very popular due to its versatile usage in various engineering applications especially in machining problems. In this PSO has been used to optimize the machining parameters. [1]

This paper discuss of the literature review of optimization of milling machining process parameters for composite materials. Machining process has characteristics that describe their performance relative to efficient use of machine tools by setting optimum cutting parameters. The traditional optimization techniques are not suitable because milling machining operation is highly constrained in nature. For this reason we propose a modified optimization methodology based on hitherto research study for milling machining parameters. [2]

This paper discusses the use of Taguchi technique and Genetic Algorithm (GA) for minimizing the surface roughness in machining mild steel with three zinc coated carbide tools inserted into a face miller of 25 mm diameter. The experimental study was carried out in a FANUC series CNC vertical machining center (VMC). The experiments have been planned using Taguchi's experimental design technique. The machining parameters used are Number of passes (P), Depth of cut (dc), Spindle speed (N), and Feed rate (f). The effect of machining parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. The predicted values are confirmed by using validation experiments. [3]

In this paper signal-to-noise ratio method is applied to find optimum process parameters for finishing operation of mild steel with the help of CNC milling machine and high speed steel tool used. The signal-to-noise ratio applied to find optimum process parameter for CNC finishing machining .A L9 orthogonal array and analysis of variance (ANOVA) are applied to study the performance characteristics of machining parameter (spindle speed, feed, depth, width) with consideration of high surface finish and high material removal rate(MRR) .The surface finishing and material removal rate have been identified as quality attributes and assumed to be directly related to productivity improvement. Results obtained by taguchi method and signal-to-noise ratio match closely with (ANOVA) and the feed are most effective factor for MRR. And spindle speed is the most effective factor for surface roughness. Multiple regression equation is formulated for estimating predicted value surface roughness and material removal rate. [4]

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. [5]

Milling is the mainly common form of machining. It is a material removal process, which can produce a variety of features on a part by cutting away the unnecessary material. The optimization is performed within the practicable region defined by the important constraints .In order to optimize the cutting conditions, the experimental relationships between input and output variables should be time-honored in order to expect the output. Optimization of these analytical models helps us to select suitable input variables for achieving the best productivity performance. In this review paper the study is enclosed concerning the optimization of dissimilar input parameters and results are analyzed. Particle swarm optimization (PSO) method is used for resulting the best possible set of values of input variables for most material removal rate. [6]

In this paper Taguchi technique was employed to find out the optimal cutting parameters in face milling operation of AISI 1005 steel using TIN coated tool. Three cutting parameters i.e. spindle speed (N), depth of cut (dc) and feed rate (f) were optimized with consideration of surface roughness (Ra) and material removal rate (MRR). Experiments have been performed based on L9 orthogonal array. Effect of cutting parameter were analyzed using ANOVA and the results shows that the depth of cut and feed rate influences the responses the most. Furthermore, confirmation experimental test has been conducted based on optimal parameter to justify the results. Surface roughness and MRR obtained at optimal process parameters were 2.97 μm and 0.96923 g/min respectively. [7]

In this paper milling process parameters are optimized in case of face milling - Metal removal rate on 6061-T6 Aluminium work-piece using Design of Experiments (DOE) and Response Surface Methodology (RSM) and by taking into consideration feed rate, depth of cut and spindle speed as input parameters. [8]

The objective of the present work is to apply Taguchi method to investigate the effects of milling parameters such as cutting speed, depth of cut and feed rate on surface roughness, MRR.The present work carrying on vertical milling machine and High Speed Steel is selected as cutting tool to machine the OHNS Steel. [9]

This experimental investigation was observed the machining performance with various cutting speed, feed and depth of cut using side and face milling cutter. Mainly surface roughness where investigated employing Taguchi design of experiments and analysis of variance (ANOVA). The significant machining parameters are identified by using signal to noise ratio. The result of the experiments indicates cutting speed play a dominating role in surface roughness in milling process parameters. [10]

The work-piece is held in a fixture, attached to a table of milling machine. Three table movements are possible in a

Milling machines i.e., crosswise, vertical, and longitudinal but rotational or swivel movement are also found with respect to the table in some cases. In improving Process of Milling, a very important role is played by the quality of surface. The fatigue strength, corrosion resistance, or creep life is improved by a good surface. Surface roughness affects a number of functional attributes of parts, such as, friction between two contacted parts, parts wearing, reflection of light transmission of heat, distributing ability and lubricant holding , capacity of load bearing, coating or fatigue resisting etc. This study presents a systematic approach to determine the effect of process parameters (depth of cut, spindle speed, feed rate) on surface roughness of milling operation on Stainless Steel work piece using Taguchi method.

1. Milling Parameters

- **Depth of cut**
  Depth of cut is the thickness of metal that is removed during machining. The perpendicular distance measured between the machined surface and the uncut surface of the work piece is taken. This is measured in mm.
- **Spindle Speed**
  The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (rpm).
- **Feed Rate**
  Feed rate is the velocity at which the cutter is fed, that is, advanced against the work piece. It is expressed in units of mm per revolution.

III. METHODOLOGY

1. Material Selection

Stainless Steel (SS) of dimensions 300x200x25 mm and Mild Steel (MS) of dimensions 800x400x20 mm have selected as work piece material.

Stainless steel (SS) is an alloy of Iron with a minimum of 10.5% Chromium. Chromium produces a thin layer of oxide on the surface of the steel known as the passive layer. This prevents any further corrosion of the surface. Increasing the amount of Chromium gives an increased resistance to corrosion. Stainless steel also contains varying amounts of Carbon, Silicon and Manganese. Other elements such as Nickel and Molybdenum may be added to impart other useful properties such as enhanced formability and increased corrosion resistance.

Mild steel is a type of carbon steel with low carbon content, and it's also called low carbon steel. Ranges will vary based on the source, but will generally be between 0.05 percent to 0.25 percent by weight. Higher carbon steel, on the other hand, will range between 0.30 percent and 2.0 percent carbon. Beyond this, steel is classified as cast iron. Mild steel is not an alloy steel, and therefore does not contain large amounts of other elements besides iron.

2. Design of Experiment and Parameters

Taguchi parametric design methodology was adopted. The experiments were conducted using L9 Orthogonal Array (OA) with three parameters (Spindle Speed, Feed, and Depth of cut) with three levels (level 1, level 2 and level 3). The process parameters, their symbols and their values at different levels are shown in the table 1.

Table I: Process Parameters with their Levels.

Work piece	Process Parameter	Unit	Level 1	Level 2	Level 3
Stainless Steel	Spindle speed (A)	rpm	240	300	400
	Feed rate (B)	mm/ min	120	150	200
	Depth of cut (C)	mm	0.5	0.6	0.4
Mild Steel	Spindle speed (A)	rpm	178	200	250
	Feed rate (B)	mm/ min	150	200	230
	Depth of cut (C)	mm	0.6	0.4	0.3

Optimization of process parameters is the key step in the Taguchi Method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi Method are insensitive to the variation of environmental conditions and other noise factors.

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value.

Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi Method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments.

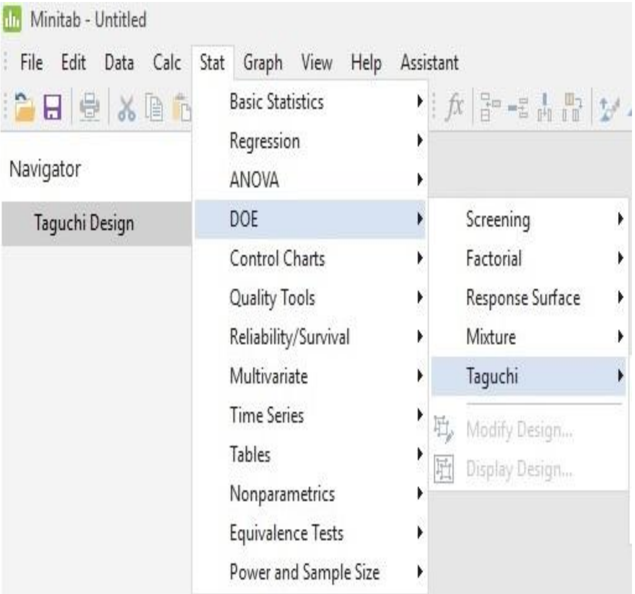

Fig.2. Selection of Taguchi Design of Experiment in Minitab 19

Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way.

Table II: Taguchi L9 Orthogonal Array

Experiment No.	Spindle Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

All the 9 experiment have done using the Taguchi L9 Orthogonal Array. Minitab 19 software has used to analyze the Taguchi design and to calculate results.The Milling operation has conducted on all the nine specimens using the Taguchi L9 Orthogonal Array and their surface roughness has measured using the surface roughness tester.

IV. RESULT AND DISCUSSION

The initial process parameters selected:

Table III: Initial Process Parameters

Material	Initial Process Parameters	Surface Roughness (µm)
Stainless Steel	$A_2B_2C_3$	1.2
Mild Steel	$A_2B_2C_3$	1.2

As we have discussed before that the milling operation has performed on all the nine specimens and surface roughness has calculated using the surface roughness tester. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value.

The value of the overall loss function is further transformed into a Signal to Noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e., the lower-the better, the larger-the-better, and the more nominal- the-better. The S/N ratio for each level of Process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. The loss function of the smaller the better quality characteristics can be expressed as:

$$\text{S/N Ratio } (\eta) = -10 \times (1/n) \log_{10}\{\Sigma Y^2\}$$

Where,

Y= observed data at i^{th} trial

n= number of trials

For example the S/N ratio is calculated for first experiment is as follows:

$$\eta_1 = -10\,(1/1)\log_{10}[(3.2)^2]$$
$$\eta_1 = -10.1030$$

for second experiment

$$\eta 2 = -10\,(1/2)\log_{10}[(3.8)^2]$$
$$\eta 2 = -11.5957$$

Table below shows the Surface Roughness measured for the nine specimens of Stainless Steel and Mild Steel.

Table IV: Surface Roughness

Experiment Number	Surface Roughness (µm)	
	For Stainless Steel	For Mild Steel
1	3.2	2.5
2	3.8	3.2
3	4.0	4.0

4	2.0	1.6
5	1.2	1.2
6	2.5	3.8
7	1.6	2.0
8	1.4	1.6
9	2.0	2.5

1. S/N Ratio Analysis

In order to quantify influence of each level of parameters, mean of S/N ratio for A were computed by averaging S/N ratio for experiment Number 1, 2, 3, for level 1, 4, 5, 6 for level 2 and 7, 8, 9 for level 3. Mean of S/N ratio for each level of other milling parameters were calculated in a similar way. Parameters with large difference indicate high influence to surface roughness as its level is changed.

S/N Ratio calculated for the Stainless Steel and Mild Steel material for the nine experiments are given in the table IV.

Table V: S/N Ratio

Experiment Number	S/N Ratio	
	For Stainless Steel	For Mild Steel
1	-10.1030	-7.9588
2	-11.5957	-10.1030
3	-12.0412	-12.0412
4	-6.0206	-4.0824
5	-1.5836	-1.5836
6	-7.9588	-11.5957
7	-4.0824	-6.0206
8	-2.9226	-4.0824
9	-6.0206	-7.9588

2. Response Table for S/N Ratio

In this experimental study from the table VI (a) and VI (b) we can say that parameter A and B has largest difference following its levels for Stainless Steel and Mild Steel material respectively, whereas each level of parameter C shows less effect to output for both the material. Based on S/N ratio, new operation parameters were obtained through maximum level of each parameter.

Response Table for both the material are given below with their delta values.

Response Table for Signal to Noise Ratio

Table VI(a): for Stainless Steel

Level	Spindle Speed(A)	Feed(B)	Depth of Cut(C)
1	-11.247	-6.735	**-5.902**
2	-5.188	**-5.367**	-6.995
3	**-4.342**	-8.674	-7.879
Delta	6.905	3.306	1.977
Rank	1	2	3

3. Variation of Parameter with S/N Ratio for Stainless Steel:

Variation of parameter with their S/N Ratio has plotted below:

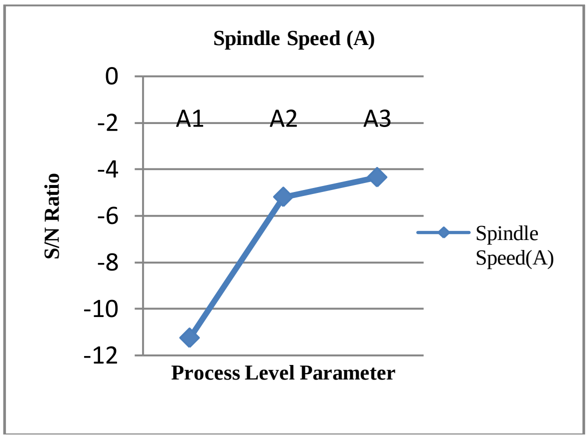

Fig. 3 Variation of S/N Ratio with Spindle Speed

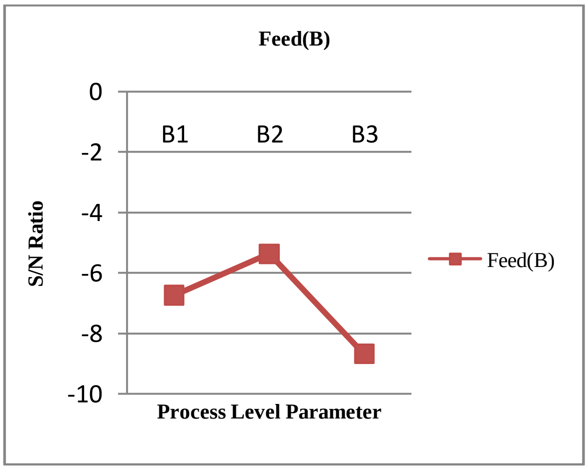

Fig. 4 Variation of S/N Ratio with Feed

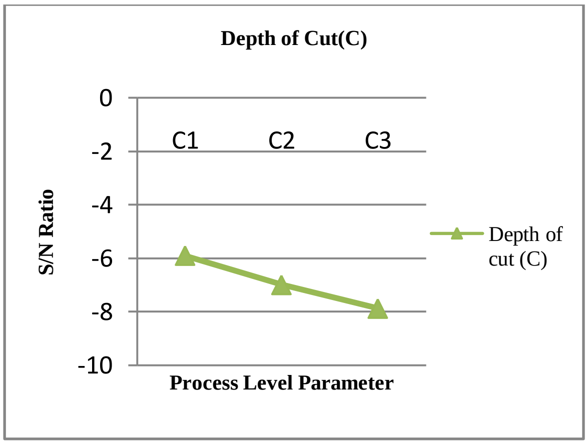

Fig. 5 Variation of S/N Ratio with Depth of cut

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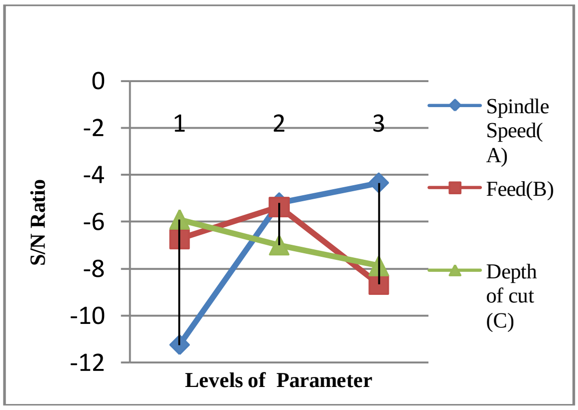

Fig.6 Variation of S/N Ratio with Process Parameter

From Table VI (a), it shows that the value of delta for parameters A, B, and C are 6.905, 3.306 and 1.977 respectively. The delta value for each parameter concludes that Spindle Speed is the most effective parameter followed by feed and depth of cut for surface roughness in case of stainless steel material.

Table VI (b): For Mild Steel

Level	Spindle Speed(A)	Feed(B)	Depth of Cut(C)
1	-10.034	-6.021	**-6.548**
2	**-5.754**	**-5.256**	-7.381
3	-6.021	-10.532	-7.879
Delta	4.280	5.276	1.330
Rank	2	1	3

3.Variation of Parameter with S/N Ratio for Mild Steel:
Variation of parameter with their S/N Ratio has plotted below:

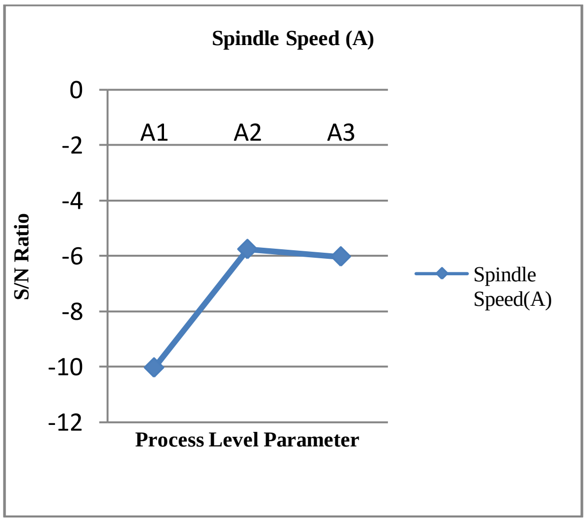

Fig. 7 Variation of S/N Ratio with Spindle Speed

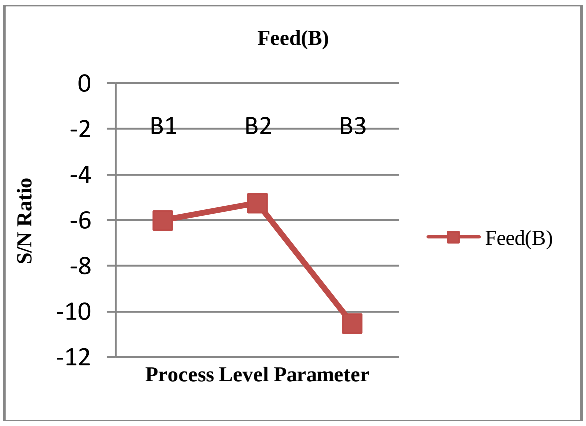

Fig. 8 Variation of S/N Ratio with Feed

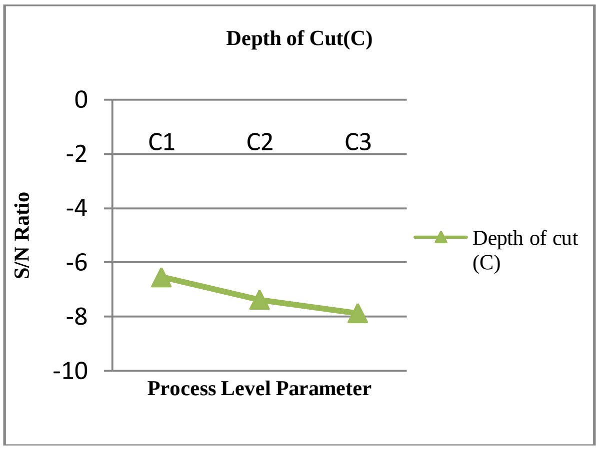

Fig. 9 Variation of S/N Ratio with Depth of Cut.

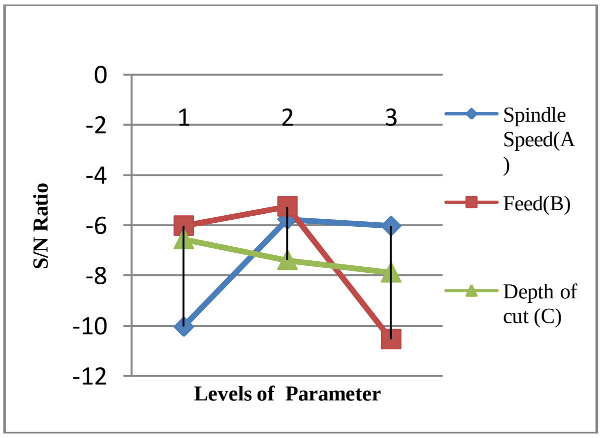

Fig.10 Variation of S/N Ratio with Process Parameter

Table VI (b) shows that the value of delta for parameters A, B, and C are 4.280, 5.276 and 1.330 respectively. The delta value for each parameter concludes that feed is the most effective parameter for surface roughness followed by spindle speed and depth of cut in case of mild steel material.

From the above table we can find out that the optimal parameters for milling operation for stainless steel are A_3 B_2 C_1 and for mild steel are A_2 B_2 C_1. The combination of factors and levels which gives maximum S/N ratio gives the optimum milling parameters. A confirmation test has conducted using the optimum milling parameters which are A_3 B_2 C_1 and A_2 B_2 C_1 for stainless steel and mild steel material respectively. The surface roughness calculated in confirmation test using the optimum milling parameters is 0.85 µm and 0.72 µm for stainless steel and mild steel material respectively. Result of confirmation test clearly shows that the experiment conducted gives the satisfactory result and using the optimum milling parameters we can get good surface finish. Hence the result of experiment gives the expected outcome.

V. CONCLUSION AND FUTURE SCOPE

This experiment was based on the optimization of milling parameters to minimize the surface roughness using stainless steel and mild steel material. The Taguchi Method of L9 orthogonal array has used to perform the experiment. The milling operation has performed on all the specimens using the Taguchi design of experiment. Then the surface roughness has found out using a surface roughness tester. An optimum parameter combination for the minimum surface roughness was obtained by using the analysis of Signal-to-Noise (S/N) ratio.

The confirmation tests indicated that it is possible to minimize the surface roughness significantly by using the suitable parameters. The experimental results confirmed the validity of the used Taguchi method for enhancing the quality of the surface and optimizing the milling parameters. The experimental results show that the milling parameters are the important factors to improve the quality of the surface so we can say that the combination of the suitable parameters is necessary for the good surface finish.

The influences of the spindle speed, depth of cut and feed rate on surface roughness of the face milling operation have been studied. The experiment will perform on stainless steel and mild steel material and obtained data will be analyzed by using the Minitab 19 software. It has been observed that, Taguchi's orthogonal array provides a large amount of information in a small amount of experimentation. All the three parameters are important and they will contribute a lot in the result output.

Future Scope

This experimental study shows that the milling machine parameters plays a important role to improve the surface quality hence by using the optimum milling parameters we can obtain a good surface finish. The results of this study will help the industries to get the better surface finish using these milling parameters.

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