ENHANCING THE SUBMERSIBLE PUMP ROTOR PERFORMANCE BY TAGUCHI OPTIMIZATION TECHNIQUE FOR TURNING CUTTING PARAMETERS

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Abstract - *Due to their low hysteresis losses silicon steel is one of the most suitable materials for rotors. Silicon stamping stacked together by pressure die casting process to form a rotor. However, their uneven surface roughness creates excessive static friction between rotor and stator. As the friction increases the pump does not rotate which leads to the pump failure. This necessitates a process optimization when machining silicon steel stampings with HSS tool. This project outlines an experimental study to achieve this by employing Taguchi techniques. Combined effects of three cutting parameters, namely cutting speed, feed rate and depth of cut on performance measure surface roughness (R_a), were investigated by employing an orthogonal array, signal-to-noise ratio, and analysis of variance.*

***Key Words*: Surface Roughness (R_a); orthogonal arrays; Analysis of variance (ANOVA)**

1. INTRODUCTION

Surface roughness is an important measure of the technological quality of a product and a factor that greatly influences manufacturing cost. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent; it is very difficult to calculate its value through theoretical analysis. Therefore, machine operators usually use “trial and error” approaches to set-up turning machine cutting conditions in order to achieve the desired surface roughness. Obviously, the “trial and error” method is not effective and efficient and the achievement of a desirable value is a repetitive and empirical process that can be very time consuming. The dynamic nature and widespread usage of turning operations in practice have raised a need for seeking a systematic approach that can help to set-up turning operations in a timely manner and also to help achieve the desired surface roughness quality. [1]

Developments in cutting tools and machine tools in the last few decades have made it possible to cut materials in their hardened state [2]. High speed steel is considered to be one of the most suitable tool materials for machining stampings because of their high density. This high density affords it incredible durability and hardness and shock and vibration resistance while still allowing for its machinability into tools and drill bits.

Surface finish is an important parameter in manufacturing engineering. It is a characteristic that could influence the performance of mechanical parts and production costs [3].

2. TAGUCHI METHOD

Taguchi techniques have been used widely in engineering design [4]. The main trust of the parameter design consist a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analysing data, in order to obtain information about the behaviour of the given process. The treatment of the experimental results is based on the analysis of variance (ANOVA).

The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps [6]

Identify the performance characteristics and select process parameter to be evaluated. Determine the number of levels for the process parameter and possible interactions between the process parameters.

- Select the appropriate orthogonal array and assignment of process parameters
- Conduct the experiments based on the arrangement of the orthogonal array.
- Calculate S/N ratio.
- Analyze the experimental results using the S/N ratio and ANOVA.
- Select the optimal levels of process parameters.
- Verify the optimal process parameters through the conformation test.

3. EXPERIMENTAL PROCEDURE

3.1. EQUIPMENT AND MATERIALS

The goal of this experimental work was to improve the performance of the rotor by investigate the effects of cutting parameters on surface roughness. In order for this, cutting speed, feed rate and insert radius were chosen as process parameters. The air gap between rotor and stator is kept constant therefore depth of cut is not used in this paper.

The work material was silicon steel in the form of round bars with 70mm diameter and 100 mm cutting length. Silicon steel Stampings have a thickness of 0.4mm was stacked together by pressure die casting process to form a rotor. Copper was used in die casting process. The chemical composition of silicon steel which was used in experiments as shown in table 1

The turning tests were conducted in dry conditions on CNC lathe having maximum spindle speed of 3500rpm and maximum power of 15KW.

Table - 1: Chemical Composition of Silicon Steel

Fe	C	Si	Mn	P	S	Cr
96.52	.0408	2.33	.359	0.026	0.004	0.052 1
Mo	**Al**	**Cu**	**Ti**	**V**	**Pb**	
.0215	.216	.416	.0136	.0007	.0027	

Table - 2: Assignment of the Levels to the Factors

Symbol	Cutting parameters	Level 1	Level 2	Level 3
A	Cutting speed(rpm)	360	610	860
B	Feed rate (mm/rev)	0.12	0.22	0.32
C	Insert radius (mm)	0.1	0.2	0.3

3.2. SELECTION OF CUTTING PARAMETERS AND THEIR LEVELS

The initial cutting parameters were as follows: insert radius of 0.2mm, feed rate of 0.25mm/rev and cutting speed of 550rev/min. Three levels were specified for each parameter as given in table 2. The parameter levels were chosen within the intervals recommended by the cutting tool manufacturer.

4. DETERMINATION OF OPTIMAL CUTTING PARAMETERS

4.1. DESIGN OF EXPERIMENTS

The orthogonal array chosen was L_9, which has 9 rows corresponding to the number of parameter combinations (26 degrees of freedom), with 4 columns at three levels as shown in table 2. The first column was assigned to the cutting speed, the second column to the feed rate, the third column to the depth of cut, and fourth column to the error.

Table - 3: Orthogonal Array L_9 of Taguchi

Test No.	Column			
	Cutting Speed	Feed Rate	Depth of Cut	Error
1	1	1	1	
2	1	2	2	
3	1	3	3	
4	2	1	1	
5	2	2	2	
6	2	3	3	
7	3	1	1	
8	3	2	2	
9	3	3	3	

Surface roughness measurements were performed by using Kosaka Leap SE1200 sampling length of 2.3mm.

4.2. ANALYSIS OF SIGNAL-TO-NOISE (S/N) RATIO

There are three categories of performance characteristics, i.e. the lower-the-better, the high-the-better, and the nominal-the-better. To obtain optimal machining performance, the lower-the-better performance characteristic for surface roughness should be taken for obtaining optimal machining performance. The S/N ratio for lower-the-better performance is specified by the following equation [1].

$$S/N_L = -10\log_{10}[1/n \sum_{i=1}^{n} (1/y_i)^2] \qquad (1)$$

Where n, is the number of observations and y is the Observed data.

Table 4 shows the experimental results for surface roughness and the corresponding S/N ratio using Eq. (1). For example, the mean S/N ratio for cutting speed at level 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1-3, 4-6, and 7-9, respectively. The mean S/N ratio for each level of the cutting parameters is summarized and called the mean S/N response table for surface roughness (Table 5).In addition the mean S/N ratio for nine experiments is also calculated and listed in Table 5.

Table – 4: Experimental Results for Surface Roughness & S/N Ratio

Test No.	Cutting Parameter Level			Performance Measure	
	A	B	C		
	Cutting Speed	Feed Rate	Insert Radius	Measured Surface Roughness	Calculated S/N Ratio for Surface Roughness
1	360	0.12	0.1	2.235	-6.98
2	360	0.22	0.2	4.546	-13.15
3	360	0.32	0.3	7.342	-17.32
4	530	0.12	0.2	2.432	-7.72
5	530	0.22	0.3	1.354	-2.63
6	530	0.32	0.1	0.912	0.8
7	860	0.12	0.3	1.846	-5.32
8	860	0.22	0.1	2.026	-6.13
9	860	0.32	0.2	4.428	-12.92

Table – 5: Response table mean S/N ratio for surface roughness factor and significant interaction

Symbol	Cutting Parameter	Mean S/N Ratio			
		Level 1	Level 2	Level 3	Max-min
A	Cutting Speed	-12.48	-3.18	-8.127	9.3
B	Feed Rate	-6.68	-7.3	-9.81	3.13
C	Insert Radius	-4.106	-11.26	-8.424	7.159

Total mean S/N ratio = -7.93

Table - 6: ANOVA Table for Surface Roughness

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Contribution (%)
Cutting Speed	2	129.5	64.75	4.23	50.93
Feed Rate	2	16.21	8.10	0.53	6.375
Depth of Cut	2	77.94	38.97	2.55	30.65
Error	2	30.6	15.3	-	12.03
Total	8	254.27	-	-	100

4.3. ANALYSIS OF VARIANCE

The purpose of the ANOVA is to investigate which of the process parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. First, the total sum of the squared deviations SS_T from the total mean of the S/N ratio η can be calculated as [5]

$$SS_T = \sum_{i=1}^{a} \sum_{j=1}^{n} (\eta_{i.} - \eta..)^2 \quad (2)$$

Where, *n* is the number of experiments in orthogonal array and η_i is the mean S/N ratio for j_{th} experiment.

The total sum of the squared deviations SST is decomposed into two sources: the sum of the squared deviations SS_P due to each process parameter and the sum of the squared error SS_e. SS_P can be calculated as:

$$SS_P = n \sum_{i=1}^{a} (\eta_{i.} - \eta..)^2 \quad (3)$$

Where *p* represents one of the experiment parameters, *i* the level number of this parameter *p*. *a* repetition of each level of the parameter *p*. The sum of squares from error parameters SS_e is

$$SS_e = SS_T - SS_A - SS_B - SS_C \quad (4)$$

The total degrees of freedom is $D_T = n - 1$, where the degrees of freedom of the tested parameter $D_p = a - 1$. The variance of the parameter tested is $V_P = SS_P/D_P$. Then, the F-value for each design parameter is simply the ratio of the mean of squares deviations to the mean of the squared error ($F_P = V_P/V_e$). The corrected sum of squares S_P can be calculated as:

$$S_P = SS_P - D_P V_P. \quad (5)$$

The percentage of contribution C can be calculated as:

$$C = S_P / SS_T \quad (6)$$

Statistically, there is a tool called the F-test named after Fisher to see which process parameters have a significant effect on the performance characteristic. In performing the F-test, the mean of the squared deviations SS_m due to each process parameter needs to be calculated. The mean of the squared deviations SS_m is equal to the sum of the squared deviations SS_d divided by the number of degrees of freedom associated with the process parameter. Then, the F-value for each process parameter is simply a ratio of the mean of the squared deviations SS_m to the mean of the squared error SS_e. Usually the larger the F-value, the greater the effect on the performance characteristic due to the change of the process parameter.

Table 6 shows the results of ANOVA for surface roughness. It shows that the only significant factor for surface roughness is cutting speed, which explains 50.93% of the total variation. The next largest contribution comes from insert radius with 30.65%. The change of the feed rate in the range given by Table 2 has an insignificant effect on surface roughness. Therefore, based on the S/N and ANOVA analyses, the optimal cutting parameters for surface roughness are the cutting speed at level 2, the feed rate at level 3, and the insert radius at level 1.

4.4. CONFIRMATION TESTS

Once the optimal level of the process parameters is selected, the final step is to predict and verify the improvement of the performance characteristic using the optimal level of the process parameters. The estimated S/N ratio η using the optimal level of the process parameters can be calculated as [6]

$$\eta = \eta_n + \sum_{i=1}^{q} (\eta_i - \eta_n) \quad (7)$$

Where, ηn is the total mean of the S/N ratio, q_i, is the mean S/N ratio at the optimal level, and q is the number of the process parameters that significantly affect the performance characteristic. The estimated S/N ratio using the optimal cutting parameters for surface roughness can then be obtained and the corresponding surface roughness can also be calculated by using Eq. (1).Table 7 shows the results of the confirmation experiment using the optimal cutting parameters of surface roughness. Good agreement between the predicted machining performance and actual machining performance is shown. The increase of the S/N ratio from the initial cutting parameters to the optimal cutting parameters is 8.348 dB. The improvement of the S/N ratio for the individual performance characteristic is shown in Table 7. Based on the result of the confirmation test, the surface roughness is decreased 2.615 times, in the foregoing discussion; the experimental results confirm the prior parameter design for the optimal cutting parameters with the multiple performance characteristics in turning operations.

Table - 6: Confirmation Test

	Initial Cutting Parameter	Optimal Cutting Parameters	
		Prediction	Experiment
Level	A2B2C2	A3B2C1	A3B2C1
Surface Roughness (μm)	2.954	0.87	1.13
S/N Ratio(dB)	-9.408	1.20	-1.06

Improvement of S/N ratio = 8.348

CONCLUSIONS

The following conclusions can be drawn based on the results of the experimental study on turning silicon steel stampings with HSS tools:

- Taguchi's robust orthogonal array design method is suitable to analyze the surface roughness (Turning) problem as described in this paper.
- It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters.
- The interaction cutting speed/insert radius is the most important of the other analyzed parameters. The remaining parameters cutting speed/feed rate and feed rate/insert radius have no significant influence on the surface roughness.
- In turning, use of lower cutting speed (510 rpm), medium feed rate (0.22 mm/rev) and low insert radius (0.1 mm) are recommended to obtain better surface roughness for the specific test range.
- The improvement of surface roughness from initial cutting parameters to the optimal cutting parameters is about 261.5%.
- The static friction was reduced by implementing the obtained parameters.

Further study could consider more factors (e.g., temperature, depth of cut, tool life, etc.) in the research to see how the factors would affect surface roughness.

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