OPTIMIZATION OF SURFACE ROUGHNESS OF A DRILLED HOLE ON SUP 11A BY TAGUCHI'S OPTIMIZATION TECHNIQUE

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Abstract

In this paper, an attempt has been made to optimize the surface roughness of a drilled hole in a leaf spring by *Taguchi's Optimization Technique*, to reduce the rejection which is taking place during the drilling operation while manufacturing of leaf spring. An orthogonal array, signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to investigate the optimal drilling parameters of SUP 11A spring steel strip and HSS drilling bit. This paper will yield the optimal combination of drilling parameters which will provide the optimum surface roughness on the hole during the drilling process of the leaf spring. After implementing the optimum combination, the manufacturing non-conformities has been reduced 4.99% to 3.99% out of total production and 19.91 to 12.06% out of total non-conformities.

Keywords: **ANOVA, SUP 11A, Surface roughness, S/N Ratio, Taguchi Method.**

INTRODUCTION

A leaf spring is a beam of cantilever design used to absorb the shock loads. Mostly, used in passenger and commercial vehicles as a part of the suspension system that connects the wheel base and the chassis of high criticality in terms of safety of the vehicles. The advantage of leaf spring over helical spring is that the ends of the leaf spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device [1]. A leaf spring is generally bent in an arc-shape and has a rectangular cross-section. It has holes drilled both at the centre as well as at the sides to accommodate the centre bolt and the U-clamps (for fixing the leaves) respectively(Fig.:1). the largest amount of money spent on any one class of cutting tools is spent on drills. Therefore, from the viewpoint of cost and productivity, modelling and optimization of drilling processes are extremely important for the manufacturing industry [2]. Amongst traditional machining processes, drilling is one of the most important metal-cutting operations, comprising approximately 33% of all metal-cutting operations [3, 4].While drilling the holes, the combination of parameters should be such that the surface roughness remains the optimum, as the surface roughness of a machined product could affect the several functional attributes of the product, such as contact causing surface friction, wearing, light reflection, heat transmission, lubricant holding capacity and resisting fatigue. In this paper, Taguchi's Optimization Technique has been employed todetermine the optimal combination of drilling parameters, so as to obtain the optimum surface roughness.

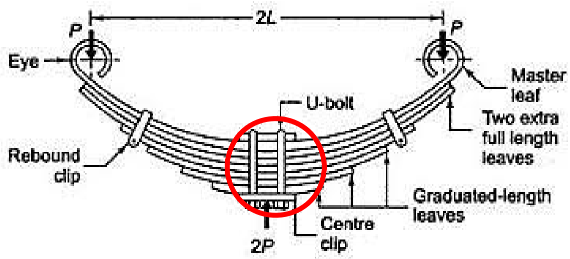

Fig. 1: Showing the position of Drilled Hole in a Leaf Spring.

Design of Experiment: Taguchi's Method

Dr. G. Taguchi of Nippon Telephones and Telegraph Company Japan is the developer of the Taguchi method [5], which involves reducing the variations in a process through robust design of experiments. He proposed that engineering optimization of a process or product should be carried out in a three-step approach, i.e. system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. Following on from system design is parameter design. The objective of parameter design is to optimize the settings of the process parameter values for improving quality characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from parameter design are insensitive to variation in the environmental conditions and other noise factors. Finally, tolerance design is used to determine and analyze tolerances around the optimal settings recommend by the parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the required performance, and involves tightening tolerances on the product parameters or process parameters for which variations result in a large negative influence on the required product performance. Typically, tightening tolerances means purchasing better-grade materials, components, or machinery, which increases cost. However based on the above discussion, parameter design is the key step in the Taguchi method to achieving high quality without increasing cost[6]. This method for designing experiments investigates how different parameters affect the mean and variance of a process performance characteristic and defines how well the process is functioning.

Product/process diagram [5]:

A Product/process diagram is used to indicate the various factors that influences of a Product\process. The figure 2 shows the various influencing factors of Product/process.

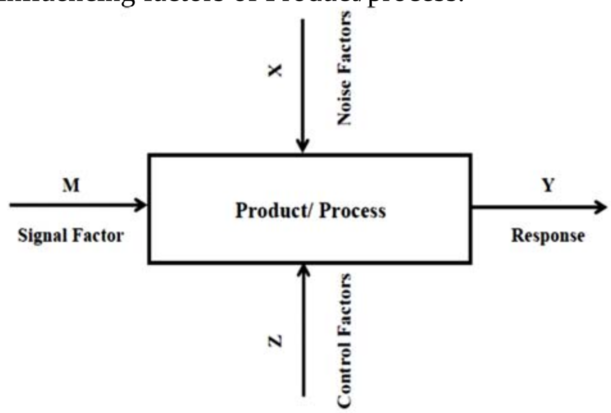

Fig.2: Product/process diagram

- The Signal Factor M consists of the input into the Product/Process, such as product design or Sequence of Processes.
- The Control Factors are those factors that can be controlled by the operator in order to obtain the required output. For Example: Speed, Cutter Radius, etc.
- The Noise Factors are the uncontrollable factors that influence the process to a great extent. They are responsible for the deviation of the output from the required output. For Example: Temperature, Humidity, Friction, Vibration, etc.
- Response is the outcome of the Product/process due to Signal Factor, changes in Control factor and Noise Factor.

Basically, experimental design methods [7] were developed originally by Fisher [8]. However, classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only [5]. As a result, time, cost, and labour saving can be achieved. Instead of having to test all possible combinations like the factorial design, the Taguchi method tested pairs of combinations in a more efficient way. This allows for the collection of necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an intermediate number of variables (3 to 50) [9], few interactions between variables and when only a few variables contribute significantly. The Taguchi's arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, the arrays can be found online. The arrays are selected by the number of parameters (variables) and the number of levels (states). The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values [10]. In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard deviation, SD) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of characteristic; lower is better (LB), nominal is best (NB), or higher is better (HB) [11]. Here, lower-the-better means lower the optimized value, better will be the results, higher-the-better means, higher the optimized value, better will be the results and nominal-the-better means, nominal the optimized value, better will be the results. A greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters was the level with the greatest S/N ratio [12]. The S/N ratio for each level of parameters is computed based on the S/N analysis. In this case, lower-the-better criteria will be used, as it yields the optimal results. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analysis, the optimal combination of the process parameters can be predicted.

The parameter design of the Taguchi method includes the following steps [13]:

1. Identify the quality characteristics and process parameters to be evaluated.
2. Determine the number of levels for the process parameters and possible interactions between the process parameters.
3. Select the appropriate orthogonal array and assign the process parameters to the orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Analyze the experimental results using the signal-to-noise ratio and statistical analysis of variance.
6. Select the optimal levels of process parameters.
7. Verify the optimal process parameters through a confirmation experiment.

Experimental Work

The drilling operation was carried out on a precision makeover Rockwell drilling machine. Here the feasible drilling parameters are feed rate (varying from 0.05 to 0.15 mm/rev) and speed (varying from 325 to 850 rpm) respectively. The experiment was carried out on a 10.5mm hole drilled on a spring steel (SUP11A) flat and was kept constant throughout the experiment. The high speed steel (HSS) drill bit was also kept constant throughout the experiment. The Drilling parameters and their levels are shown in the following table.

Factors	**Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**
A	Feed Rate	mm/rev	0.05	0.10	0.15
B	Speed	Rpm	325	450	850

TABLE 1: Drilling Parameters and their Levels

Since the metal selected for experiment is SUP11A, is a type of Spring Steel (Carbon Steel) having adequate properties for a spring. The composition (in %) of SUP11Ais shown in the following table.

C	Si	Mn	P	S	Cr	B
0.61	0.23	0.91	0.03	0.03	0.82	0.0005

TABLE 2: Composition of SUP11A

Selection of Orthogonal Array (OA)

Since there are 2 parameters and 3 levels, the L9 orthogonal array has been selected. [9]

Factors / Experiments	Surface Roughness Parameters			
	A	B	C	D
	Feed Rate	Speed	Errors	Errors
1	1	1	-	-
2	1	2	-	-
3	1	3	-	-
4	2	1	-	-
5	2	2	-	-
6	2	3	-	-
7	3	1	-	-
8	3	2	-	-
9	3	3	-	-

TABLE 3: Experimental Layout using an L9 OA

Calculation of S/N Ratio

In this paper, since the surface roughness has to be optimized, so lower-the-better characteristic would yield the optimum results. The S/N ratio for lower-the-better characteristic can be given as-

S/N = -10log (MSD) [14]

Where, MSD = Mean Square Deviation in the output characteristic and is given as-

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad [14]$$

Where, n = No. of observations

yi = Observed data

Test Drive	Surface Roughness (µm)	S/N Ratio (dB)
1	1.5	-3.5218
2	1.2	-1.5836
3	1.0	0
4	1.7	-4.6089
5	1.4	-2.9225
6	1.2	-1.5836
7	2.0	-6.0206
8	1.8	-5.1054
9	1.6	-4.0824

TABLE 4: Experimental Results for S/N Ratio

Since the experimental design is orthogonal, it is then possible to separate out the effect of each parameter at different levels [10]. For example, the mean S/N ratio for the feed rate at levels 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1–3, 4–6 and 7–9 and respectively. The mean S/N ratio for each level of the other parameters can be computed in the similar manner. The mean S/N ratio for each level of the parameters is summarized and called the S/N response table for the total surface roughness [10].

Symbol	Parameters	Mean S/N Ratio (dB)		
		Level 1	Level 2	Level 3
A	Feed Rate	-1.7018	-3.0383	-5.0695
B	Speed	-4.7171	-3.2038	-1.8887

TABLE 5: S/N response table for the total surface roughness

Results

On the basis of various experiments and analysis carried out, following are the results that we obtained.

The following figures show the S/N response graph.

The graph to show the effect of feed rate has been plotted (fig. 3.).

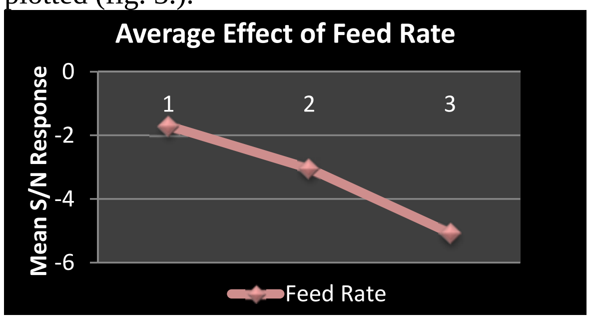

Fig.3: Effect of Feed Rate

The graph to show the effect of Speed has been plotted (fig.4.)

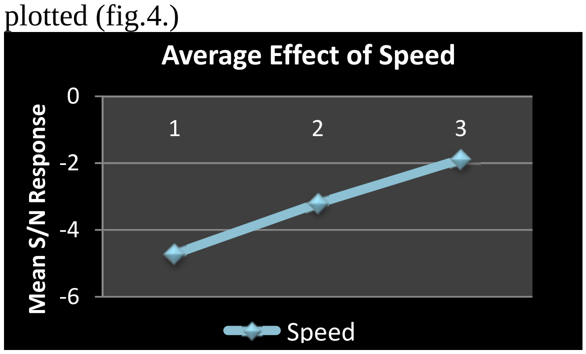

Fig.4: Effect of speed

The combined effect has been shown in the graph (fig. 5)

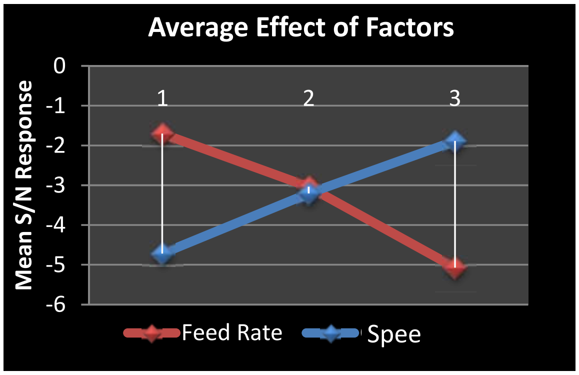

Fig.5: Effect of drilling parameters

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested [15]. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. 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 S/N ratio, into contributions by each of the design parameters and the error.
The purport of the analysis of variance (ANOVA) was to gain those parameters which are significantly affecting the quality attribute. The total sum of square deviation, SS_T can be calculated using [14]

$$SS_T = \sum_{i=1}^{y} y_i^2 - C.F$$

Where, *n* represents the number of experiments in the orthogonal array, y_i is the total surface roughness of i^{th} experiment and *C.F.* is the correction factor. *C.F* may be computed as:

$$C.F = \frac{T^2}{N}$$

Where, *T* is the sum of all total surface roughness.

The total sum of square deviations i.e. SS_T was segregated into two ways: the sum of squared deviation, SS_d *owing* to each process parameter and the sum of square error, SS_e. The percentage contribution which is denoted by *P*, in which each process parameter is the total sum of square deviation, SS_T that is a ratio of the sum of square deviation, SS_d because of each process parameter to the total sum of square deviation, SS_T.

To the point of view of statistical study, there is a test called *F*-ratios (variance ratio) to study which parameters have significant effects. For performing the *F* test, the mean of square deviation, SS_m *due* to each process parameter requires due calculation. The mean of square variations, SS_m *is* equal to the sum of square deviation, SS_d *divided* by the number of degree of freedom linked with the process parameters. As a result of it, the *F* value for each process parameter is merely the ratio of the mean of square deviation, SS_m to the mean of square error, SS_e.

Sym.	Para-meters	DOF	Sum of Squares (SS)	Vari-ance (V)	Vari-ance Ratio (F)	Contri-bution (%)
A	Feed Rate	2	17.253	8.626	50.74	57.6
B	Speed	2	12.019	6.009	35.35	40.1
	Errors	4	0.68	0.17		2.27
	Total	8	29.952			

TABLE 6: ANOVA table for % Contribution Calculation

From the above ANOVA table (Table 6) , the percentage contribution of each parameter is calculated. The contribution of these parameters is:
Feed rate = 57.6%
Speed = 40.1%

From the above results it can be seen that the feed rate is the most significant factor that contributed the maximum to the surface roughness of the material due to drilling. Thus based on the S/N ratio and ANOVA, the optimum combination of the parameters and their levels for achieving the optimum surface roughness is A1, B3 i.e., feed rate at level 1 and speed at level 3.

Pie diagram and bar chart to show the contribution of various process parameters has been drawn (fig.6& fig.7)

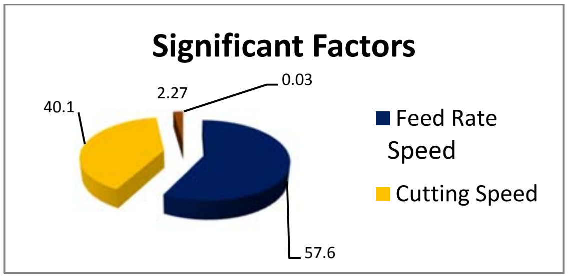

Fig 6: Contribution of Significant Factors (a)

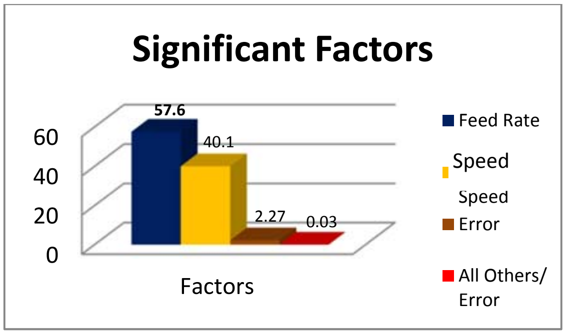

Fig 7: Contribution of Significant Factors (b)

Confirmation Test

The confirmation test is used to verify the estimated results with the experimental results. If the optimal combination of parameters and their levels coincidently match with any one of the experiments of the OA, then the confirmatory test is not required. The confirmation test was not required in the present study because the optimum combination of parameters and their levels, i.e., A1, B3 matched with the third experiment of the OA.

Conclusions

From the analysis of the results of the present study, the following can be concluded:

- Taguchi's robust design method is suitable for optimizing the surface roughness of a drilled hole of a leaf spring material SUP 11A.
- The significant parameters for the surface roughness in drilling SUP 11A are feed rate andspeed with their contribution of 57.6% &40.1% respectively.
- The optimal conditions for the surface roughness in drilling SUP 11A are A1, B3 i.e., the feed rate of 0.05 mm/rev and speed of 850 rpm respectively.

References

[1] R.S. Khurmi, JK Gupta;*A Textbook of Machine Design*; S.Chand Publication; Edition 2006

[2] B.Y. Lee, H.S. Liu, Y.S. Tarng;Modelling and optimization of drilling process;*Journal of Materials Processing Technology 74 (1998) 149–157.*

[3] Chen WC, Tsao CC (1999) Cutting performance of different coated twist drills. J Mater Process Technol 88:203–207

[4] Zhao H (1994) Predictive models for forces, power and hole oversize in drilling operations. PhD thesis, University of Melbourne, Australia

[5]Nanaji Kshirsagar, Awneesh Yadav, Srinivas Athreya, SahilPatil, Rizwan Hassan , VineethMenon; Surface Finish Optimization by Taguchi Method;*Proceedings of the NCNTE-2012,Third Biennial National Conference on Nascent Technologies Fr. C. Rodrigues Institute of Technology, Vashi, Navi Mumbai, Feb 24-25, 2012 Department of Mechanical Engineering.*

[6] W.H. Yang, Y.S. Tarng; Design optimization of cutting parameters for turning operations based on the Taguchi method; *Journal of Materials Processing Technology 84 (1998) 122–129*

[7] D.C. Montgomery, Design and Analysis of Experiments, Wiley, Singapore, 1991.

[8] R.A. Fisher, Statistical Methods for Research Workers, Oliver and Boyd, London, 1925.

[9] Peter Woolf; e-book for *Design of Experiments: Taguchi Methods*; version 1.0; University of Michigan

[10] S. Kamaruddin, Zahid A. Khan and S. H. Foong; Application of Taguchi Method in the Optimization of Injection Moulding Parameters for Manufacturing Products from Plastic Blend. IACSIT International Journal of Engineering and Technology, Vol.2, No.6, December 2010 ISSN: 1793-8236.

[11] Phadke MS (1989) Quality engineering using robust design.Prentice-Hill, Englewood Cliffs, NJ

[12] TarunGoyal, Ravinderjit Singh Walia, and T. S. Sidhu;Study of Coating Thickness of Cold Spray ProcessUsing Taguchi Method; Materials

and Manufacturing Processes, 27: 185–192, 2012 Copyright ©Taylor & Francis Group, LLC.

[13] Y. S. Tarng and W. H. Yang; Department of Mechanical Engineering; National Taiwan University of Science and Technology; Application of the Taguchi Method to the Optimization of the Submerged Arc Welding Process; Journal of *Materials and Manufacturing Processes, Vol.* 13, *No.3,* 455-467, 19.98

[14] Roy, R.K., 1990, "*A Primer on the Taguchi method*". Competitive Manufacturing Series, Van Nostrand Reinhold, New York.

[15] Minitab User Manual Release 13.2 (2001) Making data analysis easier. MINITAB Inc., State College, PA

[16] Ramon Balisnomo; Introduction to Taguchi Methods; Presentation; September 5, 2008.

[17] Rudolf N. Cardinal; Guide to ANOVA; Graduate-level statistics for psychology and neuroscience; ANOVA in practice, and complex ANOVA designs; Version of 2 May 2004.