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OPTIMIZATION OF BLANK PARAMETERS OF ROLLED THREADS BY TAGUCHI METHOD

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Abstract -- **This paper presents a study for optimizing the blank parameters of rolled threaded auto components. The experiments have been designed to optimize the outer diameter of thread M8×1.25 6g by Taguchi Method. The outer diameter of the external thread is dependent on the parameters like surface roughness, out of roundness and material's properties such as tensile strength etc. An orthogonal array L_9 (OA), signal-to-noise(S/N) ratio and analysis of variance (ANOVA) were employed to investigate the range of outer diameter of a screw thread. The optimum combination of surface roughness, out of roundness and tensile strength of materials has been shown in this paper.**

Keywords -- Rolled threads, M8, Taguchi Method, Optimization, Analysis of Variance (ANOVA), and Confirmation test.

I. Introduction

Threaded components and fasteners are most widely used in automobile components and many industrial applications. For the industry which produces the thread is a key skill to adopt the accurate and precise machining of threads because there are so many parameters which affect the dimensions of thread. Threads may be generated by the thread chasing, thread milling, casting, thread rolling, thread grinding etc. Out of these processes, thread rolling process has various advantages. The surface finish of rolled threads is very smooth, and the process induces compressive residual stresses on the work piece surfaces, thus improving fatigue life [1].

Thread rolling is a cold forming process operation in which the threads are formed by rolling a thread blank between hardened dies that cause the metal to flow radially into the desired shape [2]. The auto industry, one of the largest fasteners market, typically consumes between 2800 to 3100 fasteners in the assembly of an average family vehicle. Externally threaded fasteners comprise the bulk of fasteners used in these applications with over 90% of being produced by thread rolling [3]. Thread rolling requires a tooling investment to be made in the heads and rollers, which is higher than a single-point threading insert. However, for applications that involve hardened material, high surface finish and surface integrity as wells as production volumes, thread rolling technology may be more cost effective over the long haul. For optimizing the outer diameter of a thread, process parameters surface roughness, material properties like tensile strength etc and out of roundness are considered in this paper. In this paper, Taguchi approach has been used for designing the experiment to determine the optimal diameter of screw thread. The work has been carried out on MS, EN8 and EN 47 materials at M/s Gayatri Auto Industries on Reciprocating Die Thread Rolling Machine.

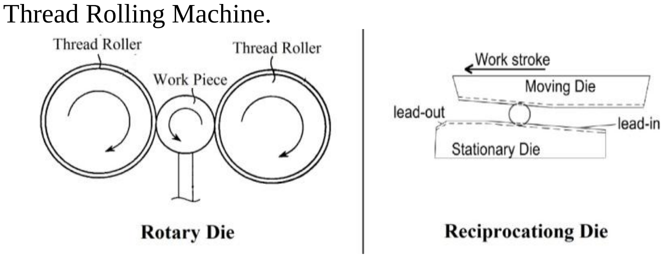

Fig.1 Principle of Thread Rolling

II. The Taguchi Approach

The quality engineering method proposed by Taguchi is a well-known technique that provides a systematic and efficient methodology for the process optimization. Taguchi defines the quality of a product in terms of loss imparted by the product. Some of these losses are due to the deviation of the product functional characteristics from its desired target value and this is called losses due to function variations. The uncontrollable factors, which cause the functional characteristics of a product to deviate from their target values are called noise factor, which can be external or internal. By studying the effect of individual factors on results, best factor combination can be determined [4]. Taguchi designs experiments using specially constructed tables known as "orthogonal arrays" (OA). The use of the tables makes the design of experiment easy and relatively lesser number of experimental trails to study the entire parameter space. As a result it saves the time and money. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. Usually there are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the-nominal-the-better. The S/N ratio for each level of process parameters is computed on the basis of the S/N analysis. Regardless the quality characteristic a greater S/N ratio correspond the better quality characteristics. Therefore, the optimal level of process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameter is statistically

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significant. With the S/N and ANOVA analysis, the optimal combination of parameters can be predicted. Finally a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design analysis [5].

III. Experimental Setup

The specimen of different materials has been selected. The materials which have being chosen are widely being used to manufacture automobile components. These materials are Mild steel, Medium Carbon Steel (EN-8), and Spring Steel (EN 47).

A. Specification of machine:

Make & Model: Masters Reciprocating Die Thread Rolling Machine
Job diameter: 3 to 18 mm
Length: 100 mm
Max rolling thrust: 36 tones
Motor: 9 KW

Fig.2 Master Thread Rolling Machine

B. Specification of specimen:

Material: MS, EN 8, EN 47
Blank Diameter: $7.16^{\pm 0.005}$mm
Length: 30 mm
Straightness: Max. 3 mm / meter

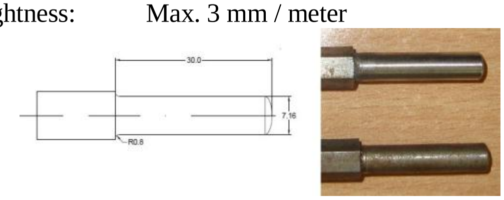

Fig.3 Blank Specification

IV. Optimization of Screw Thread Parameters

A. Selection of thread parameters and their levels

Thread rolling experiments were carried on Flat Die Thread rolling machine which makes thread tangentially on the blank. The parameters were defined by varying the surface roughness in the range 0.25-1.5 μRa, tensile strength 500-750 N/mm² and out of roundness 4-12 μ. Most of these were selected in the light of the data available during manufacturing and in the literature. Three levels were selected for all three parameters as shown in Table 1.

Table 1:Levels of parameters

Symbol	Parameters	Levels		
		1	2	3
A	Surface Roughness (μRa)	0.25	1	1.5
B	Tensile Strength(N/mm^2)	500	600	750
C	Out of of roundness (μ)	4	10	12

B. Selection of Orthogonal Array

The selection of appropriate orthogonal array (OA) depends on the total degree of freedom of the parameters. In this study, since each parameter has three levels so the total degree of freedom (DOF) is equal to 8. Basically the degree of freedom for the OA should be greater than or at least equal to those of process parameters. Therefore, an L9 orthogonal array with four columns and nine rows was appropriate. Each row of table represents an experiment with different combination of parameters and their levels. The last column of OA is left empty for error detection of experiments [4].

Table 2: Experimental Plan Using an L 9 Orthogonal Array

No.	Parameters			
	A	B	C	D
	Surface roughness	Tensile strength	Out of roundness	–
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2

8	3	2	1	3
9	3	3	2	1

C. Procedure of conducting the experiment

Screw thread of M8×1.25 was produced on flat die rolling machine as per the experimental plan shown in table 2. The blank diameter in range $7.16^{\pm 0.005}$ mm is taken from the lot and is rolled tangentially on the rolling machine. The rolling die is moving at a speed of 30-60 m/min (for carbon steels).Correct selection of rolling speed is essential to ensure good thread quality and long roll life. Also the required speed depends upon the elongation of material, thread form, machine capability and the tensile strength of the material to be rolled in N/mm^2. For this purpose, three types of material namely mild steel, EN8 and EN47 are used in this experiment for better results. The dimension of a screw thread is the function of mainly selected material and its surface roughness i.e. the dimension stability of a thread mainly

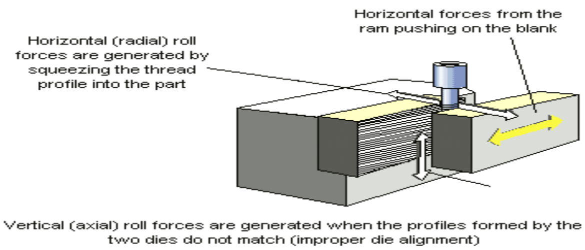

Fig. 4 Flat Dies Thread Rolling Process

depends upon these two factors which is considered in this study. Each rolled thread is precisely measured with the help of hand micrometer (accuracy ± 0.001mm, make: Mitutoyo, Japan) and the values are computed.

D. Signal to Noise (S/N) ratio

The signal to noise ratio was used to measure the sensitivity of the quality characteristics being investigated in a controlled manner. In Taguchi method the term 'signal' means the desirable effect for the output characteristics and the term 'noise' represents the undesirable effect or the signal disturbance for the output characteristics which is having the adverse influence on the outcomes. The S/N ratio can be defined as [4]:

$$S / N = -10 \text{Log} (MSD) \quad (1)$$

where, MSD is mean square deviation for the output characteristics and is defined as:

$$MSD = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \quad (2)$$

where, N = number of observation
y_i = observed data

A high value of S/N ratio implies that the signal is much higher than the disturbance effects. As mentioned earlier in this paper, there are three categories of quality characteristics higher-the-better, nominal-the-better and lower-the better. To obtain the optimal diameter of a thread we choose the following quality characteristics [6]:

Larger is the Best characteristic:

Data sequences for outer or nominal diameter of the thread, higher the better performance characteristics are pre-processed as:

$$S / N = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2}$$

Table 3 shows the experimental results and the corresponding values of S/N ratio using Eq. (1) and (2). Since the experimental design is orthogonal, then it is possible to separate out the effect of each parameter at different levels. The mean S/N ratio for each level of the parameter is summarized in Table 4 and called S/N response table.

Table 3: Experimental Results and S/N Ratio

Experiment	Outer Diameter	S/N Ratio
1	7.95	18.013
2	7.82	17.88
3	7.74	17.77
4	7.92	17.98
5	7.79	17.82
6	7.59	17.60
7	7.88	17.93
8	7.75	17.79
9	7.56	17.57

Table 4: The Mean S/N Response table

Symbol	Parameter	Level 1	Level 2	Level 3
A	Surface Roughness	17.88	17.80	17.76
B	Tensile Strength	17.97	17.83	17.65
C	Out of roundness	17.81	17.81	17.79

Figures 5, 6 and 7 show the S/N graphs for the variations in the outer diameter of the threads:

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

where, T is the sum of total outer diameters.

Table 5: ANOVA table for outer diameter

Symbol	Parameters	DOF, f	Sum of Squares, S	Variance, V	Variance Ratio, F	Percentage Contribution, ρ
A	Surface Roughness	[2]	0.025	0.0125	2.23	12.96 %
B	Tensile Strength	[2]	0.154	0.077	13.75	79.87 %
C	Out of roundness	[2]	0.0026	0.0013	0.232	1.34%
All other / Error		2	0.0112	0.0056		5.8 %
Total		8	0.1928			100 %

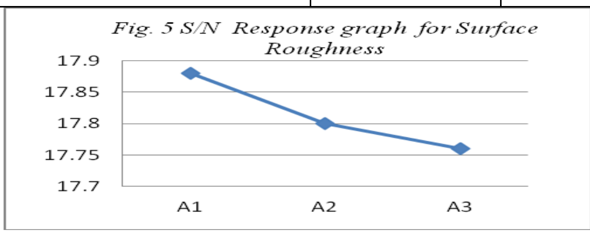

Fig. 5 S/N Response graph for Surface Roughness

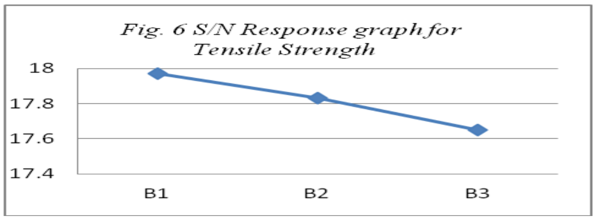

Fig. 6 S/N Response graph for Tensile Strength

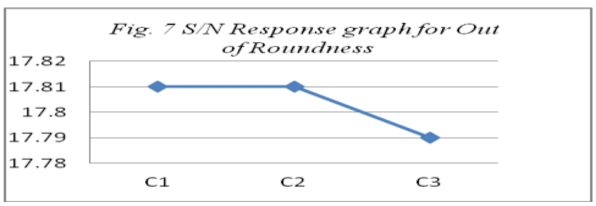

Fig. 7 S/N Response graph for Out of Roundness

E. Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplish 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. First, the total sum of squared deviations SS_T from the total mean S/N ratio can be calculated as [5]:

$$SS_T = \sum_{i=0}^{n} yi^2 - C.F.$$

where, n is the number of experiment in orthogonal array, y is the outer diameter of the i^{th} experiment and C.F. is the correction factor and can be calculated as [5]:

The total sum of squared deviations SS_T is decomposed into two sources: the sum of squared deviations SS_d due to each design parameter and the sum of squared error SS_e. The percentage contribution ρ by each of the design parameter in the total sum of squared deviations SS_T is a ratio of the sum of squared deviations SS_d due to each design parameter to the total sum of squared deviations SS_T.

Statistically, there is a tool called an *F* test named after Fisher to see which design parameters have a significant effect on the quality characteristic. In performing the *F* test, the mean of squared deviations SS_m due to each design parameter needs to be calculated. The mean of squared deviations SS_m is equal to the sum of squared deviations, SS_d divided by the number of degree of freedom associated with the process parameters. Then, the *F* value for each process parameter is simply the ratio of the mean of squares deviations SS_m to the mean of the square error SS_e.

Table 5 shows the result of ANOVA for the measuring of outer diameter at the different levels.

The *F* ratios were obtained for 95% level of confidence. In addition to this percentage contribution of each parameter is also calculated. From study we found that the material property is the most significant factor. The parameters of a thread majorly depend upon its tensile strength. The percentage contribution from these parameters is surface roughness (12.96%), tensile strength (79.87%), and out of roundness contributed (1.34%). Thus, based on the S/N ratio and ANOVA analyses optimal combination of parameters and their levels for achieving nominal outer diameter is A_1, B_1, C_1 i.e. surface roughness at level 1, tensile strength at level 1, and out of roundness at level 1.

F. Confirmation Test

The experimental confirmation test is the final step in verifying the results drawn based on Taguchi's design approach. The confirmation test is used to verify the estimated results with the experimental results. If the optimal combination of parameters and their levels are coincidently matched with one of the experiment in the OA, then the confirmatory test is not required. Estimated value of outer diameter at optimum level was calculated by adding the average performance to the contribution to each parameter at the optimum level which can be calculated by the following equation:

$$Y_{opt} = m + (m_{Aopt} - m) + (m_{Bopt} - m) + (m_{Copt} - m)$$

$$m = \frac{T}{n}$$

where, m is the average performance, T is the grand total of average outer diameter for each experiment, n is the total number of experiment and m_{Aopt} is the average outer diameter for parameter A at its optimum level, m_{Bopt} is the average outer diameter for parameter B at its optimum level and m_{Copt} is the average outer diameter for parameter C at its optimum level.

Confirmation test was required in the present case study because the optimum combination of parameters and their levels i.e. did not correspond to any experiment of the orthogonal array. A blank screw is taken and is rolled at the same optimal combination of parameters and their levels i.e. A_1, B_1, C_1 on the same flat die rolling machine and made up of same material. And its diameter is measured. The value of outer diameter obtained from the experiment was compared with the estimated value as shown in table 6. From table 6 the difference between the experimental and estimated value is found to be 0.01.

Table 6: Results of confirmation test

	Optimal Condition		
	Estimated	Experiment	Difference
Levels	A_1, B_1, C_1	A_1, B_1, C_1	–
Outer diameter (in mm)	7.96	7.95	0.01
S/N Ratio	-	18.01	-

V. Conclusion

From the analysis of the results in thread rolling operation using Taguchi approach, the following conclusions have been drawn from the present study:

- The optimum conditions are A_1, B_1, C_1 i.e. surface roughness (1μ), tensile strength (500 N/mm^2) and out of roundness (4μ)
- The nominal diameter is 7.95 mm.
- Material property of the product is significant parameter while out of roundness is insignificant parameter.

The contribution of parameter is surface roughness (12.96%), tensile strength (79.87%) and out of roundness (1.34%).

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