Modified Taguchi Approach for optimizing the process parameter using the fictitious parameter

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Abstract. Taguchi approach is adopted to optimize the process parameters and improve the quality of components that are manufactured. Nature of the output response in any scientific investigation has to be understood through experimentation prior to the development of a suitable mathematical model. When several input variables are involved in the scientific problem, it is very difficult to develop a relation between the output responses in terms of input variables. The objective of this paper is to determine the expected range for the process parameters in the optimization process by introducing fictitious parameter.

Keywords: Taguchi Method, Statistical conditioning, Chauvenet’s Deviation Ratio, tensile strength.

1. Introduction

Taguchi method was initially developed by Taguchi and Konishi (1987). It is very much useful in almost all fields like manufacturing, engineering, Biotechnology etc., particularly in the Design of Experiments for knowing the variations. By using this technique achieving the desired results it involves careful selection of process parameters and use the fictitious parameter and omitting the odd man by using the concept of statistical conditioning of the data and also determine the range of the process parameters. Most of these researchers have utilized the concept of design of experiments. It is used to study a large number of design variables by conducting minimum number of experiments. Taguchi has established
orthogonal array (OA) to describe a large number of experimental results. Statistical conditioning of data will be useful to predict the expected range.

Taguchi has devised a standard method for analysing the test results by defining a set of orthogonal array (1989). This method demands a few number of experiments and provides information of the full factorial design of experiments.

Rao et al suggested Taguchi Methodology as a statistical tool for biotechnological applications. Foster (2000) studied basic Taguchi design of experiments. Domnita Fratilia and Cristian Caizar identified the Application of Taguchi method to selection of optimal lubrication and cutting conditions in face milling of AIM93. Srinivasa Rao et al (2008) studied the effect of drilling induced damage on notched tensile strength and pin-bearing strength of woven GFR-epoxy composites. Singaravelu et al (2009) examined Taguchi’s approach for reliability and safety assessments in the stage separation process of a multistage launch vehicle. Parameshwaran Pillai et al (2011) studied Taguchi’s approach to examine the effect of drilling induced damage on the notched tensile strength of woven GFR-epoxy composite. Srinivasa Athreya and Venkatesh (2012) have examined the influence of process parameters in improving the surface roughness of Lathe facing operation. Taguchi full factorial design with three input parameters each having three levels. Sahiti et al (2016) studied Application of Taguchi method for optimum weld process parameters of pure aluminium. Dhariya Pratap et al. (2016) studied optimization of process parameters for friction stir welded AA7075-SIC composite joints by Taguchi method. Rajeev Kumar et al (2017) identified Optimum drilling parameters of coir fiber-reinforced polyester composites. Here we are using that data for studying the process parameters and determine the range by using the fictitious parameter. They have found different optimal machining conditions to achieve high tensile strength. However, optimum process parameters can be easily found using Taguchi’s design of experiments considering L9 orthogonal arrays and introducing the fictitious parameter. This paper presents the range of tensile strength by using the fictitious parameter. It also demonstrates the advantages of opting fictitious parameter and using the Chauvenet’s’ ratio to get complete information through few experiments considering the existing test data of Dhariya Pratap Singh, Vikram Singh and Sudhir kumar (2016). Rajyalakshmi and Nageswara rao (2018) examined the expected range of the output response for the optimum input parameters utilizing the modified Taguchi approach.
A Good amount of experimental work done by Dhariya Pratap Singh et al (2016) useful for identifying optimum process parameters to improve tensile strength of welded joints. Their test results can be utilized to validate the Taguchi design of an experiment which demand less number of experiments and provides complete information without testing. They have adopted signal to noise (S/N) ration transformation for each test run. They have selected $L_9$ Orthogonal array for ‘3’ input parameters having ‘3’ levels in a zigzag way. They have conducted full factorial experiments for ‘3’ factors each at ‘3’ levels which leads ‘27’ experiments.

The main objective this study is to apply statistical conditioning of the repeated test data by using Chauvenet’s criterion and eliminating the odd measured data and evaluating the mean value of tensile strength. For the selected input parameters the levels are set in increasing order as being regularly followed by the researchers. From the selected data of $L_9$ orthogonal array (OA) predictions are made for the ‘27’ full factorial experiments. A methodology is suggested to examine the range of tensile strength and validating through comparison of all ‘27’ experiments. It is very interesting note that, the test data (after verification of the statistical conditioning) is found to be within the expected range.

2. ANOVA

Many factors or process parameters influence the outcome of the experiments. It is possible through design of experiments to carry out experiments in a systematic way and assess individual contributions of process parameters and their intricate relationship. Reliable empirical relations can be developed for the output responses in terms of input variables. Optimum range of the process parameters can be arrived through statistical conditioning and Chauvenet’s ratio. The expected range of the output responses can be provided for the specified process parameters.

Current design of experiments involves ration speed, welding speed and tool geometry and tensile strength of welded joint as the independent process variables; levels for each process variable; appropriate orthogonal array to assign process variable to respective column of orthogonal array; Considered the Mean tensile strength for all process parameters provided by Dhariya Pratap Singh, Vikram Singh and Sudhir kumar (2016).
Table-1 gives the levels of process parameters and the output as per L9 orthogonal array. ANOVA is done for the optimum process parameters ratio speed, welding speed and tool geometry to obtain % contribution of each parameter. The process parameters viz., are C, D, F respectively.

The ANOVA results of Table-2 indicate that ratio speed 63.95% contribution, whereas the welding speed and tool geometry have 25.91%, and 10.14% contributions.

ANOVA has been performed for the optimum process to estimate tensile strength for the assigned levels of process parameters for each test run using the additive law:

$$\hat{\phi} = \sum_{j=1}^{\phi} \phi_j - (n_p - 1)\phi_{mean}$$

(1)

Here $\hat{\phi}$ is the estimate of the output response; $\phi_{mean}$ is the gross mean of $\phi$ for the 9 test runs; $\phi_j$ is the mean value at the specified process parameter level ($j$); and $n_p=3$, is the number of process parameters.

From ANOVA Table-2, the process parameters to achieve Maximum tensile strength are $C_2D_2F_1$. Confirmation experiments are mandatory.

As per the Taguchi design of experiments, the number of experiments ($N_{Taguchi}$) for the selected input parameters and levels is

$$N_{Taguchi}=1+(\text{Number of factors})\times(\text{Number of Levels}-1)$$

(2)

In the present study, for nine test runs (i.e., $N_{Taguchi}=9$) and 3 levels, equation (2) gives four number of allowable factors.

A fictitious factor (fourth factor) D is introduced as in M. Sahiti et al (2016) for tensile strength in Table-3 and determine the limits. The expected range tensile strength is arrived by considering the levels of lowest and highest mean values of $\phi$ for the fictitious parameter. Test results in Tables 5 and 6 are within the expected range.

### 3. Statistical Conditioning of the data

Output will be influenced by the experimental data and error in measurements. It will be a statistical approach to improve the data. Statistical conditioning of the repeated test data by using Chauvenet’s criterion and eliminating the odd data and evaluating the mean value of tensile strength. We expect that all the points are in the expected range if we remove the odd data from the given set of repeated experiments.
Chauvenet’s Deviation Ratio: Chavenet’s criterion provides a consistent basis for the decision to reject or retain the data. If the data point \( y_i(j) \) lies within the limits of following equation then retain the data point otherwise reject it.

\[
\mu - DR_0 \sigma_i < y_i(j) < \mu + DR_0 \sigma_i
\]

where ‘\( \mu \)’ is the mean and ‘\( \sigma \)’ is the standard deviation and we consider the data of ‘5’ repeated test runs. So that we take \( DR_0 \) is 1.65.

Chavenet’s table:

|   |   |
|---|---|
| 3 | 1.38 |
| 4 | 1.54 |
| 5 | 1.65 |
| 6 | 1.73 |
| 7 | 1.80 |
| 8 | 1.87 |
| 9 | 1.91 |
| 10| 1.96 |
| 15| 2.13 |
| 20| 2.24 |
| 25| 2.33 |
| 50| 2.57 |
| 100| 2.81 |
| 300| 3.14 |
| 500| 3.29 |
| 1,000| 3.48 |

4. Concluding remarks

Present work deals with the specification of Tensile strength influence parameters to achieve optimum tensile strength of welded joints by adopting the Taguchi approach. Here we are unable to determine the range, since repeated test data is not available for applying the statistical conditioning for all ‘27’ experiments.

Taguchi approach suggests a few experiments and estimates the results for the full factorial experimentation. Introduction of the fictitious parameter for the same test runs provides the expected range of the output responses. By using the fictitious parameter the % contribution of the factors are 63, 26, 10 and 1% respectively of the factors ration speed, welding speed, tool geometry and the fictitious. Fictitious parameter can predict the value with more accuracy.
Table 1: Selected factors and their levels

| Factors                        | Levels |
|--------------------------------|--------|
|                                | 1      | 2      | 3      |
| Tool rotational speed (V, rpm) | 800    | 1000   | 1200   |
| Welding speed (mm/sec)         | 0.8    | 1.3    | 1.8    |
| Feed rate (F, mm/min)          | 4      | 6      | 8      |

Limits of Orthogonal Array (OA) L9

| Test run | Levels of input parameters | Tensile strength | Estimated with fictitious |
|----------|----------------------------|-----------------|--------------------------|
|          | V  | t  | F   | Fictitious               |                     |
| 1        | 1  | 1  | 1   | 1                         | 252                | 249.23 | 252 |
| 2        | 1  | 2  | 2   | 2                         | 266                | 266.56 | 266 |
| 3        | 1  | 3  | 3   | 3                         | 240                | 242.23 | 240 |
| 4        | 2  | 1  | 3   | 2                         | 272                | 274.23 | 272 |
| 5        | 2  | 2  | 1   | 3                         | 292                | 289.22 | 292 |
| 6        | 2  | 3  | 2   | 1                         | 288                | 288.56 | 288 |
| 7        | 3  | 1  | 2   | 3                         | 231                | 231.56 | 231 |
| 8        | 3  | 2  | 3   | 1                         | 268                | 270.22 | 268 |
| 9        | 3  | 3  | 1   | 2                         | 251                | 248.23 | 251 |

Table 2: ANOVA for Tensile strength

| Input Parameters | Mean-1 | Mean-2 | Mean-3 | Sum of Squares | % Contribution |
|------------------|--------|--------|--------|----------------|----------------|
| V                | 252.67 | 284    | 250    | 2144.6979      | 63.95          |
| t                | 251.67 | 275.33 | 259.67 | 869.0313       | 25.91          |
| F                | 269.33 | 263    | 254.33 | 340.2378       | 10.14          |

Overall Mean = 262.22 = G
In Dummy low = 260, High = 265
262.22-260=-2.22 and 265-262.22=2.78
### Table: 3 Levels of process parameters with a fictitious parameter

| Input Parameters | Mean-1 | Mean-2 | Mean-3 |
|------------------|--------|--------|--------|
| V                | 252.67 | 284    | 250    |
| t                | 251.67 | 275.33 | 259.67 |
| F                | 269.33 | 263    | 254.33 |
| Fictitious       | 265    | 261.22 | 260    |

| Test run | Levels of input parameters | Tensile strength | Limits            |
|----------|----------------------------|------------------|-------------------|
| V        | t                          | F                | Fictitious        |
| 1        | 1                          | 1                | 1                 | 252              | (249.79, 254.79) |
| 2        | 1                          | 2                | 2                 | 266              | (263.79, 268.79) |
| 3        | 1                          | 3                | 3                 | 240              | (237.79, 242.79) |
| 4        | 2                          | 1                | 3                 | 272              | (269.79, 274.79) |
| 5        | 2                          | 2                | 1                 | 292              | (289.78, 294.78) |
| 6        | 2                          | 3                | 2                 | 288              | (285.79, 290.79) |
| 7        | 3                          | 1                | 2                 | 231              | (228.79, 233.79) |
| 8        | 3                          | 2                | 3                 | 268              | (265.78, 270.78) |
| 9        | 3                          | 3                | 1                 | 251              | (248.79, 253.79) |
Table: 4 Estimates measured values and the statistical conditioning of the data

| Test run | Levels of input parameters | Tensile Strength | Expected range       |
|----------|---------------------------|------------------|----------------------|
|          |                           |                  |                      |
|          | V  t  F                   |                  |                      |
| 1        | 800 0.8 4                  | 249.23           | (247.01, 252.01)     |
| 2        | 800 1.3 6                  | 266.56           | (264.34, 269.34)     |
| 3        | 800 1.8 8                  | 242.23           | (240.01, 245.01)     |
| 4        | 1000 0.8 8                 | 265.56           | (263.34, 268.34)     |
| 5        | 1000 1.3 4                 | 304.22           | (302, 307)           |
| 6        | 1000 1.8 6                 | 282.23           | (280.01, 285.01)     |
| 7        | 1200 0.8 6                 | 240.23           | (238.01, 243.01)     |
| 8        | 1200 1.3 8                 | 255.22           | (253, 258)           |
| 9        | 1200 1.8 4                 | 254.56           | (252.34, 257.34)     |
| 10       | 800 0.8 6                  | 242.9            | (240.68, 245.68)     |
| 11       | 800 0.8 8                  | 234.23           | (232.01, 237.01)     |
| 12       | 800 1.3 4                  | 272.89           | (270.67, 275.67)     |
| 13       | 1000 1.3 8                 | 257.89           | (255.67, 260.67)     |
| 14       | 1000 1.8 4                 | 257.23           | (255.01, 260.01)     |
| 15       | 1000 1.8 6                 | 250.09           | (248.68, 253.67)     |
| 16       | 1200 0.8 4                 | 280.56           | (278.34, 283.37)     |
| 17       | 1200 0.8 6                 | 274.23           | (272.01, 277.01)     |
| 18       | 1200 1.3 6                 | 297.89           | (295.67, 300.67)     |
| 19       | 800 1.3 8                  | 289.22           | (287, 292)           |
| 20       | 800 1.8 4                  | 288.56           | (286.34, 291.34)     |
| 21       | 800 1.8 8                  | 273.56           | (271.34, 276.34)     |
| 22       | 1000 0.8 4                 | 246.56           | (244.34, 249.34)     |
| 23       | 1000 0.8 8                 | 231.56           | (229, 234, 234.34)   |
| 24       | 1000 1.3 4                 | 270.22           | (268,273.09)         |
| 25       | 1200 1.3 6                 | 263.89           | (261.67, 266.67)     |
| 26       | 1200 1.8 6                 | 248.23           | (246.01, 251.01)     |
| 27       | 1200 1.8 8                 | 239.56           | (237.34, 242.34)     |
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