*Asian Journal of Convergence in Technology* *Volume II, Issue III*
*Issn No.:2350-1146, I.F-2.71*

# Application of Taguchi Method for Optimization of Parameters in Mitigation of Stress concentration Factor of Thin Rectangular Plate under Static Loading

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***Abstract*** **- Taguchi method is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters by considering experiments in "orthogonal array" with an aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well balanced experiments. In this study the Taguchi method is used to find the parameters for reducing stress concentration factor of a thin rectangular plate having central circular hole. The orthogonal array, signal to noise ratio and the analysis of variance are employed to study the factors responsible for inducing stress concentration factor. In these analysis two factors namely distance and shape of auxiliary hole were considered. Accordingly a suitable orthogonal array was selected and the experiments were carried out. After conducting the experiment stress concentration factor is calculated and signal to noise ratio was calculated. With the help of graphs optimum parameter values were obtained and the confirmation experiment was carried out. Finite element analysis results were provided to illustrate the effectiveness of this approach.**

***Index Terms – Stress concentration factor, auxiliary holes, Hypermesh.***

## I. Introduction

Dr Genichi Taguchi is a Japanese quality management consultant who has developed and promoted a philosophy and methodology for continuous quality improvement in products and processes. Within this philosophy, Taguchi shows how the statistical design of experiments (SDOE or DOE) can help industrial engineers design and manufacture products that are both of high quality and low cost. His approach is primarily focused on eliminating the causes of poor quality and on making product performance insensitive to variation. Any discontinuity in the structure penetrates the strength of the structure .An applied external force causes inner forces in the carrying structure. Inner forces are distributed differently in each part of structure. When inner forces go around holes or notches they will concentrate near such obstacle. These make the structure weak and susceptible to failure. Therefore it is necessary to investigate the state of stress around the holes for safety and proper design of such structures. Efforts are being made to reduce this stress concentration effect. Several methodologies can be available for solution of such problem. The proposed method is to study a plate of dimension 200mm X 100mm X 1mm with a circular hole at centre under uniform distributed static loading of 6 MPa by finite element method. The material of plate selected for analysis is steel having E=240GPa and Poisson's ratio=0.3.Here an attempt has been made to demonstrate the application of Taguchi's method to optimize the parameters to mitigate the stress concentration factor of a thin rectangular plate having central circular hole.

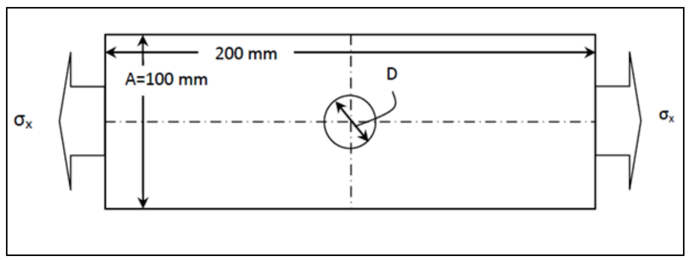


Fig. 1 Model of plate with centre circular hole under in plane static loading

## II. TAGUCHI METHOD

A full factorial design of experiments considers all possible combinations for selected factors. If the numbers of parameters considered are more this is the case in many practical examples, a full factorial design results in a large number of experiments. Taguchi methodology can be used to reduce this large number of experiments to a practical level. It is done by selecting a small set of experiments from all possible experiments. The method of selecting a limited number of experiments, which produces the maximum information, is known as a partial fraction experiment. Taguchi analysis provides guidelines for factorial experiments to improve its accuracy. It investigates how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.

The experimental design by Taguchi method involves orthogonal arrays to arrange the parameters affecting the process and the levels in which they should be varied. It determines the contribution of each factor that affect the process and their optimum values for required response with minimum number of experimentation thus saving efforts, time and resources.

## III. STEPS IN TAGUCHI METHOD

(1) Establishment of objective function,
(2) Identification of the factors and their levels,
(3) Selection of an appropriate orthogonal array (OA),
(4) Experimentation,
(5) Analysis of the data and determination of the optimal levels and
(6) Confirmation experimentation

## IV. APPROACH TO THE EXPERIMENTAL DESIGN

In accordance with the steps involved in Taguchi method a series of experiments are to be conducted. Here the experiments are carried out with HYPERMESH software. Stress concentration can be reduced by placing auxiliary holes along with the main hole. The auxiliary holes can be placed in the region along the main hole which is ellipsoid in shape. The minor diameter of that ellipsoidal shape is equal to the diameter of the main hole and major axis is taken equal to the length of the plate. So the diameter of auxiliary hole will be controlled by the ellipsoid shape. Obviously the diameter of auxiliary circular hole will be reduced as it moves away from the main hole. The distance of auxiliary hole from main hole is measured in the direction of length of plate from centre to centre. The auxiliary holes are placed with increasing distance. The distances taken are 15mm, 30mm, 45mm. The model of plate with D/A ratio 0.1 is selected. The diameter of main hole is 10mm for this case. Ellipse 1 is the ellipse having a/b ratio 4 where a and b are its major and minor axis respectively. Ellipse 2 have a/b ratio is 3. Following images are taken from AUTOCAD (2013) which shows how the dimensions of auxiliary hole change according to the boundary of ellipse. As the auxiliary holes will move away from the main hole their dimensions will reduce due to ellipsoidal shape which is shown in fig. 2, 3 and 4 below.

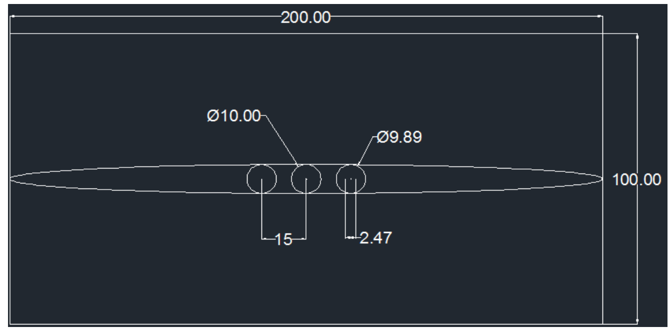


Fig. 2 Circular holes at distance 15mm from main hole

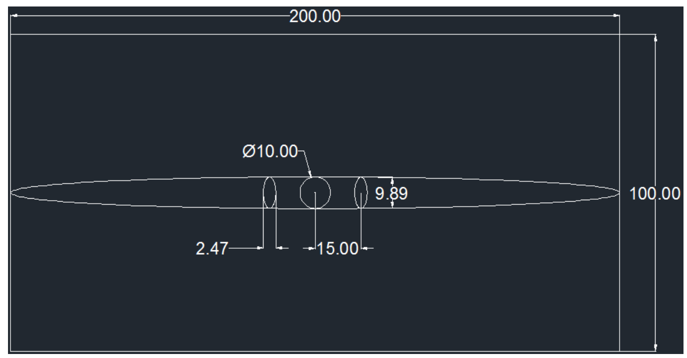


Fig 3 Ellipse 1 at distance 15mm from main hole

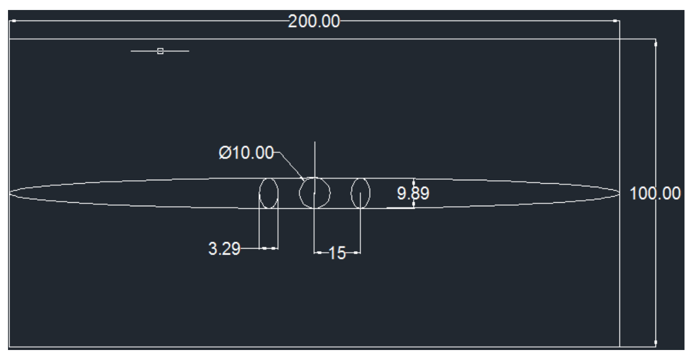


Fig 4 Ellipse 2 at distance 15mm from main hole

### *A. Identification of main function and its side effects*

Main function: Rectangular plate under in plane loading
Side effect: Induction of stress concentration factor

Before proceeding to the next step it is necessary to list down all the factors that are going to affect the stress concentration factor induced within the plate under in plane loading. From those factors control factor and noise factors are identified and are listed in the table 1 below.

TABLE I
CONTROL AND NOISE FACTORS

| Control factor | Noise factor |
|---|---|
| Shape of auxiliary hole | Material properties |
| Size of auxiliary hole | Vibrations |
| Distance of auxiliary hole from main hole | Environmental conditions |

After listing the control and noise factors decisions on the factors that affect the performance will have to be ascertained and only those factors must be taken into consideration in constructing the matrix for the experimentation. All other factors are considered as noise factors.

### *B. Identifying the testing conditions and quality characteristic to be observed*

Quality characteristic: Stress concentration factor
Work piece material: Steel

### *C. Identify the objective function*

Objective function: Smaller the better

S/N ratio for this function: $\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n} y^2 i)$

Where $\eta$ =sample size and y= stress concentration factor

### *D. Identify the control factors and their levels*

The factors and their levels were decided for conducting the experiment based on brain storming session that was held with a group of people. The factors and their levels are shown in table 2.

TABLE II
CONTROL FACTORS AND THEIR LEVELS

| FACTORS | | LEVELS | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Shape of auxiliary hole | Circle | Ellipse 1 | Ellipse 2 |
| Distance of auxiliary hole from main hole (mm) | 15 | 30 | 45 |

### *E. Selection of orthogonal array*

The orthogonal array is arrays in which columns are mutually orthogonal i. e. for any pair of column, all combinations of factor level occur, and they occur for equal number of times. In simple words in orthogonal array, equal chance is given to the every level of every parameter .The Taguchi orthogonal array layout gives the way to perform minimum number of experiments which are sufficient to give the full information of all the factors that affect the desired response. It consists of an inner array and an outer array. The inner array is made up of the orthogonal array (OA) selected from all the possible combinations of the controllable factors to perform the minimum number of experiment. The outer array contains the combinations of the uncontrollable factors. In the present study, in comparison to noise factors, the controllable factors have considerably high impact on the stress concentration factor. Therefore, only inner array has been considered. There are many standard orthogonal arrays available, with the combinations of number of controllable factors and number of their levels. L9 orthogonal array is selected for the present investigation in which nine experiments need to be performing with three parameters having three levels each. The selected orthogonal array along with the details of levels of each parameter is shown in Table 3

TABLE III
L9 ORTHOGONAL ARRAY

| Exp. No. | Control factors | |
|---|---|---|
| | A | B |
| 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 |

### *F. Analysis of signal to noise ratio*

TABLE IV
ANALYSIS OF SIGNAL TO NOISE RATIO

| Sr. No. | Shape | Distance (mm) | SCF | S/N ratio | Mean |
|---|---|---|---|---|---|
| 1 | Circle | 15 | 1.79 | -5.05706 | 1.79 |
| 2 | Circle | 30 | 1.95 | -5.80069 | 1.95 |
| 3 | Circle | 45 | 2.02 | -6.10703 | 2.02 |
| 4 | Ellipse 1 | 15 | 1.71 | -4.65992 | 1.71 |
| 5 | Ellipse 1 | 30 | 1.94 | -5.75603 | 1.94 |
| 6 | Ellipse 1 | 45 | 1.96 | -5.84512 | 1.96 |
| 7 | Ellipse 2 | 15 | 1.85 | -5.34343 | 1.85 |
| 8 | Ellipse 2 | 30 | 1.83 | -5.24902 | 1.83 |
| 9 | Ellipse 2 | 45 | 2.03 | -6.14992 | 2.03 |

### *G. Analysis of variance*

The purpose of ANOVA is to investigate which of the process parameter significantly affect the performance characteristic. The stress concentration factor observed is entered as a response for this analysis. The results generated by the MINITAB 16 in terms of S/N ratio and mean are used to draw the conclusions. The Table 4 indicates the S/N ratio and mean for nine experimental run factor level set for each trial. The response table and main effects plot generated for mean and S/N ratio is shown below. Every value in the response table for means gives average of mean for a parameter for each level. Similarly all average values for means are given in a table. Delta value given in the table gives the variations in mean within the levels, more the variation more is the delta value and hence more is the contribution of that factor in the response. The rank for each control factor given in a table gives the order in which every factor is contributing in a particular response and it is decided on the value of delta. From higher to lower value of delta ranks of all factors are decided. Hence in the same order rank is given to the control factors. Response table for means and SN ratio for stress concentration factor is shown below in table 5 and 6.

TABLE V
RESPONSE TABLE FOR MEANS OF STRESS CONCENTRATION FACTOR

| Column | Factors | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| 1 | Shape | -5.655 | -5.420 | -5.581 | 0.235 | 2 |
| 2 | Distance (mm) | -5.020 | -5.602 | -6.034 | 1.014 | 1 |

TABLE VI
RESPONSE TABLE FOR S/N RATIO OF STRESS CONCENTRATION FACTOR

| **Column** | **Factors** | **Level 1** | **Level 2** | **Level 3** | **Delta** | **Rank** |
|---|---|---|---|---|---|---|
| 1 | Shape | 1.920 | 1.870 | 1.903 | 0.050 | 2 |
| 2 | Distance (mm) | 1.783 | 1.907 | 2.003 | 0.220 | 1 |

## *H. Main effect plot for stress concentration factor*

The main effect plot for means and S/N ratio is shown in Figure 5 and 6. The main effects plot graphically represents the effect of factors on the response which helps to compare the effect of each level of the control factor on the response under study. The reference line drawn is showing the average mean for overall response. From the main effect plots it is clear that the stress concentration factor will minimum at level 2 for shape of auxiliary hole and level 1 for distance of auxiliary hole.

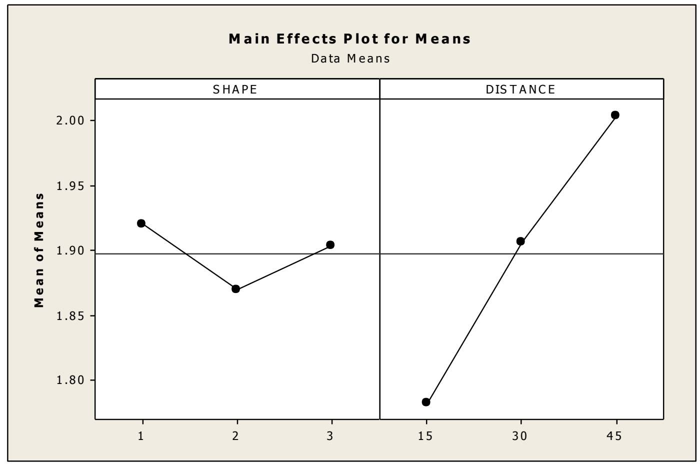


Figure 5 Main effect plots for mean

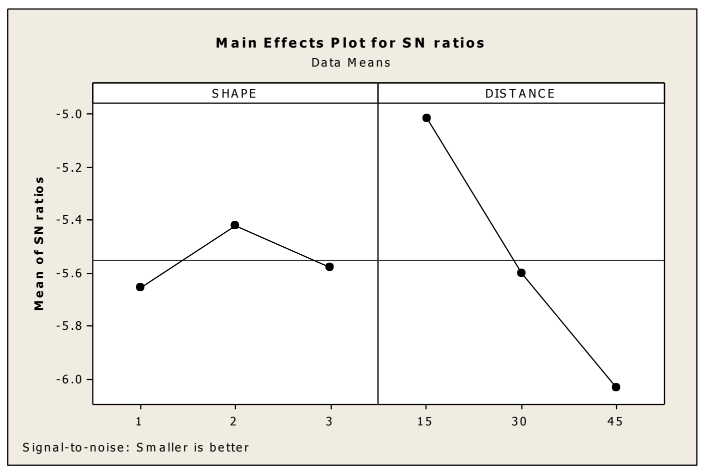


Figure 6 Main effect plots for S/N Ratio

## *I. Percent contribution*

The optimum levels of controlling parameters are found out by using mean and S/N ratio analysis. The rank has given the order in which each factor is contributing to the response. Now in order to find out significant factors involved in the analysis determination of their percent contribution F ratio is needed. Applying analysis of variance, ANOVA it can be done. The ANOVA for stress concentration factor is shown in Table 7. The percent contribution is a function of sum of squares of each control factor. It is shown in the Table 7. In L9 array which is chosen for analysis, total degrees of freedom available are 9-1= 8. Three levels of each factors are considered, so all factors are assigned with 2 degrees of freedom each. The percentage contribution of each factor is shown graphically in Fig. 7.

TABLE VII
ANOVA FOR STRESS CONCENTRATION FACTOR

| Sr. No | Factor | SS | D O F | MSS | F ratio | % contribution |
|---|---|---|---|---|---|---|
| 1 | Shape | 0.0039 | 2 | 0.0019 | 0.025 | 4.12 |
| 2 | Distance (mm) | 0.07296 | 2 | 0.03648 | 0.48 | 77.15 |
| 3 | Error | 0.0177 | 4 | 0.075345 | | 19.73 |
| 4 | Total | 0.09456 | 8 | | | 100 |

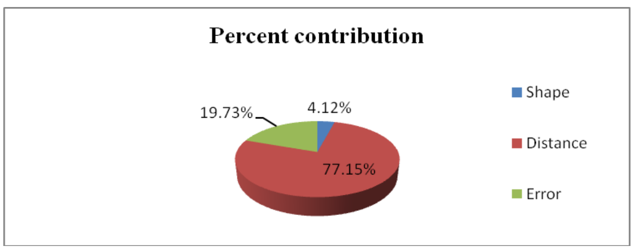


Fig 7 Pi chart for percent contribution

### J. *Confirmation experiment*

The final step of the Taguchi method is the confirmation experiments conducted for examining the quality characteristics. In order to verify the results obtained from Taguchi analysis, a confirmation experiment need to be performed .The model used in the confirmation tests is defined with the total effect generated by the control factors. The factors are equal to the sum of each individual. The steps conducting a confirmation experiment are:

1) Determine the preferred combination of the level of the factors and interactions indicated to be significant in the analysis.
2) Determine preferred level for the factors indicated to be insignificant for the analysis
3) Calculate the estimated mean for the preferred combination of the levels of significant factors and interactions.
4) Calculate estimated standard deviation for the estimated standard deviation for the preferred combination of significant factors and interactions.
5) Determine the sample size for the confirmation experiment.
6) Calculate the confidence interval value.
7) Calculate the confidence interval for the true mean around the estimated mean.
8) Conduct tests under specified conditions.
9) Compare the confirmation tests average result to the confidence interval for the true mean.
10) Determine the next course of action.

Based on above mentioned steps, the optimum combination of the levels for the plate parameters to minimize the stress concentration factor is given below. To perform a confirmation experiment, specimens of plates are prepared for response with optimum levels of parameters obtained from the Taguchi analysis. The configuration of samples to be tested for different responses along with observed results is as given in Table 8.

TABLE VIII
OPTIMUM CONDITIONS OF PLATE PARAMETERS FOR DIFFERENT RESPONSES

| Response | CONTROL FACTORS | | OBSERVED RESULTS |
|---|---|---|---|
| | SHAPE | DISTANCE (MM) | |
| SCF | ELLIPSE 1 | 15 | 1.71 |

### K. *Estimated mean of all responses*

Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the estimated result against experimental value. It may be noted that if the optimal combination of parameters and their levels coincidently match with one of the experiments in the Orthogonal Array, then no confirmation test is required. Estimated value of all the responses at optimum condition was calculated by adding the average performance to the contribution of each parameter at the optimum level using the following equations.

Estimated stress concentration factor at optimum condition is computed by

$$\hat{\mu} = \overline{A2} + \overline{B1} - \overline{T}$$

TABLE IX
ESTIMATED STRESS CONCENTRATION FACTOR AT OPTIMUM CONDITION

| Grand Average | Shape | Distance (mm) | SCF |
|---|---|---|---|
| $\overline{T}$ | $\overline{A2}$ | $\overline{B1}$ | |
| 1.89 | 1.87 | 1.78 | 1.75 |

TABLE X
COMPARISON OF EXPERIMENTAL, ESTIMATED VALUE OF SCF

| Sr. No. | Response | Estimated value | Observed value |
|---|---|---|---|
| 1 | SCF | 1.75 | 1.71 |

### *L. Confidence interval*

The estimated results are only a point estimate based on the averages of the results obtained from the experiments. While performing the confirmation experiment it is better to have a range of value than having an exact value of predicted results within which the observed values should fall with some confidence. This range is called as confidence interval (C.I.). It has a maximum and minimum value between which the observed value should fall. It can be calculated by statistical way by using following expression:

$$C.I = \pm \sqrt{(F(1,n2) \times Ve) / Ne}$$

Where F (1, n2) is the F value from F table at a required confidence level at DOF 1 and error DOF n2.
Ne = Effective number of replications
Using these equations confidence interval for all responses is calculated which is shown in table 11. The F value is taken for 95% of confidence.

TABLE XI
COMPARISON BETWEEN EXPERIMENTAL RESULTS AND PREDICTED RESULTS

| Sr. No. | Response | Confidence Interval | | Observed Result |
|---|---|---|---|---|
| | | Lower | Upper | |
| 1 | SCF | 0.99 | 2.51 | 1.71 |

So from the TABLE XI it is clear that the observed results are falling within the confidence interval of predicted results hence the confirmation experiment has validated the result.

## V.CONCLUSIONS

This paper has presented an application of the parameter design of the Taguchi method in the optimization of stress concentration factor. The following conclusions can be drawn based on the above results of this study:
-Taguchi's Method of parameter design can be performed with lesser number of experimentations as compared to that of full factorial analysis and yields similar results.
-The FEM results demonstrate that the distance of auxiliary hole from main hole is the main parameter among the two factors.
-The confirmation experiment was conducted to verify the optimal parameter responsible for reducing stress concentration factor. The percent contributions of shape and distance are 4.12 and 77.15 respectively.

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