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# Optimization of Strain Gauge Transducer for Weighing Application Using GRA Method

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***Abstract* - The main objective of current research is optimization of strain gauge transducer used in weighing application by maximizing sensitivity and minimizing volume. A simple model of strain gauge based 'Double Ended Shear Beam' transducer is considered for Finite Element Analysis (FEA). Taguchi method has been applied to construct an orthogonal array based on selected parameters. Next, multi-objective optimization is performed. As Taguchi method is unable to perform multi-objective optimization combined approach of Taguchi and Grey Relational Analysis (GRA) is carried out. This combined approach gives optimum parametric combination based on highest Grey Relation Coefficient (GRC). Analysis of Variance (ANOVA) is statistical technique is used to investigate contribution of each process parameters on the performance characteristic.**
***Keywords:* Strain gauge, Transducer, Sensitivity, Volume, Taguchi, FEM, GRA, ANOVA.**

## I.INTRODUCTION

Earlier in weighing industry lever scale were widely used. This mechanism involve principle weight balancing but this process is more time consuming and not reliable. Continuously the research is going on for new innovative design in the engineering field. Optimization is one of the area where design engineering are focusing foe obtaining the best result under given circumstances. A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured [2-3]. The various types of load cells include hydraulic load cells, pneumatic load cells and strain gauge load cells. Strain gauge load cells are widely used due to its accuracy and lower unit cost as compared with other types of load cell. For current research work shear beam type such as 'Double Ended Shear Beam' load cell is used. The characteristic of this load cell is similar to single ended type load cell. It is widely used in weighbridge application [4].

The electrical resistance of many metals change when the metals are mechanically elongated or contracted. The strain gauge utilizes this principle and detects a strain by changes in resistance [1]. A load cell is made by bonding strain gauges to a spring material. To efficiently detect the strain, strain gauges are bonded to the position on the spring material where the strain will be the largest. As in all 'Double Ended Shear Beam' load cell strain gauges are mounted on a thin web in the center of the cell's machined cavity.

## II.DESIGN OF EXPERIMENT

Design of experiments is a statistical technique introduced in 1920 by Sir R.A. Fisher in England. It is used to determine the optimal factor settings of a process and thereby achieving improved process performance, reduced process variability and improved manufacturability of products and processes [5]. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations [6]. 'Double Ended Shear Beam' type load cell structure and working of this load cell is similar to simply supported beam which aids bending. So, to avoid excessive bending various dimensional parameters are studied, those are 'length', 'height', 'thickness' and 'cavity dimensions (i.e. cavity length, cavity height and cavity radius)'. As strain gauges are fit inside the cavity at an angle $45^0$, so it is not critical parameter. Remaining three parameters, namely 'length ', 'height' and 'thickness' are considered critical parameters shown in Fig.1. The parameters and corresponding levels for 'Double Ended Shear Beam' type load cell, is shown in Table I.

TABLE IPARAMETER AND LEVEL FOR 'DOUBLE ENDED SHEAR BEAM' TYPE LOAD CELL

| Sr. No. | Parameter | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| 1 | Length | mm | 137.90 | 197 | 256.10 |
| 2 | Height | mm | 35 | 50 | 65 |
| 3 | Thickness | mm | 30.10 | 43 | 55.90 |

EN 24 Steel is a material used, having high wear resistance, high toughness and strength property with its material density $7840 \times 10^{-5}$ Kg/mm$^3$, Young's Modulus $2.1 \times 10^5$ N/mm$^2$, Poisson Ratio 0.3 and Yield strength 600N/mm$^2$.To carry out analysis following assumptions were made,

1. Load cell is fixed to rigid support by means of bolts.
2. Uniformly distributed load is acting on top surface of load cell.
3. At the location of strain gauges values of strains are measured.

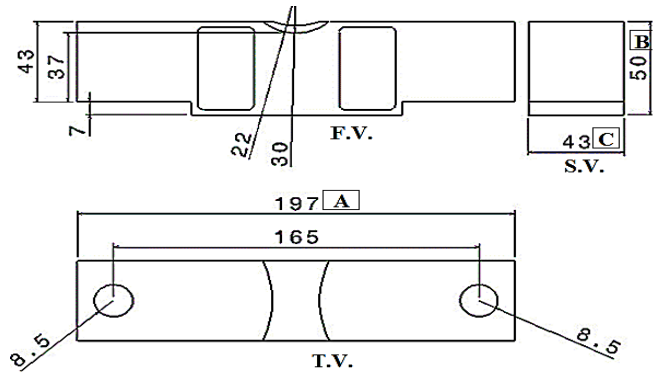


Fig.1 'Double Ended Shear Beam' type load cell with its critical dimensional parameters [7]

L9 OA is selected represented in Table 2 to make the further experiments. This array specifies 9 experiments. The L9 OA comprising of 3 parameters with each having 3 levels are represented in the Table II.

TABLE II L9 DESIGN MATRIX

| Experiment No. | Parameter 1 | Parameter 2 | Parameter 3 |
|---|---|---|---|
| 1 | 137.9 | 35 | 30.1 |
| 2 | 137.9 | 50 | 43 |
| 3 | 137.9 | 65 | 55.9 |
| 4 | 197 | 35 | 43 |
| 5 | 197 | 50 | 55.9 |
| 6 | 197 | 65 | 30.1 |
| 7 | 256.1 | 35 | 55.9 |
| 8 | 256.1 | 50 | 30.1 |
| 9 | 256.1 | 65 | 43 |

Sensitivity and volume are the two response variable are selected. "Larger the better" quality characteristic for sensitivity, whereas "smaller the better" quality characteristic for volume. Signal to noise (S/N) ratio is determined for response variable, using Eq.1 for "smaller the better" and Eq.2 "larger the better" characteristic. Values of S/N ratio are tabulated in Table III.

$$n = -10\ \log_{10}[\text{ mean of sum of square of measured data}] \quad (1)$$

$$n = -10\ \log_{10}[\text{ mean of sum squares of reciprocal of measured data}] \quad (2)$$

***Finite Element Method (FEM)***

Finite Element Method (FEM) is a numerical technique, which give near accurate solutions to complex field problems. FEM involves dividing the complex structures into known number of smaller structures. This is called discretization or meshing, which makes the technique more effective in analyzing irregular shaped structures of engineering problems. Structural analysis for constructed orthogonal array represented in Table II is carried out by finite element analysis (FEA). Fig. 2 shows steps of FEM.

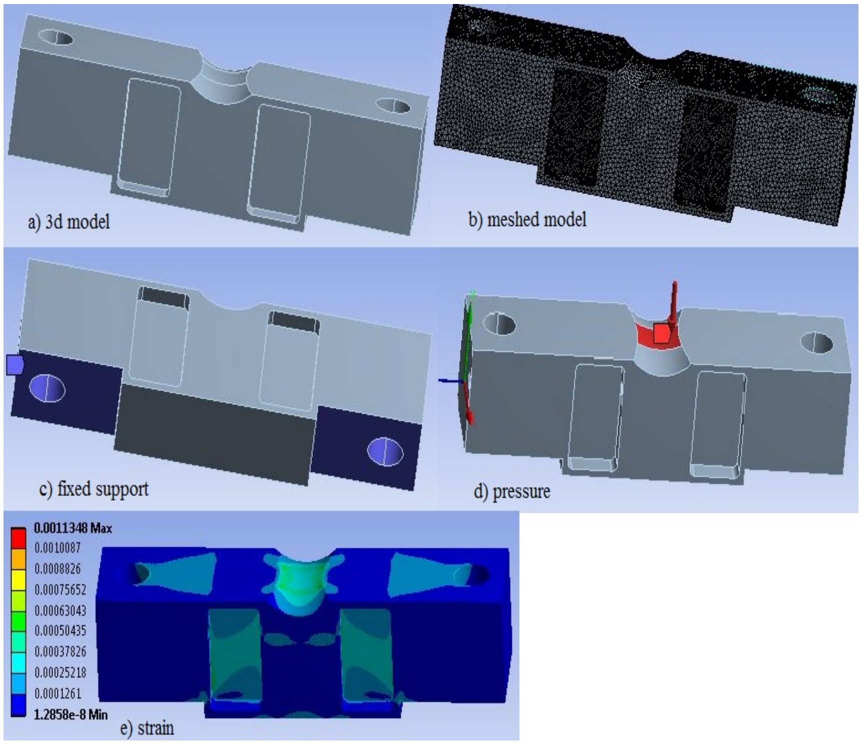


Fig. 2 Steps in FEM

## III.RESULTS AND DISCUSSION

***Effect of process parameters on volume***

In order to study the effect of process parameters on volume, experiments were conducted using L9 OA represented in Table II. The analyzed data and signal to noise ratio (S/N) are given in Table 3. The Minitab 16© software tool is used to analyze the parameters.

TABLE III ANALYZED DATA AND S/N RATIO OF OBSERVED RESULTS

| **Orthogonal Array** | **Analyzed data** | | **S/N ratio (DB)** | |
|---|---|---|---|---|
| | **Volume** | **Sensitivity ($X 10^{-3}$)** | **Volume** | **Sensitivity** |
| 1 | 105626.342 | 12.40 | -100.475 | -38.132 |
| 2 | 224775.931 | 6.20 | -107.035 | -44.152 |
| 3 | 388948.825 | 3.70 | -111.798 | -48.636 |
| 4 | 213486.677 | 8.40 | -106.587 | -41.514 |
| 5 | 412802.109 | 4.80 | -112.315 | -46.375 |
| 6 | 256762.306 | 15.00 | -108.191 | -36.478 |
| 7 | 358130.032 | 6.00 | -111.081 | -44.437 |
| 8 | 239508.947 | 19.80 | -107.586 | -34.067 |
| 9 | 515508.588 | 4.50 | -114.245 | -46.936 |

From Fig.3 it is clear that, Volume increase with increase in dimension of length, height and thickness of load cell. As volume is "smaller the better" type quality characteristic, from Fig.3 , it can be seen that the third level of length (A3), third level of height (B3), third level of thickness (C3) result in minimum value of volume.

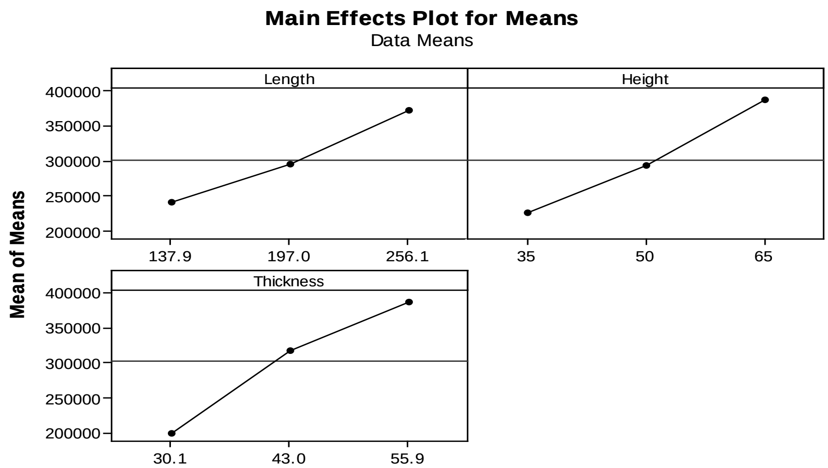


Fig. 3 Effects of process parameters on volume

***Effect of process parameters on Sensitivity***

From Fig.4 it is clear that, sensitivity increase with increase in dimension of length, and decrease with increase in thickness. Sensitivity increase with increase in height first and then decrease. As sensitivity is 'larger the better' type quality characteristic, from Fig.4 , it can be seen that the third level of length (A3), third second of height (B2), first level of thickness (C1) result in maximum value of sensitivity.

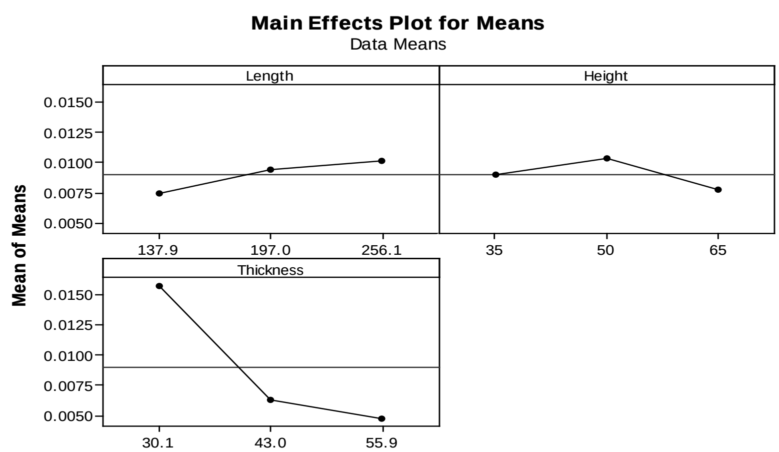


Fig.4 Effects of process parameters on sensitivity

***Multi response parametric optimization***

Taguchi method is used for optimizations of parameters using signal to noise ratio. Higher signal to noise ratio means closer to optimal of parameters. It can optimize the single response only and unable to optimize if the number of responses are more than one [8]. In many cases, parameters cannot be set only for one response, as the objective would be to minimize and maximize some response. So for current research work there is a need of multi response optimization. Grey Relational Analysis (GRA) method is used for multi response optimization. The multi response optimization first convert multiple objective into single objective [9]. The various steps in GRA include normalization of process parameters for calculating grey relational coefficient (GRC). The mean of GRC was taken for calculating GRG. The highest GRG was taken as optimum combination.

The obtained S/N ratio data are converted to normalized values using Eq.6 and Eq. 7. The normalized data is more evenly distributed without units and it is used for further analysis. The Eq.3 used for 'smaller the better' and Eq. 4 for 'larger the better. And their values are represented in Table IV.

$$x_i^*(k) = \frac{max\, x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - min\, x_i^0(k)} \quad (3)$$

$$x_i^*(k) = \frac{x_i^0(k) - min\, x_i^0(k)}{max\, x_i^0(k) - min x_i^0(k)} \quad (4)$$

***Determination of deviation sequence***

The deviation sequence $\Delta_{oi}(k)$ is the absolute difference between the reference sequence $x_i^0(k)$ and the comparability sequence $x_i^*(k)$ and it is calculated from normalized value represented in Table 4. It is determined using Eq.5. Values are represented in Table IV.

$$\Delta_{oi}k = |x_0^*(k) - x_i^*(k)| \quad (5)$$

TABLE IV NORMALIZED S/N RATIO AND DEVIATION SEQUENCE

| **Normalized S/N ratio** | | **Deviation Sequence** | |
|---|---|---|---|
| **Volume** | **Sensitivity** | **Volume** | **Sensitivity** |
| 0.000 | 0.721 | 1.000 | 0.279 |
| 0.476 | 0.308 | 0.524 | 0.692 |
| 0.822 | 0.000 | 0.178 | 1.000 |
| 0.444 | 0.489 | 0.556 | 0.511 |
| 0.860 | 0.155 | 0.140 | 0.845 |
| 0.560 | 0.834 | 0.440 | 0.166 |
| 0.770 | 0.288 | 0.230 | 0.712 |
| 0.516 | 1.000 | 0.484 | 0.000 |
| 1.000 | 0.117 | 0.000 | 0.883 |

***Calculation of Grey Relational Coefficient (GRC)***

GRC are calculated to express the relationship between the ideal and actual normalized S/N ratio. The grey relational coefficient can be expressed by Eq.6. Values are represented in Table V.

$$\gamma_{0,i}(k) = \frac{\Delta_{min} + \xi.\Delta_{max}}{\Delta_{0i}(k) + \xi.\Delta_{max}} \quad (6)$$

Where, $\Delta_{min}$ is zero,$\Delta_{max}$ is one, $\Delta_{0i}$ $(k)$ is the deviation sequence & $\xi$ distinguishing coefficient $\xi \in (0,1)$generally it is considered as 0.5 [10].

***Determination of weighted Grey Relational Grade (GRG)***

The grey relational grade is calculated by averaging the values of grey relational coefficient corresponding to each performance characteristic. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. It can be calculated by using Eq.7 and values are represented in Table V.

Table V Grey relational coefficients and grade values

| **Volume** | **Sensitivity** | **GRG** | **Rank** |
|---|---|---|---|
| 0.333 | 0.642 | 0.488 | 7 |
| 0.488 | 0.419 | 0.454 | 9 |
| 0.738 | 0.333 | 0.536 | 6 |
| 0.473 | 0.494 | 0.484 | 8 |
| 0.781 | 0.372 | 0.576 | 4 |
| 0.532 | 0.751 | 0.642 | 3 |
| 0.685 | 0.413 | 0.549 | 5 |
| 0.508 | 1.000 | 0.754 | 1 |
| 1.000 | 0.361 | 0.681 | 2 |

$$\gamma(x_0, x_i) = \frac{1}{m}\sum_{i=1}^{m}\gamma(x_0(k), x_i(k)) \qquad (7)$$

Where, $\gamma(x_O, x_i)$ the grey relational grade for the $j_{th}$ experiment and m is the number of performance characteristics.

The obtained GRG is considered a single response for designed experiments and analysis of variance (ANOVA) is carried out for finding most significant parameters which affect the multi objective response. ANOVA is given in Table VI. ANOVA calculations are based on F-ratio, which is the ratio between the regression mean square and the mean square error. This ratio is used to measure the most affecting parameters. If calculated value of F-ratio is higher than its tabulated value, then the factor is significant [11]. ANOVA table shows the percentage contribution of each parameter. It is clear from ANOVA table that parameter only length is significant for multi objective response whereas remaining parameters are less significant.

TABLE VI ANOVA FOR GREY RELATIONAL GRADE

| Parameter | DOF | Seq SS | Adj SS | Adj MS | F | P | % Contribution |
|---|---|---|---|---|---|---|---|
| Length | 2 | 0.042981 | 0.042981 | 0.0214905 | 14.02 | 0.067 | 53.3515 |
| Height | 2 | 0.021018 | 0.021018 | 0.010509 | 6.86 | 0.127 | 26.0892 |
| Thickness | 2 | 0.013498 | 0.013498 | 0.006749 | 4.4 | 0.185 | 16.7548 |
| Error | 2 | 0.003065 | 0.003065 | 0.0015325 | - | - | 3.8045 |
| Total | 8 | 0.080562 | - | - | - | - | 100.0000 |

Using Taguchi method, response table has been generated to separate out the effect of each level of process parameters on grey relational grade as represented in Table VII**.**

TABLE VII RESPONSE TABLE FOR GREY RELATIONAL GRADE (GRG)

| Levels | Length (mm) | Height (mm) | Thickness (mm) |
|---|---|---|---|
| 1 | 0.492 | 0.507 | 0.628 |
| 2 | 0.567 | 0.595 | 0.540 |
| 3 | 0.661 | 0.619 | 0.554 |
| Max | 0.661 | 0.619 | 0.628 |
| Min | 0.492 | 0.507 | 0.540 |
| Delta | 0.169 | 0.113 | 0.088 |
| Rank | 1 | 2 | 3 |
| Total mean value of GRG is 0.574 | | | |

***Prediction of Grey Relational Grade under optimum Parameters***

After evaluating the optimal parameter settings, the next step is to predict and verify the improvement of quality characteristics using the optimal parametric combination.

The optimal Grey relational grade *($\eta_{opt}$)* is predicted using Eq.8.

$$\eta_{opt} = \overline{T} + \left(\overline{A}_{(1/2/3)} - \overline{T}\right) + \left(\overline{B}_{(1/2/3)} - \overline{T}\right) + \left(\overline{C}_{(1/2/3)} - \overline{T}\right) \qquad (8)$$

$\overline{T}$ = overall mean of the response

$\overline{A}_{(1/2/3)}, \overline{B}_{(1/2/3)}, \overline{C}_{(1/2/3)}$ = average values of response at the first or second or third levels of parameters A, B and C respectively.

$$\eta_{opt} = 0.574 + (0.661 - 0.574) + (0.619 - 0.574) + (0.628 - 0.574)$$
$$= 0.76$$

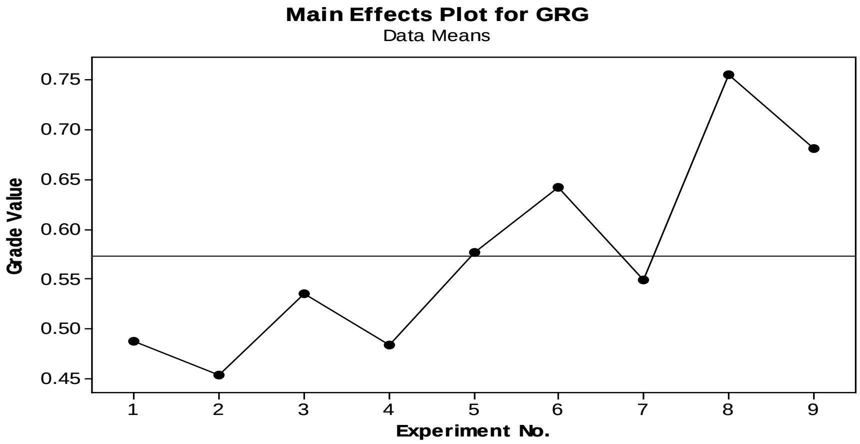


Fig.5 Graph shows ranking of experiment no. with respective grade value

Based on ranking order obtained from Table V and Fig.5, experiment no.8 is considered the best response value. Basically, larger the grey relational grade, better the corresponding characteristics. From the response table for grey relational grade, the best combination of the process parameters is set with A3B3C1.

## IV.CONCLUSIONS

The aim of research work is to find the optimum shape of strain gauge based load cell to get the better response or in other words to improve the load cell performance by minimizing volume and maximizing sensitivity. Design of experiment techniques have been utilized for investigation and optimization of selected parameters, in order to get better response The conclusion based on multi objective optimization using Taguchi with GRA are summarized as follows:

1. 'Double Ended Shear Beam' type load cell, used for research work having volume 328196.92 $mm^3$ and sensitivity 4.70X $10^{-3}$ μstrain/N. The Optimization method gives results as volume 317948.92 $mm^3$and sensitivity 15.30 X $10^{-3}$ μstrain/N i.e. volume is reduced by 3.12% and sensitivity is increased by 69.28%.

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