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# Parametric Optimization of Rectangular Beam Type Load Cell Using Taguchi Method

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***Abstract:-***In this work, Rectangular beam type load cell is considered for stress and strain analysis by using finite element method. The stress analysis is carried out to minimize the weight of Rectangular beam- type load cell without exceeding allowable stress. The intention of the work is to create the geometry of Rectangular beam-type load cell to find out the optimum solution. FEM software HyperWorks11.0.0.39 is using for parametric optimization of Rectangular beam type load cell.

If the stress value is within the permissible range, then certain dimensions will be modified to reduce the amount of material needed. The procedure will be repeated until design changes satisfying all the criteria. Experimental verification will be carried out by photo-elasticity technique with the help of suitable instrumentation like Polariscope. Using Photo-elasticity technique, results are crosschecked which gives results very close to FEM technique. Experimental results will be compared with FEM results. With the aid of these tools the designer can develop and modify the design parameters from initial design stage to finalize basic geometry of load cell.

***Index terms—***Strain gauge, Load cell, Sensitivity, optimization, Volume, Taguchi, FEM.

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## 1. INTRODUCTION

Load cell is a device normally use in weighing, industrial automation and research applications. The capacity of load cell is vary from 20 kg up to 20 tons. One of the most popular types of load cell is Rectangular beam type load cell. A load cell is a transducer that converts a force into electrical signal. The force is sensed by a strain gauge that will be converted into electrical signals.

The main objective of this project is to do parametric optimization and analysis of rectangular beam type load cell using Taguchi method. Rectangular Beam type load cells were analyzed by carrying out Finite Element Analysis (FEA) of different configurations by varying the different dimensions and finally an optimum design was arrived at for a given load range.

### 1.1 Description of Load Cell and Experimental Usage:

Most industrial measurements of force are made with strain gauge load cell. It utilizes strain gauges bonded to steel body to give an electrical output proportional to applied force. It is universal load cell suitable for both tension and compression modes. Different types of load cells are beam type, 'S' type, cantilever type etc. These are used for tension measurements, weighing, industrial automation and research applications, etc. For parametric optimization, we have considered following Rectangular beam type load cell.

Fig. 1: Rectangular Beam Type Load Cell

For this load cell, we have to design the model such the maximum average strain at hole area should be close to 1000 μ strain. Material properties for the Rectangular beam type load cell are as follows

Table No. 1: Load cell Material and Properties

| Material | Young's Modulus | Poisson's Ratio | Density |
|---|---|---|---|
| EN 24 | 2.1 x 105 MPa | 0.3 | 7840 Kg/m3 |

## 2. OBJECTIVE:

The intention of the work was to minimize the weight of Rectangular beam type load cell without exceeding allowable stress. For this load cell, we have designed a model in such a way that the maximum stress in the Rectangular beam type load cell should not exceed above limits. We have considered Rectangular beam type load cell for parametric optimization by using finite element method.

The purpose of this work was to create the geometry utilizing parameters for all the variables, deciding which variables to use as design, state and objective variables to obtain an accurately converged solution. The Rectangular beam type load cell is made up of steel EN 24 with load carrying capacity is 2500 N (250 % of rated capacity = 100 N).

## 3. LITERATURE REVIEW:

The Literature Review provides technological input about Rectangular beam type load cell, parametric optimization and analysis using finite element method and Photo elasticity.

### 3.1 Load Cell

We have considered Rectangular beam type load cell for parametric optimization. A typical construction for a strain gauge load cell is shown in Figure. (Cells to measure both tension and compression require merely the addition of suitable mechanical fittings at ends). The load-sensing member is shorten enough to prevent column buckling under the rated load and is proportional to develop about 1500 μ strain at full-scale load. We will use here 1000 μ strains as maximum strain value by considering 2.5 as a factor of safety (typical design value for all forms of foil gauge transducers, materials used include SAE 4340 Steel, 17-4 PH stainless steel and 2024 T4 aluminum alloy with the last being quite popular for homemade transducers) [2].

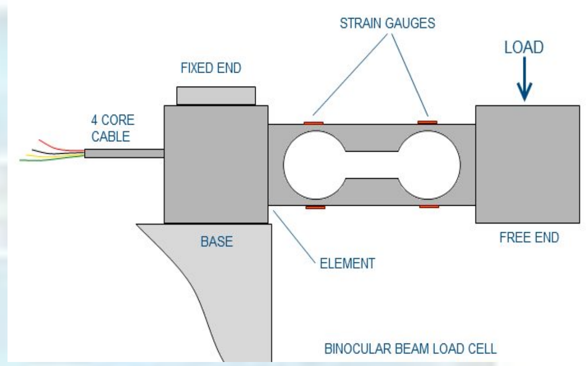


Fig. 2: Rectangular beam type load cell-Loading Conditions

## 4. FINITE ELEMENT ANALYSIS OF RECTANGULAR BEAM TYPE LOAD CELL:

Different methods were used for parametric optimization like FEM, BEM, neural network, GA coupled with BEM. The disadvantage of BEM is it considers only outer boundary of the domain. So in case if the problem is of a volume, only outer surface were considered. In neural network, a trained network were used for shape optimization of newer problem but is carried out using FEA results. FEM is the most popular numerical method. It is going to handle variety of tasks in linear, nonlinear, bucking, thermal, dynamic & fatigue analysis. Therefore FEM is superior to other methods.

### 4.1 Pre-Processing:

**Defining the Problem:**

The dimensions of the part to be analyzed as we taken it from the actual load cell available in Power Lab of Electronics Department in our college. By using, Catia software we made the model as per measured dimensions.

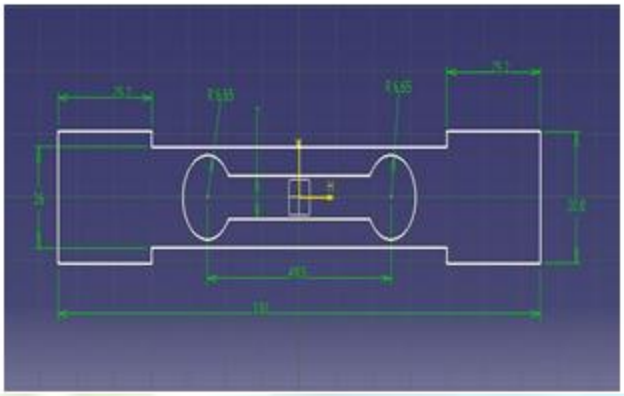

Fig. 3: Dimensions of Original Load Cell

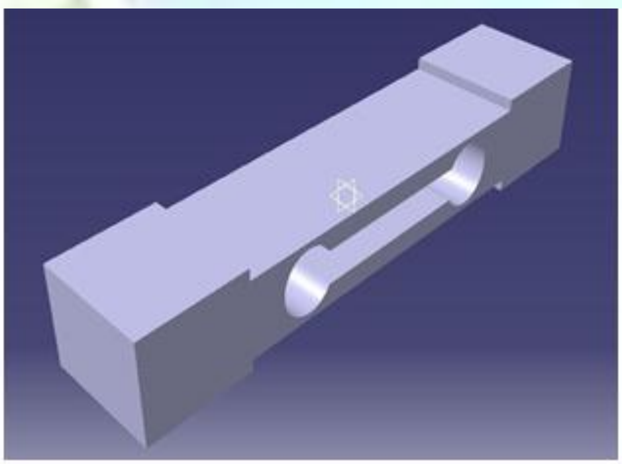

Fig. 4: Catia Modelling of Original Load Cell

### 4.2 Parametric Optimization:

The first analysis is run on a load cell with original dimensions and maximum strain value obtained above hole portion was 764 µ strains. It is necessary to find the dimensions of Rectangular beam type load cell in order to minimize the weight of it. The maximum strain above hole area in Rectangular beam type Load Cell cannot exceed 1,000 µ strains. After this various dimensions other than hole size and centre to centre distance between holes are reduced and strain values obtained during analysis. The measured factors 'a', 'b' and 'c' was varied between ± 20% tolerances in order to find optimum solution.

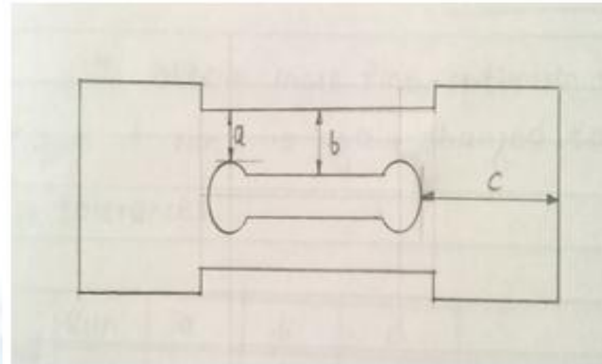


Fig.5: Factors considered for Optimization of Load Cell

| FACTORS | LEVELS | | |
|---|---|---|---|
| | -20 % | Original | + 20 % |
| 'a' | 1.08 | 1.35 | 1.62 |
| 'b' | 3.6 | 4.5 | 5.4 |
| 'c' | 26.7<br>6 | 33.45 | 40.1<br>4 |

As an experiment with 3 parameters and 3 levels of each parameter (P = 3 and L = 3), as discussed in a previous orthogonal array. We showed two Taguchi arrays for this case:

i. a 6-run array for testing each level of each parameter twice.

ii. a 9-run array for testing each level of each parameter three times.

The 9-run array is more desirable (if cost and time permit) because for each level of any one parameter, all three levels of the other parameters are tested. Of course, either array here costs less to run than a full factorial analysis, since the number of required runs for a full factorial analysis is N = LP = 33 = 27.

Table No. 5: Strain Values Using Orthogonal Arrays

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| 'a' | 'b' | 'c' | Radius of Hole (mm) | Centre to centre distance bet. Holes(mm) | μ Strain | |
|---|---|---|---|---|---|---|
| | | | | | Max | Min |
| .08 | 3.6 | 26.76 | 6.92 | 62.64 | 1412 | 1.231 x10-2 |
| 1.08 | 4.5 | 3.45 | | 49.26 | 1145 | 1.293 x10-2 |
| 1.08 | 5.4 | 40.14 | | 35.88 | 853.8 | 1.33x 10-2 |
| 1.35 | 3.6 | 33.45 | 6.65 | 49.8 | 757.8 | 1.295 x10-2 |
| 1.35 | 4.5 | 40.14 | | 36.42 | 574.9 | 1.339 x10-2 |
| 1.35 | 5.4 | 26.76 | | 63.18 | 918.9 | 1.248 x10-2 |
| 1.62 | 3.6 | 40.14 | 6.38 | 36.96 | 594.1 | 6.892 x10-3 |
| 1.62 | 4.5 | 26.76 | | 63.72 | 972.2 | 1.203 x10-2 |
| 1.62 | 5.4 | 33.45 | | 50.34 | 804.7 | 1.1x10-2 |

The value of strain nearest to 1000μ is of run 8 i.e. 972.2μ strain. So this is the optimum solution. To obtain more fine optimum solution, the value of run 8 was again varied within ± 5% tolerances.

### 4.3 Finite Element Analysis Of Photo-Elastic Model Of Rectangular Beam Type Load Cell:

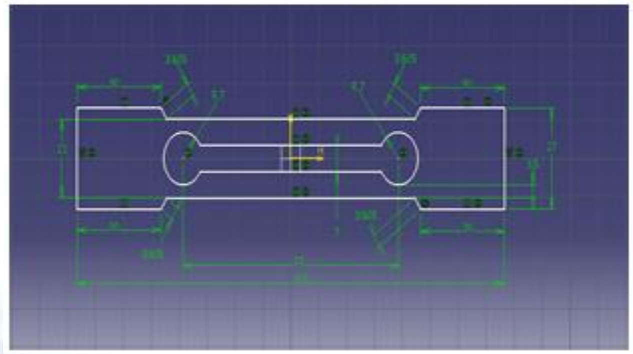

Fig. 6: Photo-elastic Model with Dimensions

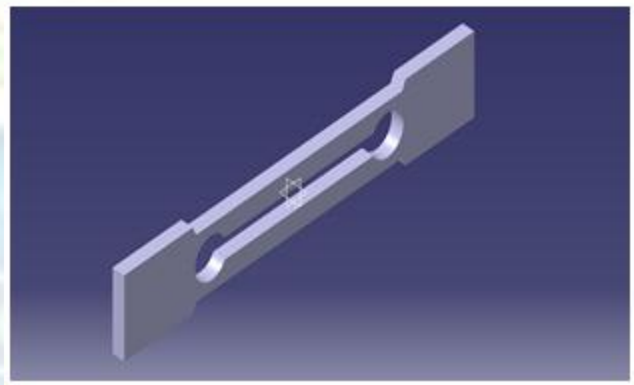

Fig. 7: Catia Modelling of Photo-elastic Model

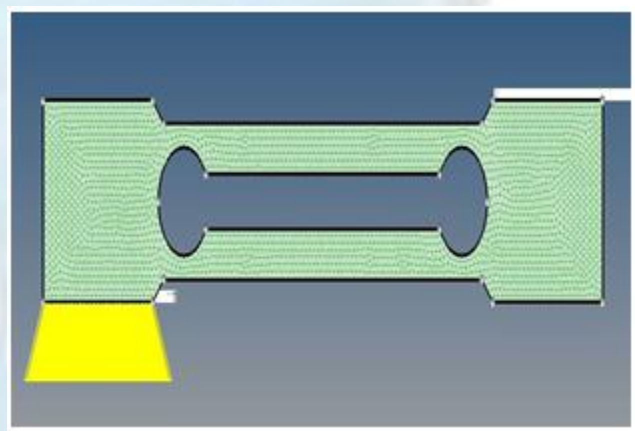

Fig.8: Loading Conditions of Photo-elastic Model

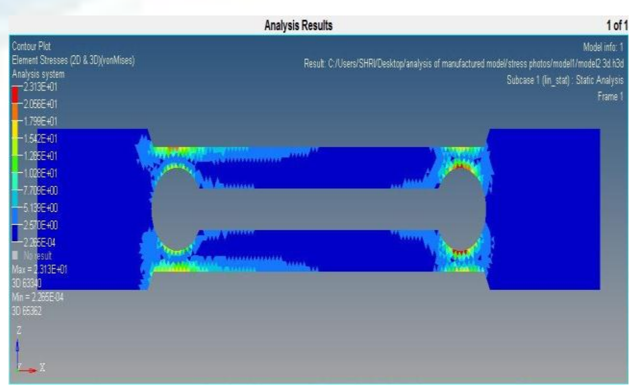

Fig. 9: Stress Distribution on Photo-elastic Model of Rectangular beam type Load cell

## 5 RESULT AND DISCUSSION:

Here we will discuss FEM and Photo-elasticity result and do comparison of these.

We can calculate percentage error.

$$\% \text{ Error} = \frac{[\sigma h - \sigma p]}{\sigma h}$$

σh - Stress determined using HyperWorks Software.

σp - Stress determined using Photo-Elasticity Technique.

$$\% \text{ Error} = \frac{23.236 - 21.52}{23.236} \text{X } 100$$

= 7.4 %

Comparison between various dimensions and volumes of original and optimized load cell.

Table No. 6: Comparison between Original and Optimized Load Cell

| Type | Dimensions of Rectangular Beam type Load cell | | | Applied Load (W) Newton | Maximum Strain | Volume( V ) mm3 | Sensitivity |
|---|---|---|---|---|---|---|---|
| | a' | b' | 'c' | | | | |
| Original Load Cell | 1.35 | 4.5 | 33.45 | 245.25 | 33.4 | 48230 | 2.99 |
| Optimized Load Cell | 1.539 | 4.275 | 25.422 | | 83 | 44730 | 4.00 |

Table No. 7: Final Result and Comparison

| Weight in pan (W), Kg. | Actual Load on Model (P), Newton | Fringe Order (N) | Stress (σ1- σ2) (Photoelasicity) N/mm2 | Stress (Hypermesh) N/mm2 | % Errors in Stresses |
|---|---|---|---|---|---|
| 0.4 | 11.984 | 9.14 | 21.52 | 23.236 | 7.4 |
| | | 9 | 21.19 | 23.403 | 9.5 |
| | | 8 | 18.84 | 20.938 | 10 |
| | | 8 | 18.84 | 21.448 | 12.2 |
| 0.5 | 14.98 | 1.5 | 27.08 | 29.373 | 7.8 |
| | | 11 | 25.90 | 29.236 | 11.4 |
| | | 10 | 23.54 | 26.17 | 10 |
| | | 10 | 23.54 | 27.256 | 13.6 |
| 0.6 | 17.972 | 2 | 28.25 | 29.373 | 3.8 |
| | | 1.5 | 27.08 | 29.719 | 11.4 |
| | | 10 | 23.54 | 25.186 | 10 |
| | | 10 | 23.54 | 26.869 | 13.6 |
| 0.7 | 20.974 | 6 | 37.67 | 40.889 | 7.9 |
| | | 16 | 37.67 | 41.448 | 9.1 |
| | | 14 | 33 | 36.953 | 10.7 |
| | | 14 | 33 | 37.607 | 12.3 |

## 6 CONCLUSION

This work presents parametric optimization using finite element method. Using Catia software directly 3D model of rectangular beam type load cell is imported into FEA software HyperWorks build with solid 92 elements. Further the optimization of model is done for reduction of weight for given criteria that maximum strain induced should be below and nearly equal to 1000 μ strain.

The hole size of load cell is reduced from 13.3 to 12.92 mm. The centre to centre between holes is increased from 49.5 to 66.234 mm. The height of gap is increased from 7 to 7.45 mm. Overall volume of load cell is reduced from 48230 mm3 to 44730 mm3. Thus, volume reduction is 7.26 %. The sensitivity observed for original load cell was 2.99 μ strain/N and for optimized load cell was 4 μ strain/N which increased by 25.25 %.

Also using Photo-Elasticity Techniques, results are crosschecked which gives results very close to FEM techniques. With the aid of these tools the designer can develop and modify the design parameters from initial design stage to finalize basic geometry of Rectangular beam type load cell.

By observing results obtained by photo-elasticity or FEM it can be seen that results of photo-elasticity is slightly varying from FEM by minimum error 3.8 % and maximum error 13.6 %.

However the results are varying in permissible range.

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