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Design Optimization of 25mm Diameter Strain Gauge Balance for Wind Tunnel Application

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Abstract

Design optimization of integral strain gauge balance with maximum diameter of the balance 25mm is presented. The purpose of this report is to design and analysis of an integral strain gauge 5 component balance. The material used for the balance is 17-4PH stainless steel. Initially model is prepared in unigraphics design software and the model imported in hypermesh software for the meshing and analysis purpose. During meshing process the selection of element size is important thing. If the quality of element is good the result will be good. The integral strain gauge balance designed with maximum stress 681 N/mm² is permitted and Minimum factor of safety is 2. The integral strain gauge wind tunnel balance with 5 component balance is designed for Normal Force of 3560 N, Side Force 2670 N and Rolling Moment 67790 N-mm.

Keywords: Integral balance, finite element analysis, five component, Rigids

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I. INTRODUCTION

The Strain gauge balances are widely used in wind tunnels for measuring the forces and moments experienced by the test model and also they are used in calibration process. Figure1.1 shows the typical strain gauge balance and its components.

Design, manufacturing and calibration of these balance is a complex procedure. Higher the capacity, lower the factor of safety for a given size of balance. Designer has to choose the dimensions so that an optimum relation between strength, capacity and bridge output voltage is achieved.

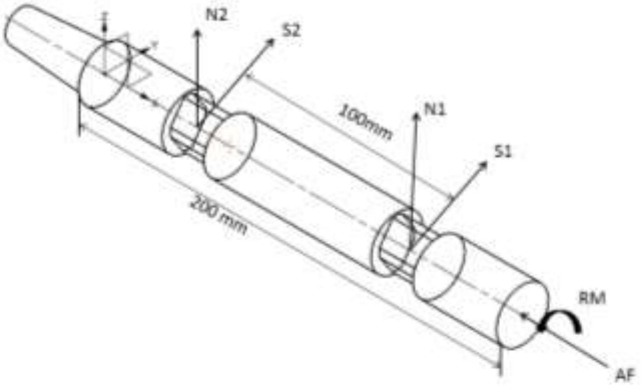

Fig. 1.1: Typical strain gauge balance and its components

A. *Different Types Balances:*

The main objective of wind tunnel is to provide air flow simulation on a scaled or full model introduced in fluid flow. Aerodynamic force and moments experienced by the model are measured by a strain gauge balance

1) *External type balances:*

They are placed outside or inside wind tunnel system test section and outside of model but they propose some interference in the air flow. And there are two types of external strain gauge balances. One piece external strain gage balance, which is made up of single piece of material and this type balances are also called as sidewall balances as they are used in half-model tests.

2) *Internal strain gauge balances:*

They are placed inside the structure or model, thus no interference is introduced in the air flow around the body by the balance aerodynamic components. There is small space inside the scaled model itself, for this reason the internal strain gage balances have to be small compared to external strain gage balances. There are mainly two types of internal strain gage balances, the integral type and multipiece type.

B. *Wind Tunnels:*

Wind tunnels are the tools in the aerodynamic research to study the effect of wind moving past solid structures. Wind tunnels consist of tubular passage with structure under the test mounted in middle. Wind is made to move past the structure by a powerful fan system. It is cheaper, safer and easier to build and test a structure or model than to build and fly a real airplane. In some cases only part of an aeroplane, engine or wing is tested in the wind tunnels. The scaled model, normally made up of aluminium or steel, the models is loaded with lot of sensors and instruments which report to the computers in the control system.

C. *Calibration Process:*

Calibration is a process of applying known loads on a load cell balance and recording the output voltage Responses by it. By this process a curve of the response output voltage versus load applied is obtained. This can be easily done in Microsoft Excel. The plot's regression equation could be used to determine any unknown loads by simply knowing the response output voltage from load cell.

II. METHODOLOGY AND DESIGN

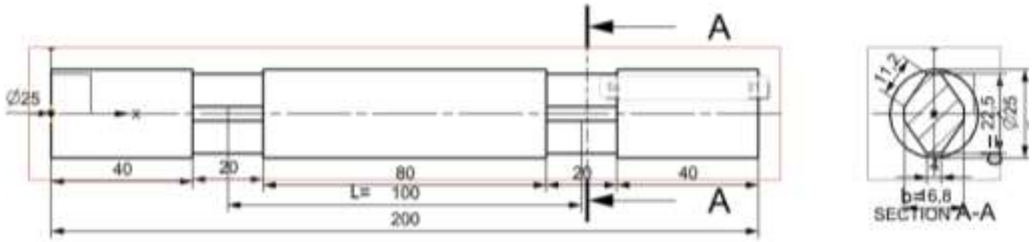

Fig. 2.1: Two dimensional sketch of the problem.

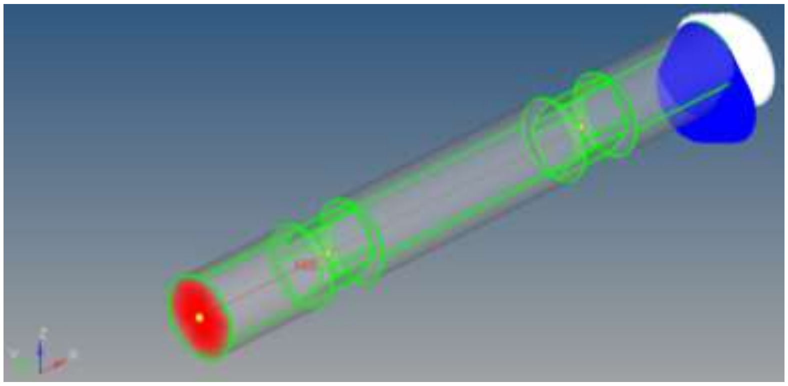

Fig. 2.2: Three dimensional model of the balance with rigid connections.

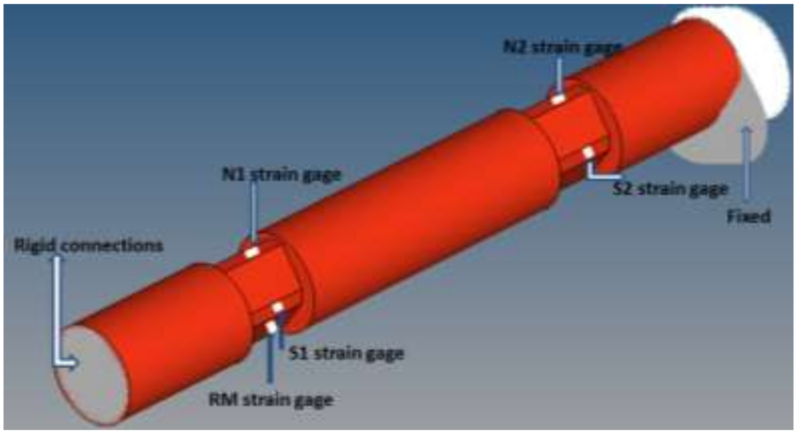

Fig. 2.3: Three dimensional model of strain gauge balance with octagon gauge cross section and components.

Figure 2.1 shows 2D sketch and the all the dimensions of strain gauge balance. Figure2.2 shows the methodology which consist of rigid connection and fixed support. Figure2.3. shows three dimensional model of the problem. Strain gauge area is 3×3 mm².The geometry is built using unigraphics software using sketcher, part model.

III. MATERIAL PROPERTIES

Table - 3.1
Physical Properties of 17-4 PH stainless steel

Specific Heat	*460 J/kg-°C at 20°C*
Melting Range	*1404 – 1440°C*
Modulus of Elasticity	*196 GPa*
Electrical Resistivity	*75 Microhm-cm at 24°C*
Density	*7.75 g/cm3*

Table - 3.2
Mechanical Properties of 17-4PH stainless steel with different heat condition

Heat Condition	*Yield strength (N/mm²)*	*Tensile Strength (N/mm²)*	*Rockwell Hardness*
H900	*1365*	*1261*	*44*
H1025	*1158*	*1116*	*38*
H1075	*1130*	*1020*	*36*
H1150	*992*	*868*	*33*
H1150M	*848*	*600*	*29*
H1150D	*1034*	*600*	*29*

IV. FINITE ELEMENT MODEL OF STRAIN GAUGE BALANCE

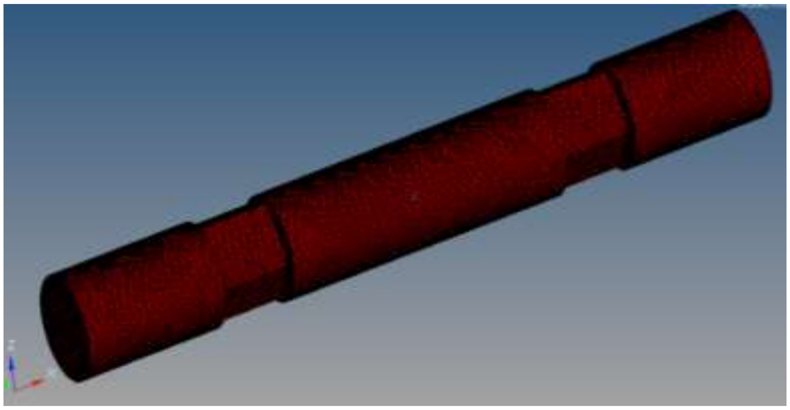

Fig. 4.1: Meshed model of the strain gauge balance

Usually type of element used in analysis method depends on analysis requirement and type of problem. Figure4.1 shows the fine mesh of balance. Selection of better type of element for particular problem plays an important role. Usually hexahedral element, tetrahedral element used for three dimensional analyses. The selected finite elements in the finite element model play an important role in the finite analysis. The 25mm diameter balance is meshed with three dimensional tetra elements. Initially the geometry is imported to Hypermesh in step file format and meshed whole body using volume tetra. The meshed body contains 86016 nodes and 420507elements. Generally accuracy depends on the type of mesh of the problem.

V. NUMERICAL ANALYSIS

Analysis for 25mm strain gauge balance has been carried out in 2 main cases. Initially the meshed structure is imported to hypermesh. The following cases of analysis are carried out.

Analysis based on calibration application by applying load for different cases as follows like1.1) N1=1779N, 1.2) N2=1779N, 1.3) S1=1334.5N, 1.4) N1=1334.5 N 1.5) RM=67791N-mm

Analysis based on the application of wind tunnel by applying all the 5 loads at the same time on the balance.

The balance contains 4 strain gauges for measurement of stress as shown in figure2.3 and there is no separate strain gauge for the measurement of Rolling Moment. Using the existed strain gauge the Rolling Moment is calculated. The stress should not cross 315 N/mm² on the strain gauges.

A. CASE 1: Analysis based on calibration application

1) Case1.1: Analysis for Normal Force N1 component

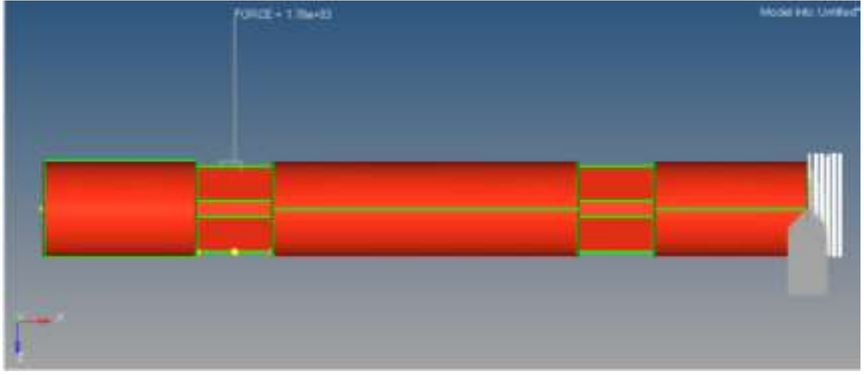

Fig. 5.1: 1779.29 N load acting on N1 gauge location

Fig. 5.2: Stress distribution on N2 gauge location due to the 1779.29N load on N1 gauge

2) Case1.2: Analysis for Normal Force N2 component

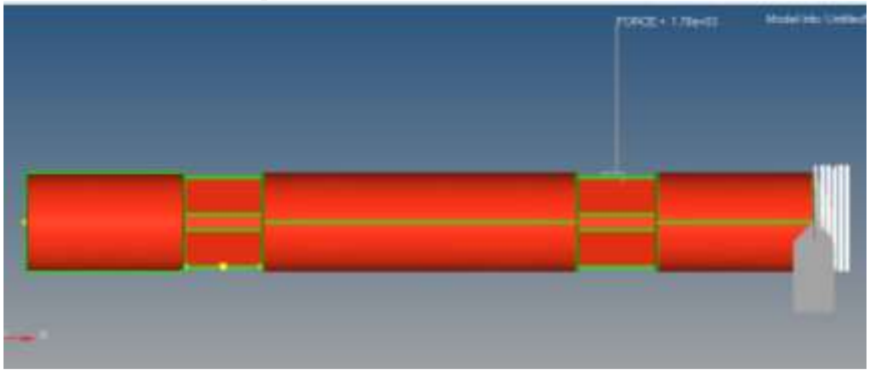

Fig. 5.3: 1779.29 N load acting on N2 gauge location

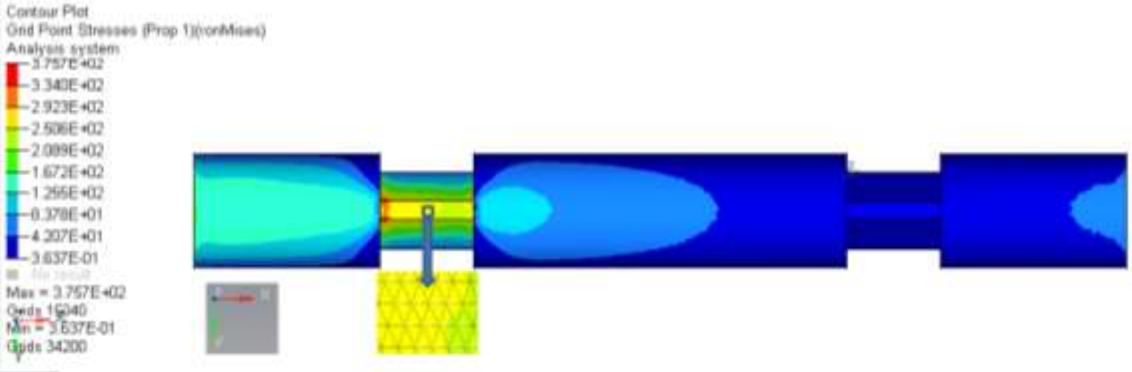

Fig. 5.4: Stress distribution on N1 gage location due to the 1779.29N load on N2 gauge.

For the 1.1 case 1779.29N load acting on the N1 gauge location and load transfer to free end not to the fixed end because of rigid connection as shown in figure2.2. Grid point stresses are collected within the gauge area of the N2 gauge location and average stress is calculated=257N/mm², strain= 12.24×10^{-4} and voltage = 2.45 mV/V. Similarly for 1.2 case 1779.29 N load acting on the N2gauge location and load transfer from N2 to N1 location then to free end.

The average stress on the N1 gauge location due to the load N2 = 271N/mm², strain=12.9×10^{-4} and voltage=2.58 mV/V

The same procedure is repeated for side force 1.3 and 1.4 cases with load of 1334.45N and results are tabulated in table 7.1.

5) *Case1.5: Analysis for Rolling Moment RM component*

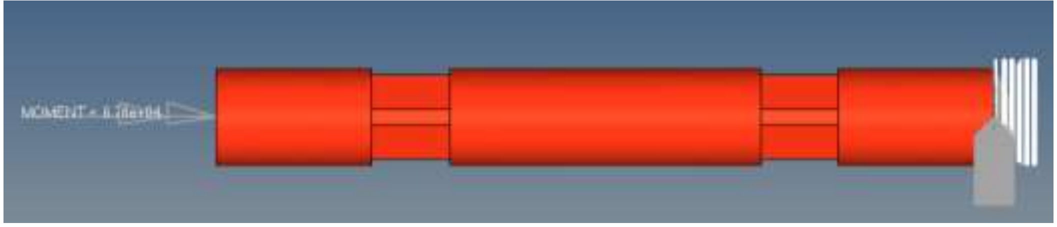

Fig. 5.9: 67790.9 N-mm rolling moment acting on the balance

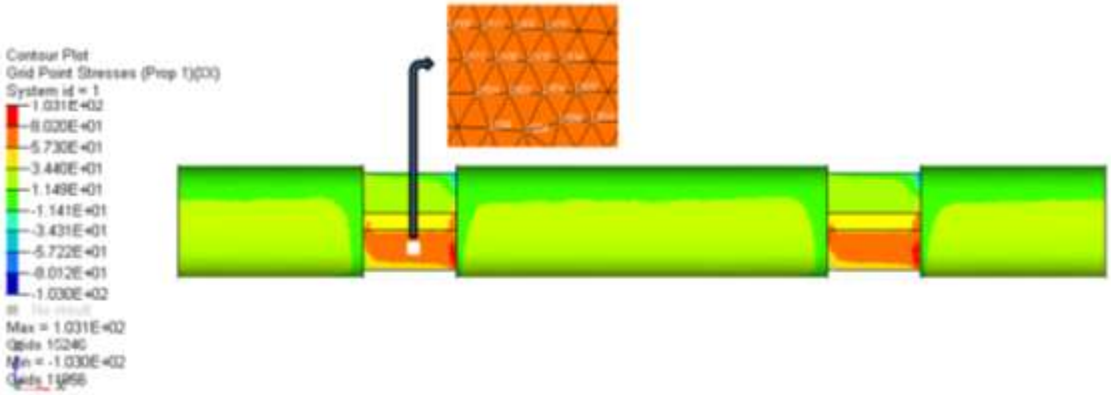

Fig. 5.10: Stress distribution on RM measurement location due to the 67790.9 N-mm rolling moment.

For the 1.5 case 67790.9 N-mm rolling moment acting on the balance and grid point stresses are collected within the area of RM location strain gauge and results are as follows stress =68 strain=2.52×10^{-4} voltage=0.65

B. CASE 2: All five loads acting at the same time on the balance

The figure5.11 shows the combined load acting on the balance and figure 17 shows the vonmises stress due to combined load. And grid point stresses are taken within the all strain gage area and average stresses are as follows
N1=268N/mm², N2=267N/mm², S1=272N/mm², S2=270N/mm², RM=79N/mm².

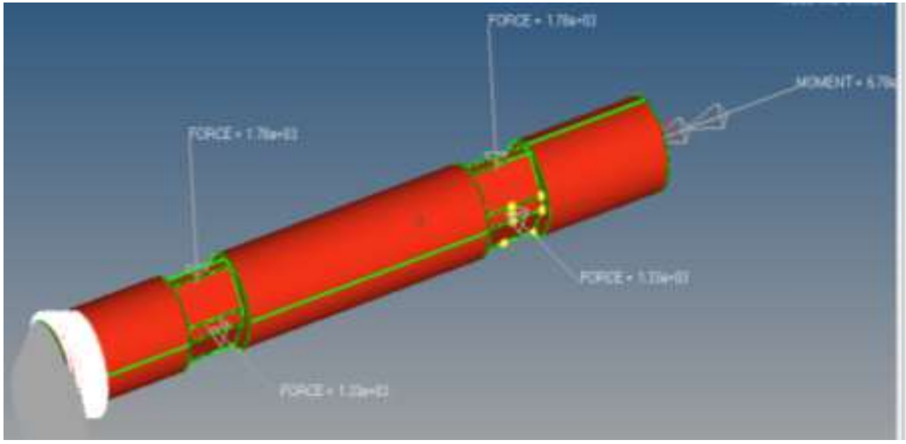

Fig. 5.11: Combined load or all the loads (N1+N2+S1+S2+RM) acting on the balance

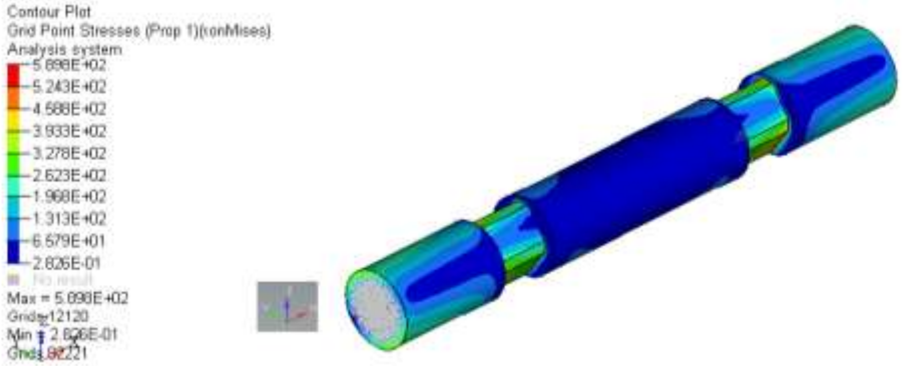

Fig. 5.12: Vonmises stress due the combined load on the balance

VI. RESULTS COMPARISON

Table - 7.1
Analytical results for octagon shape gauge section with 25mm diameter balance.

Force components	Analysis results		
	Stress (N/mm²)	Strain	Voltage (mV/V)
N1	257	12.2×10^{-4}	2.44
N2	255	12.14×10^{-4}	2.42
S1	263	12.52×10^{-4}	2.5
S2	263	12.52×10^{-4}	2.5
RM	68	3.2×10^{-4}	0.64

VII. CONCLUSIONS

The purpose this work is to design and analysis an integral five component wind tunnel strain gauge balance. Different heat condition and hardness has been studied. Optimized heat condition of 17-4PH material is = H900 it has Rockwell hardness=44 and has higher yield strength of 1365 N/mm² compared to H1025, H1075, H1150, H1150D, H1150D.

The basic objective was to get optimum Output Voltage and higher Factor of Safety for the given loads. In addition it was intended for less than 3 mV/V in other elements (N1, N2, S1, and S2) & close to 0.7 mV/V output in RM element. And minimum factor of safety is 2.

A good agreement between theoretical and FEM calculations were observed. The mesh element size for FEM was 0.8 mm.

VIII. SCOPE OF FUTURE WORK

- Analysis can be further extended for different diameter.
- Analysis can be further extended to different materials.
- Analysis can be further extended for different cross section.
- Component strain gauge balance.

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