Measurement of Aerodynamic forces using Strain gauge Transducers

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Abstract: *Aerodynamic profile is designed using Computational Fluid Dynamics software (CFD).It is mandatory to verify the results obtained from CFD studies with experimental measurements. Aerodynamic models designed for optimum lift force, drag force and pitching moments are verified using three component balance during experiment in wind tunnel. The project report highlights design procedure of a three component balance used for measurement in wind tunnel for studying the behaviour of aerodynamic models. In this project a scheme is prepared for measurement of lift force, drag force and pitching moment. The S type of load cells are manufactured and attached with the strain gauges at the middle of the load cell. These strain gauges are used to detect the strain on the load cell by placing an model on it. The detailed design work of the load cell and about its testing is highlighted in the project report.*

Keywords: *Balance, strain gauge, lift, drag, pitching moment, P3 type of strain indicator.*

1.INTRODUCTION

Aerodynamic research procedure makes use of wind tunnels. These wind tunnels are in shape of large tubes by which air is blowed into it and the object which is placed inside tends for tension and compression[6-7]. Here the object is placed exactly at the middle of the wind tunnel and tested by air blowing inside it. Air is made to move past the object by a power full fan or using a compressed air tank. Due to high velocity air flow, the aerodynamic model experiences loads normally designated as lift, drag and pitching moments. These loads need to be optimized for designing efficient models and finally a full scale prototype. Many of the aerodynamic performance measurement techniques are based on the aerofoil. This measurement can be done either externally or internally of a wind tunnel[6]. By this the forces are approached by using force balance to obtain lift, drag and pitching moments[1-2].

Itzar, University of Zagreb, had said about these three axis wind tunnel force balance that the loads are tested in the wind tunnel. These force transducers which are depending on the strain gauges are also called as spring element or the load members where the forces are being measured[6]. This spring

element after the deformation the strain is produced on the surface. Many of the transducer properties depend upon the selection of the material and the design. The actual strain gauge consists of a thin layered conductive strips arranged in a zigzag parallel lines on it and this gauge is bonded at particular points on a specific object which is used to bear loads on it. Like this for bonding the strain gauges on the object or mention here in this thesis as a load cell, the four strain gauges are used for locating the strain on it[5]. These gauges are affixed in the Wheatstone bridge circuit. The circuit is supplied with an application of energy and produced the voltage. This voltage results an output when the resistances in the circuit are different to one another. For example, let us assume a Wheatstone bridge circuit is connected with 4 resistors in which the excitation voltage is supplied, here opposite 2 resistors are connected in same manner . Therefore the output results when the circuit get balanced.

Depending on these force transducers a device normally known as wind tunnel is used for measuring the forces and the moments. There are four types of wind tunnels, but here we are going to discuss about the Wind tunnel balances and they are of two types. In one type known as internal balance the balance is fitted inside the model. In the second type these are mounted outside the model and hence are known as external balance.

It is a structural elastic device used for specific purpose to measure particular object which can be easily move through the air and load is applied on the model during the test[7]. Also, a wind tunnel balance supports the model in the test section. One of the balance main function is to resolve the total aerodynamic loads into a number of components (generally between three and six)[7]. Many types of wind tunnel balances are possible and each one is relevant to a certain set of conditions[5]. Design details of a Three-component external wind tunnel balance is presented in this project report. The load discern constituents are high accurate, strain gauged load cells with very good repeatability and linearity attributes.

Methodology of the project

The main focus of the project report is to derive the measurement of object in a wind Tunnel balance which is designed to measure the way air moves around the things and load component balancing in it. The report highlights that to describe the lift force and drag force and pitching moments of the air with moving objects in the replica in wind subway[1].The air current is generated on the model during the test. Also,it supports the representation in the test section. Mainly it is used for the aerodynamic research to study the effects of air moving past solid objects[7].

The model is placed on the platforms which is created in the wind tunnel and let the help of the supports the model is placed on it. This brings the contact between the model and the platform. The

location in the wind tunnel is selected at middle for the test section and is mounted the model, to which the load cell is to be placed to find out the three forces namely lift, drag and pitching moments[1].

2.Design Process of Balance

A load cell is a type of transducer which is used precisely for force transducer. The weight acts on a body and produces the electric signal which can be measured and make uniform. Also it is very crucial that a person who is operating will choose the right transducer and check its duration period of time. By this the process, the testing will be done easy and also requisite preservation will generate trouble free in loading an object. This sort of transducer will give highly accurate information by using strain gauges[6]. The transducers are important for entire measuring systems or machines, etc. These are available in different sizes, shapes and capacities[5]. These are designed so as to suit the application and are sensitive for the load to be measured.

As highlighted by various researchers transducers or load cells are best suited for measurements and these can be designed to optimize the performance. Most often accessible load cells are built on the proposition of change of resistance an act of responding to a application of force. These are made using strain gauges.

Strain gauge

Strain gauges are very crucial which can study the earth's physical structure and substances. They can measure strain in subways, aqueduct, masonry dams, underground cavities, etc. The main purpose of it is to incidentally ascertain stress and it varies with time and quantitatively. The resistance of strain gauge is differs with applied force and it transform variable such as pressure, rigidity, weight, etc. into a change in resistance that can be measured later on. some basic strain gauges be made up of an wrap flexible backing that supports a metallic frustrate design. It is joined to the object under stress utilizing an adhesive. The distortion in the object origin the counter to acquire pulled which eventually changes the electrical resistivity of the foil.

After study of various configurations the S shape of load cell is selected for assembling in the balance as shown in figure 01.This is since it provides ease of assembly, easy fabrication and strain gauge bonding, easy to calibrate. As per literature review it is decided to design load sensor for a maximum load of 100 N.

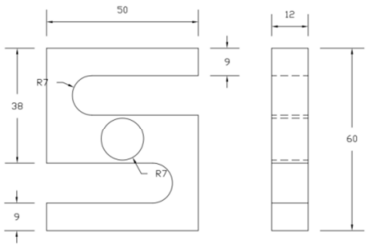

Figure 01. 2d model of transducer

In this report, the load cell has two holes, one is at the top of the surface and another is at the bottom of the surface from which tension and compression can be applied. In the middle of it, the strain gauges are fitted which measures the force applied and converts it into in an analogue or digital form. This type of load cells has one main advantage: the element causes bend due to application of force will every time make a positive and negative stress of the identical immensity. The same magnitudes of the stress make the appeal of complete Wheatstone bridge with two gauges in the tensile strain field and two in the compressive strain filed easier. This configuration gives a high output signal for a given strain level and, if the gauges are bonded close together, it minimizes thermal effects[5]. In the figure , the design of 3d model of a load cell done in the solid works software have been shown.

Material Selection

Here in this project we had used Aluminium type HE 30 material for making S type load cell. Mainly for manufacturing the load cells mostly steel and aluminium materials are used. HE 30 is aircraft quality aluminium with good mechanical properties. It is also readily available in the market.3D model prepared in Solid Works software for stress analysis is used for machining the load sensor. For this solid works part file is converted to STEP/STL file format in Solid Works software and given for machining. For machining CNC milling is used. After machining the part is inspected for dimensional accuracy, surface finish and once these are within limits, the sensor is fit for installation of strain Gauges.

3. SolidWorks

Solid works is an software which is used to design solid models in programs called CAD, CAE and are developed by Dassault System, France. In the worldwide, many of companies are using this software for designing purpose. It can make the best use of production of design and engineering assets to fabricate products of high quality, rapid, further cost-effective. In this report, this software is used to prepare the 3D model of the transducer for use in three component balance. Aluminium HE30

material is used for the load cell. The design and analysis and calibration of the transducer is done based on the design model.

Modeling and Analysis of Load cell Element

Solid Works 3D modeling software has been used to prepare 3D model of load cell element. This 3D model is used for analysis to check the sensitivity of load cell. Modeling is started by taking typical shape of S type load cell as shown in Fig. Standard modeling procedure is used to prepare 3 D model and is shown in Fig. below

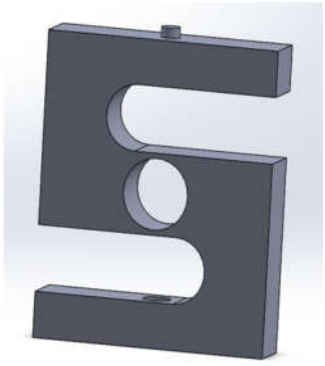

Figure 02. 3D model of a load cell element

Solid works software has analysis facility named solid works simulation using which load cell sensitivity can be checked. This module is started and step by step procedure as highlighted in the software is followed to carry out the analysis. Inputs as listed below are given as input for analysis

Material: HE 30

Fixed Geometry: Bottom of load cell is fixed

Load: 100 N on top surface of load sensor

Fixed Geometry: Bottom surface of load sensor is fixed.

Meshing: Standard 3D mesh is generated by meshing command.

Analysis: Run command starts analysis for above conditions and structural analysis is done

Stress and Strain distribution

Finite element mesh is shown in Figure below. As seen the model has solid mesh with 19545 elements (30479 nodes). Mesh is with high quality with size about 2 mm and with optimum aspect ratio.

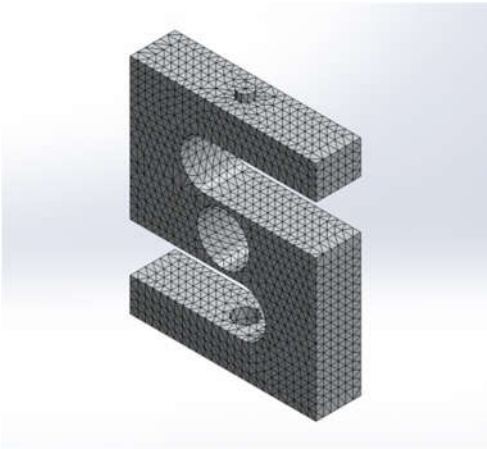

Figure 03. Finite mesh element of a Load Cell

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	2.01953 mm
Tolerance	0.100977 mm
Mesh Quality Plot	High

Mesh information - Details

Total Nodes	30479
Total Elements	19545
Maximum Aspect Ratio	3.6474
% of elements with Aspect Ratio < 3	99.8
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh:mm:ss):	00:00:01
Computer name:	

Figure 04. net information and mesh details of s type load cell

Here the above figure shows the solid type mesh is selected and standard mesh is used with 2.01953mm of element size and is tolerance is of 0.100977mm. The total no. of nodes obtain are 30479 with 19545 elements. Here in the figure below it is shown that how the loads are applied on the load cell and the fixed boundary conditions to it.

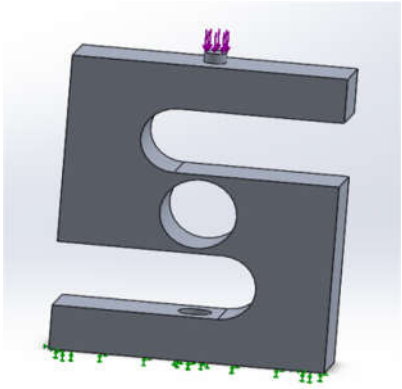

Figure 05: Applied force and Boundary Conditions

After applying the loads the analysis is done in the software and now the stress and strain distributions are given in the figures below. The strain acts more on the middle part of the load cell as it contains hole in the middle. After specifying the stress and strain distributions of the load cells the strain gauge locations are identified and are shown in figure 08. It works on the concept of Wheatstone bridge configuration. Hence, strain gauges had been installed in the load cell and calibrated by the load application on it.

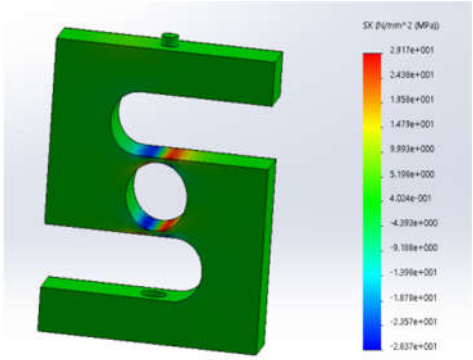

Figure 06. Stress distribution

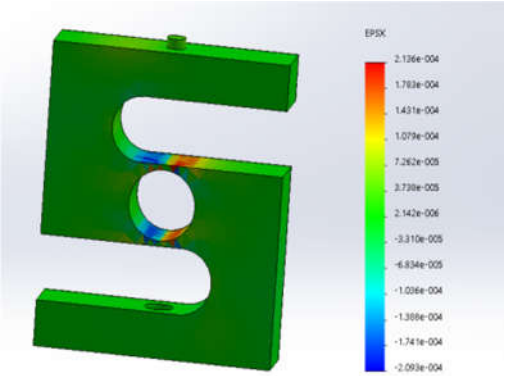

Figure 07. Strain distribution

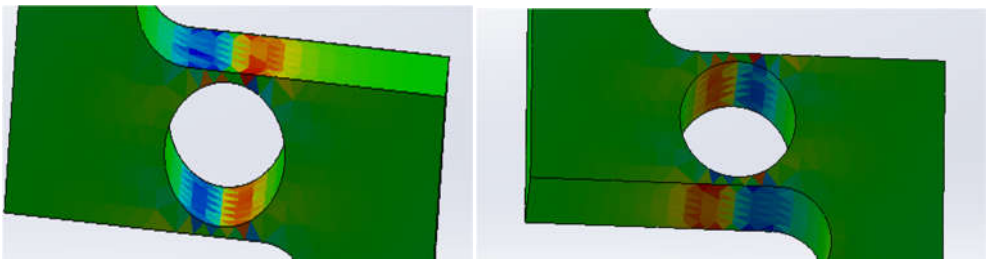

Figure 08. Strain gauge locations

Calibration of Load Sensor

Load sensors are calibrated by connecting to strain measuring instruments and calibration curve showing variation of strain with respect to load is obtained.For this purpose a strain indicator and a loading system is needed. Loading the sensor with dead weight loads in steps of 10 Newton was used for calibration.Load sensor is assembled on a bracket. Steel wires are used to hang the load cell and a loading pan is assembled in the bottom of the load cell. Load Sensor wires are connected to one channel of the strain indicator. The complete arrangement is shown in fig. down.

Figure 09. Calibration setup

Table and Result obtained

After connecting load sensor to strain indicator, instrument is initialized and a weight of 10 Newton is placed on the loading pan. Strain indicator display is noted down and this correspond to load sensor response for 10 Newton's. Above step is repeated up to 150N load in steps of 10 Newton and strain values are noted at each step. Tabulated results are plotted and given in the figure down gives these results along with the calibration curve. Therefore it is proved that the load cell can calibrate better sensitivity and will produce good accuracy of the result.

LOAD CELL CALIBRATION

Sl. No.	Load in N	Strain x10^{-6}
1	0	0
2	10	63
3	20	125
4	30	187
5	40	248
6	50	312
7	60	376
8	70	438
9	80	503
10	90	561
11	100	627
12	110	688
13	120	748
14	130	816
15	140	870
16	150	935

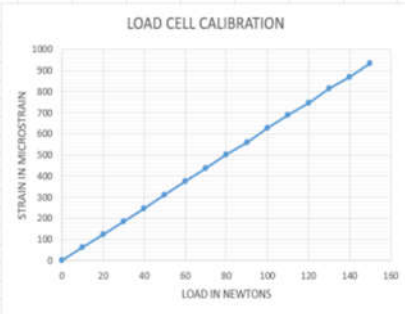

Figure 10. Calibration curve for sensor

Table 01. Typical Measurement and interpretation of Result

Typical Measurement Results					
Sl No	Load Sensor No.	Quantity Measured	Measured Micro Strain	Load = Strain/6.23	Turning moment Avg Force x 0.2 m
1	1	Lift	456	73.2 N	
2	2	drag	-230	36.92 N	
3	3	Turning Moment	110	17.66 N	3.45 N-m
4	4	Turning Moment	-105	16.85 N	

Conclusion and Future Work

From the design, it is clearly known that the load cell is designed and manufactured according to the analysis of the product. In this S shape of load cells the strain gauges are placed in the middle part and these strain gauges will help in measuring the strain in it. After placing the object or model on transducer, it will be tested by application of forces and moments. Hence, strains are noted according to the load application. This strain values have been calculated by the sensitivity of the strain per Newton. Hence it is proved that the s type of load cell will produce high sensitivity of strain on the load cell by the strain gauge measurement system. This type of load cells are used for different measuring purpose for better accuracy. Here in the project it can be concluded that the load sensor designed for the purpose of measuring three component of force namely lift, drag and turning moment has good sensitivity and it can be used for measurement in wind tunnel.

By this type of load cells their will be many uses for testing purposes and analysis, sensor manufacturing, and are used for the crack propagation, etc. At every where in our daily life these are used as to fulfill our daily need like it can detector to find out many things and locate the stress and strains and these will utilize like an daily requirement in our life.

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