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Experimental Stress Analysis of Hip Joint Implant for Fracture Analysis

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Abstract : *Hip Joint is one of the important body parts of the human body, which transmits the body forces to the legs. Different materials like stainless steel, zirconium and titanium are used in the design of hip joint. Still the perfect material on basis of strength, cost and weight are not specified. Literature survey and expert opinion in this field state that, it is very difficult to give the exact design of implant and investigate the selection of materials, shapes, effect of vibration, and prediction of failure of implant. Hip fracture is a major cause for disability in human being. Hip fractures are almost always treated with surgery by implantation. Implants are of various types accounting for the many variations in hip fractures. The design of the hip prosthesis has been modified continuously to meet the requirement of the patient with recent development in Biomedical engineering technology. Many new approaches have been defined for analysis of hip joint with better material design and cost. Existing implants are not custom made for Indian anatomical specifications and hence leads to complications in surgery. Also, choice of implant from available is a subject of debate. This proves the need for implant optimization. Use of Stainless steel as implant material for Hip joint restricted due to common problem of corrosion in service life of the stainless steel hip joint implant. So there is need to find the alternative for the material of implant which helps to increase biocompatibility of implant.*

Keywords - *Hip joint, finite element method (FEM), NI Lab-view, Ansys 14, Arduinouno.*

I. INTRODUCTION

Hip Joint: The hip joint is a true ball and socket joint surrounded by powerful and well balanced muscles, enabling a wide range of motion in several physical planes. As the structural link between the lower extremities and the axial skeleton, the hips not only transmit forces from the ground up but also carry forces from the trunk, head and neck, and upper extremities. The hip is a classical ball and socket joint. It meets the four characteristics of a synovial or diarthrodial joint it has a joint cavity; joint surfaces are covered with articular cartilage; it has a synovial membrane producing synovial fluid, and; it is surrounded by a ligamentous capsule. For ease of approach we have considered the relevant anatomy under the headings 'Body anatomy', 'Ligaments and capsular anatomy', 'Neurovascular anatomy' and 'Muscular anatomy'.

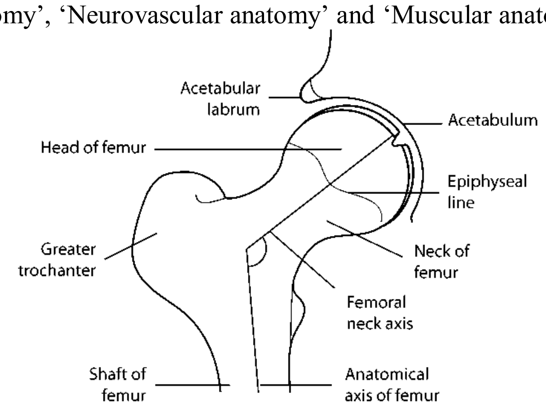

Fig.1: Cross-sectional view of the normal hip joint

Fig. 1 illustrates that the femoral head is covered with a corresponding articular cartilage beyond the reaches of the acetabular brim to accommodate the full range of motion. The covered region forms approximately 60 to 70% of a sphere. There is an uncovered area on the central area of the femoral head – the fovea capitis – for the femoral insertion of the ligamentumteres. The ligamentumteres, while containing a blood supply does not contribute to the stability of the joint. It is covered in synovium, so while it is intra-articular it is actually extra-synovial.

Biomechanics of the Hip joint: The importance of the normal hip joint is emphasized by the role this joint plays in movement and weight bearing. An understanding of the biomechanics of the hip is vital to advancing the diagnosis and treatment of many pathologic conditions. Some areas that have benefited from advances in hip biomechanics include the evaluation of joint function, the development of therapeutic programs for treatment of joint problems, procedures for planning reconstructive surgeries and the design and development of total hip prostheses. Biomechanical principles also provide a valuable perspective to our understanding of the mechanism of injury.

II. LITERATURE REVIEW

A R Shinge, et al. [1] came to the statement that SMP is a modular partial hip replacement prosthesis used for management of intra capsular neck femur fractures. Sancheti Modular Prosthesis (SMP) is the hip joint developed at SIOR (Sancheti Institute of Orthopedic Research) has been made for the patients with the fracture of the neck of femur requiring Partial Hip Replacement. Modularity is between femoral head and stem which gives better fit in femur and prevents problems due to loosening and reduces failure rates. Material used in SMP is stainless steel 316 L for stem and same material i.e. stainless steel 316 L for head. In present study, steel ball is replaced by Ultra High Molecular Weight Poly-Ethylene (UHMWPE) ball. F. Burny, et al. [2] showed the medical relevance of the monitoring of the deformation of implants as a powerful tool to evaluate nursing and rehabilitation exercises, for tracing dangerous overloads and anticipating implant failure and also to observe the healing process. This study focuses on the instrumentation of femoral implants with on board sensors. Ganapathi, et.al [3] presents the design and analysis of a hip implant using Finite element analysis. Fracture conditions are determined and the optimal design of the implant is obtained for improving healthcare and patient safety. Anthropometric parameters of the human femur bone are collected from a particular age group. These are then used to obtain a CAD model of the bone using CATIA. The Charnley implant has 4 major parts the ace tabular cup made up of stainless steel 316L, the ace tabular liner made up of Ultra High Molecular Weight Polyethylene (UHMWPE) that lubricates the joint and the femoral part with head, neck and tail portions which is also made up of stainless steel 316L. Optimization is done by varying the parameters like base cross-section, biomaterials and geometrical dimensions. Yegireddi Shireesha, et al. [4] in this particular work analysis is done on different materials like structural steel, and Ti-6Al-4V implant materials. Each femur carries ½ the body weight, analysis is done for 550kg, 650kg, 750kg load, including the cases of patient carrying certain weight. Based on the analysis it can be concluded that while comparing these two materials Ti-6Al-4V gave less deformation on static loading conditions. Ti-6Al-4V is a low density material, which has excellent biocompatible and mechanical properties, it is ideal for the use of an implant in surgeries. Success of implantation depends upon implant material and size, implantation method and its handling by the patient.

S Singh, A.P. Harsha et al. [5] stated as Titanium alloy (Ti6Al4V), when used as a material for femoral stem, recorded large displacement as compared to Chromium alloy (CoCrMo) stems. This large displacement in case of Ti6Al4V caused the stem to bend inside the cement mantle, thus destroying it. Thus, CoCrMo proved to be a better choice of material for stem, in cemented THA. Comparison between trapezium and circular cross section showed that, femoral stem with trapezium cross section underwent lesser amount of sliding and debonding, at both interfaces, as compared to circular cross section. In present study, analysis was carried out with femoral head diameter of 28 mm, 32mm and 36 mm. Implants with circular and trapezium cross sectional stems were considered and stress distribution was analyzed at interfaces and femoral components. Damien P. Byrne, Kevin J. Mulhall [10] has provided a concise review of the anatomical and biomechanical basics of the hip for the patient, clinician, physiotherapist and engineer. The approach to learning and understanding hip anatomy can be undertaken in a number of ways as can the biomechanics. Understanding of the forces. Bubesh Kumar and Dr. K.G. Muthurajan [6] concluded that hip prosthesis should have less stress in the neck area. Therefore, the new design of hip prosthesis must take these conditions in consideration for good clinical result and the decrease in the implant damage. Maximum Equivalent von Mises stresses developed in the neck of the hip prosthesis and maximum total deformation in the implant for static condition were analysed. The design of the implants should have stress distribution similar to the bone of the patient. Shantanu Singha, A.P. Harshaa [7] stated that Finite element analysis results showed that femoral stem with trapezium cross-section was better than stem with circular cross-section. Trapezoidal stem resulted in lower interfacial micro movements, and developed lower peak stresses in different femoral components. It was observed that CoCrMo was the preferred material for cemented THA. In future Fatigue loading can also be taken into account and dynamic analysis could be performed over whole gait cycle of walking. Moreover, due to computational limitations, different materials used in the present study, which are actually anisotropic, have been assumed to be isotropic in nature. Long term clinical follow up of patients having THA with large femur head diameter should be done to; ascertain the effect of large femur head on dislocation. For a more optimized design a combination of different cross sections needs to be studied which may more likely result into better stress distribution.

Roger H. [8] Emerson observed that Cement less titanium femoral fixation shows none of the liabilities of cemented titanium fixation, which puts excessive stresses into the cement mantle, leading to debonding and cracks in the cement mantle and premature failure. We no longer use this titanium stem. Since 1992, the same stem became available in chrome-cobalt alloy. The conclusions about cemented titanium stems presented in this article are not relevant to cemented chrome-cobalt stems. Cementless titanium fixation with a circumferential coating seals the endosteal bone from joint particles, and the same flexibility that damages the cement mantle promotes uniform bone ingrowth. The results of the cementless series reported here, added to other reports in the literature of similar titanium cementless stems, show that these components are especially resistant to osteolysis and have a low rate of mechanical loosening. We continue to use this cementless stem for primary THA.

III. PROBLEM FORMULATION AND MOTIVATION

Existing implants are not custom made for Indian anatomical specifications and hence cause complications in surgery. Also choice of implant is a subject of debate. This proves the need for implant optimization. Stainless steel is being used widely as a traditional material for artificial hip joint implant. But biocompatibility of the stainless steel hip joint implant is less than other traditional alloy. Hence in this paper an attempt is plan to find the alternative for the material of implant and to increase the strength and stiffness of zirconium and titanium used in the design of hip joint.

IV. NUMERICAL STRESS ANALYSIS OF HIP JOINT:

For numerical stress analysis of hip joint, we considered three different angular positions of Implant that is 0, 40 & 90 degrees. It is done using FEA analysis software ANSYS for Stainless Steel hip Implant. We had used the axis symmetry property of model in order to reduce the number of nodes and elements. As the number of elements is reduced meshing and analysis time also reduces. In analysis we had used coupled field analysis method in order to give two boundary conditions. Figures of model, meshing, boundary conditions and von-Mises stresses for different angles and different materials are shown below.

Modeling of Hip Joint for analytical modal analysis: The Hip Joint stainless steel material is selected for study. Figure 3 shows the model of Hip Joint. Modeling of Hip Joint for analytical modal analysis is done by using CATIA Software. Standard dimensions are taken from the manufacturer's catalogue viz., Ball diameter, Neck length, Neck diameter, Femur length, width of the femur, etc.

Figure 2: 3D modeling using CATIA

Table 1: Material Properties of stainless steel

Density	7860 kg/mm^3
Poison's Ratio	0.3
Young's Modulus	20000 N/mm^2

Finite Element Analysis: The geometry is meshed in mechanical model window of an ANSYS 14. The hex dominant method is applied for the geometry. This method is used for applying maximum hexahedron elements to complicated geometry. The body sizing is applied for the whole geometry and element size is given as 5 mm. The FE model of the hip joint geometry is meshed with hexahedral elements, with the global element length of 5 mm and local element length of 0.342 mm.

Numerical Stress analysis of Stainless Steel hip Implant at 0^0, 40^0 and 90^0 positions:
For the position of 0^0:

Static stress analysis is carried out for the finding out total deformation, maximum von mises stresses and the values of stresses at seven various locations for the three positions viz., 0 degrees, 40 degrees and 90 degrees' positions. Figure 3(a), Figure 4(a), Figure 5(a) shows the total deformation for three positions 0˚, 40˚ and 90˚. Furthermore, Figure 3(b), Figure 4(b), Figure 5(b) shows the maximum von mises stresses for three positions 0˚, 40˚ and 90˚. While Figure 3(c), Figure 4(c), Figure 5(c), Figure 3(d), Figure 4(d), Figure 5(d) indicates the values of stresses at 7 various locations.

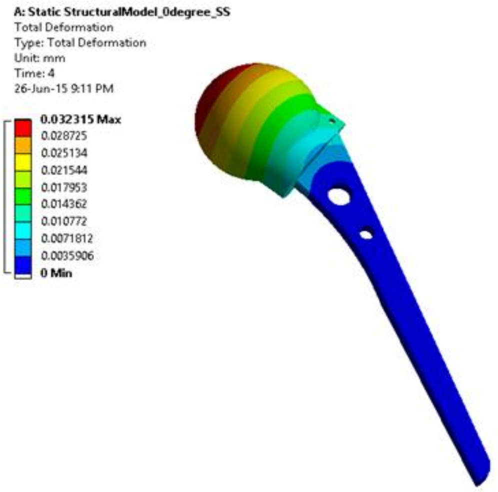

Figure 3(a): Total Deformation at the position of zero degree for Stainless steel

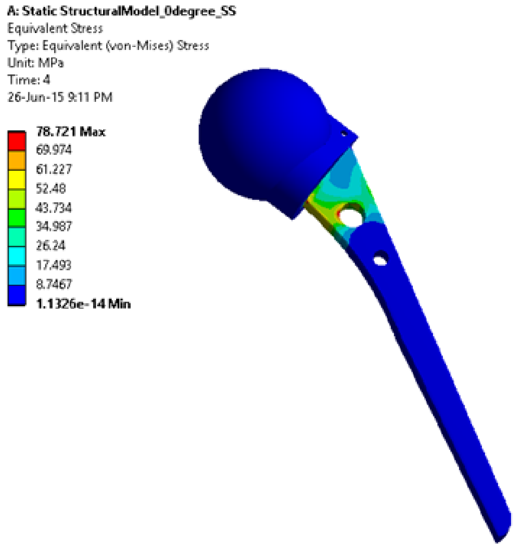

Figure 3 (b): Von mises Stress result of Steel hip joint at zero degree position.

Figure 3(a) illustrates the total deformation of the stainless steel hip joint geometry under the maximum loading of 200kg. The position of Hip joint is taken at an angle of 0 degree. Various colors like blue green yellow and red indicates the different levels of deformations.

Figure 3(b) elaborates the Equivalent Von Mises stress acting on the hip joint geometry modeled in the Catia. It is very clear that the maximum stress is acting on the portion of big hole indicating the red color. The red color indicates the maximum induced stress.

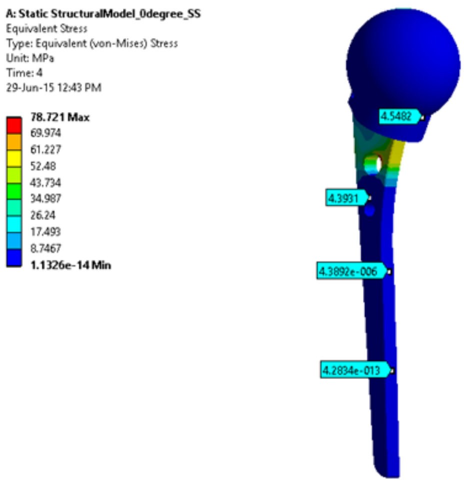

Figure 3 (c): Von mises stresses at different strain gauge locations (1, 2, 5, and 7).

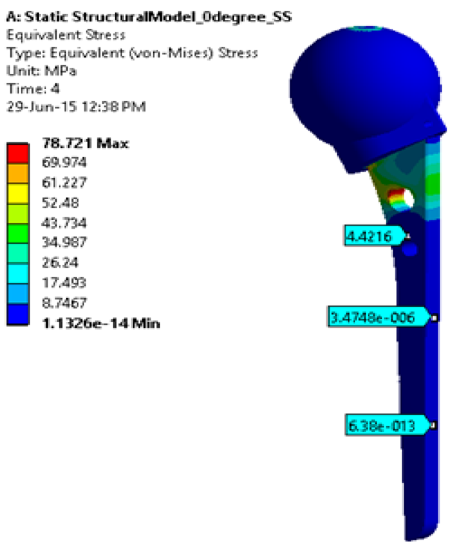

Figure 3(d): Von mises stresses at different strain gauge locations (3, 4, 6)

Figure 3(c) shows that the stresses acting at different locations of the various parts of the hip joint implant like the ball, neck and the stem. These values are taken as reference for the experimentation trial of static on hip joint implant. Figure is showing the values of stresses at the position 1, position 2, position 5 and position 7.

We have decided seven locations for finding the stresses. Since all seven locations are not visible in one view the separate image is taken for showing the values of stresses at another 4 locations viz., position 3, position 4 and position 6.

For the Position of 40 degrees

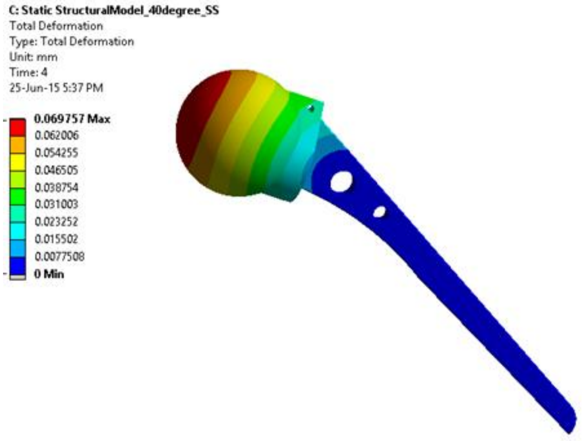

Figure 5(a): Total Deformation at Position of 40 degrees

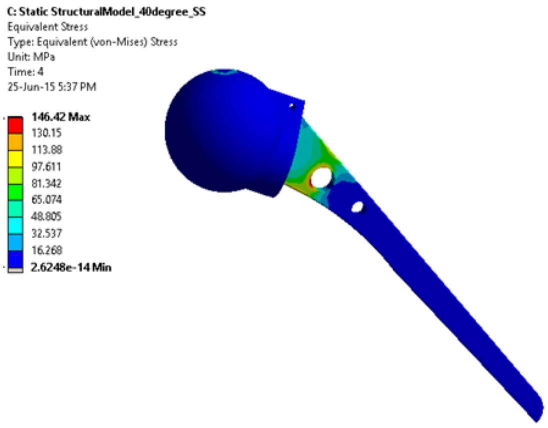

Figure 5(b): Von mises Stress result of Steel hip joint at forty degree position

Figure 5(a) illustrates the total deformation of the stainless steel hip joint geometry under the maximum loading of 200kg. The position of Hip joint is taken at an angle of 40 degree. Various colors like blue green yellow and red indicates the different levels of deformations

Figure 5(b) elaborates the Equivalent Von Mises stress acting on the hip joint geometry created in the Catia. It is very clear that the maximum stress is acting on the portion of big hole indicating the red color. The red color indicates the maximum induced stress.

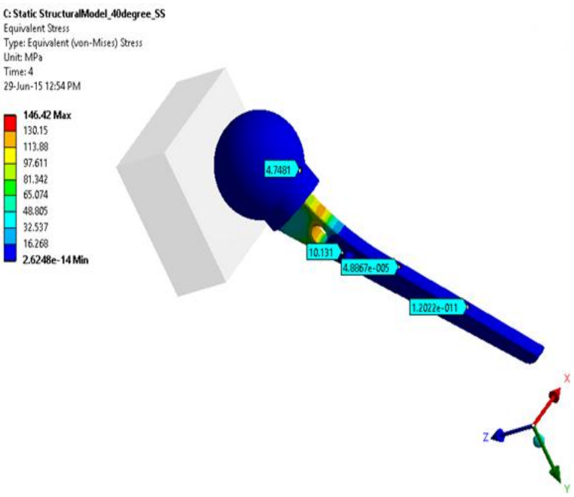

Figure 5(c): Von mises stresses at different strain gauge locations (1, 2, 5, and 7)

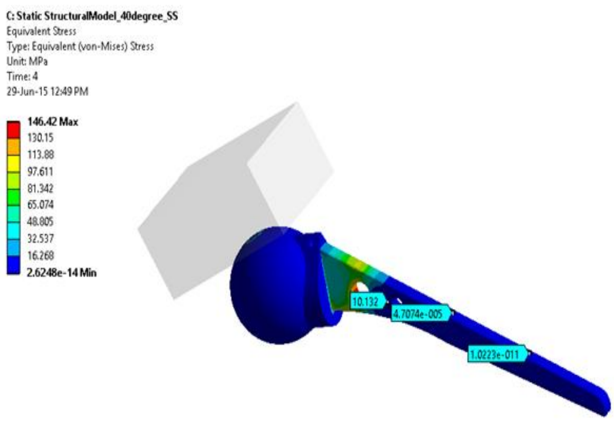

Figure 5(d): Von mises stresses at different strain gauge locations (3, 4, 6)

For the Position of 90 degrees:

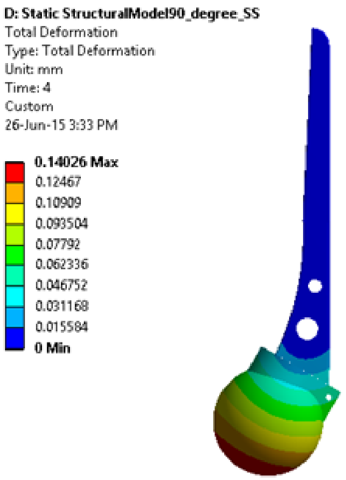

Figure 6(a): Total Deformation at Position of 90 degrees

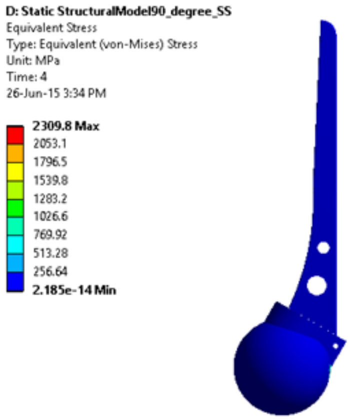

Figure 6(b): Von mises stresses at Position of 90 degrees

Figure 6(a) illustrates the total deformation of the stainless steel hip joint geometry under the maximum loading of 200kg. The position of Hip joint is taken at an angle of 90 degree. Various colors like blue green yellow and red indicates the different levels of deformations

Figure 6(b) elaborates the Equivalent Von Mises stress acting on the hip joint geometry created in the CATIA. It is very clear that the maximum stress is acting on the portion of big hole indicating the red color. The red color indicates the maximum induced stress.

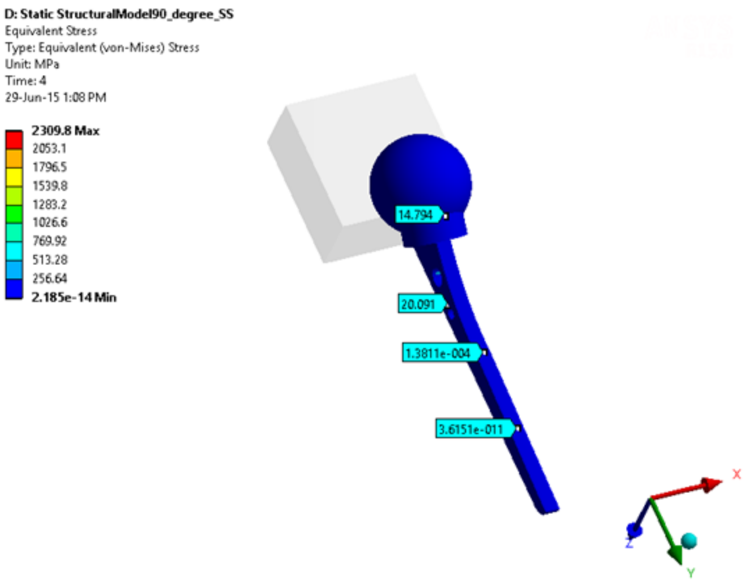

Figure 5(c): Von mises stresses at different strain gauge locations (1, 2, 5, and 7)

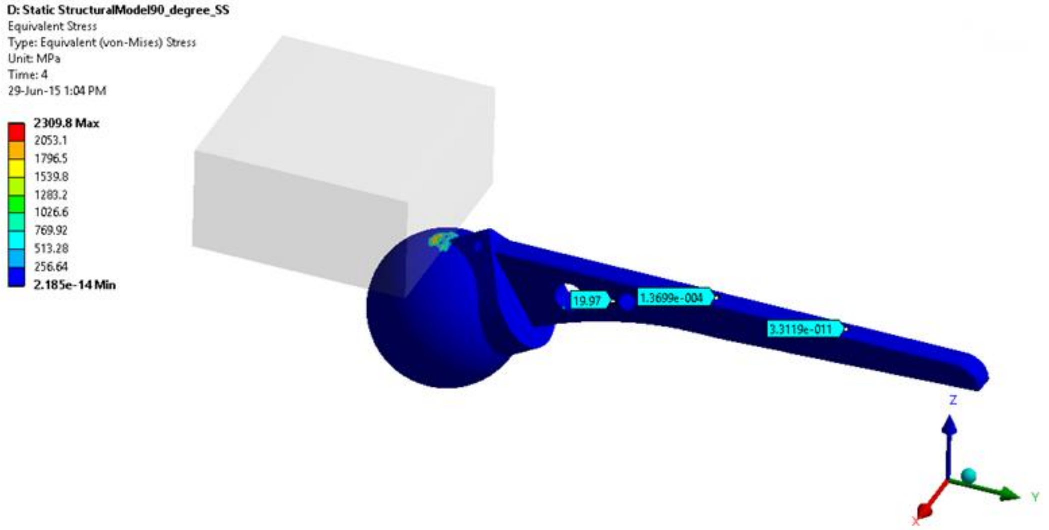

Figure 5(d): Von mises stresses at different strain gauge locations (3, 4, 6)

V. EXPERIMENTAL STRESS ANALYSIS

Experimental setup consists of Hip joint, C clamp Load cell circuitry, strain gauges and NI Data Acquisition System. C clamp is used to give boundary condition that is static loading and NI Data Acquisition System is used to capture the data that is strain and stress with the help of strain gauges. Figure 13 show the schematic diagram of experimental setup. Experiment was performed at MES College of Engineering Pune, NI Lab view Academy facility.

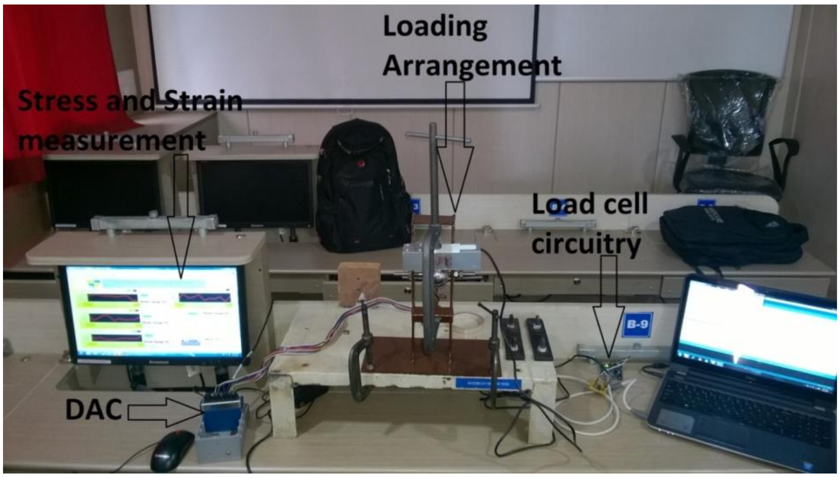

Figure 6: Experimental Setup for static stress analysis

Figure 6 illustrates the complete setup of the static loading and static stress analysis. It mainly comprises of the highlighted components of the experimentation. The experimentation set up mainly has two separate arrangements. One of them comprises of loading arrangement and another one comprising of the stress measurement. Loading arrangement has load cell arduino board circuitry connected to one computer system in which the coding for arduino is executed and which gives the value of loading in terms of kilograms continuously till the load is removed. And second arrangement has the strain gauges mounted on the hip joint implant; the Data acquisition system and the computer monitor which will give the values of stresses acted at different locations where the strain gauges are mounted.

VI. INSTRUMENTATION & HARDWARE IMPLEMENTATION:

Strain **Gauge:** Strain gauges are mounted on the Implant at 7 various locations for measuring the deformations for experimentation. And the table 2 shows the specification of strain gauges.

Table 2: Specification of strain gauges

Description	Values
Gauge Length (mm)	6.35
Overall Length (mm)	9.53
Grid Width (mm)	3.18
Overall Width (mm)	3.18
Gauge Factor	2.05
Resistance (Ω)	350

NI 9219 Module: The module is used to capture and process the data from the strain gauges and transfer the data to DAQ. Table 3 shows the specification of NI 9219 Module. Specifications of the same are stated in table 3.

Table 3: Specification of NI 9219 Module

Parameter	Description
Number of channels	4 analog input channels
ADC resolution	24 bits
Type of ADC	Delta-sigma (with analog pre –filtering)
Sampling mode	Simultaneous
Type of TEDS supported	IEEE 1451.4 TEDS Class II (Interface)

NI cDAQ-9171: It is used to capture data from the module and transfer it to program in computer. Table 4 shows the specification for the NI cDAQ-9171. Specifications of the same are stated in table 4.

Table 4: Specification of NI cDAQ-9171

Parameter	Description
Input FIFO size	127 samples
Maximum sample rate	Determined by the C Series I/O module
Timing accuracy	50ppm of sample rate
Timing resolution	12.5ns
Number of channels supported	Determined by the C Series I/O module

VII. PROGRAMMING IN LAB VIEW SOFTWARE:

A program was written in the Lab view software in order to get the values of stress and strain with the help of Data Acquisition System and strain gauges which is as shown in figure 7.

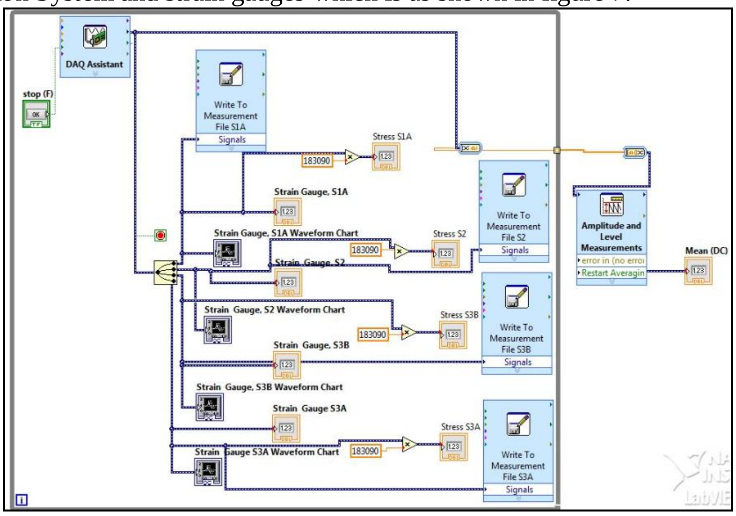

Figure 7: Programming in Lab View Software

Loading Arrangement: Following are the components used in loading arrangement.

1. C-Clamp
2. Load Cell
3. Arduino Board
4. Resistor

5. IC- INA 125P
6. Printer Cable

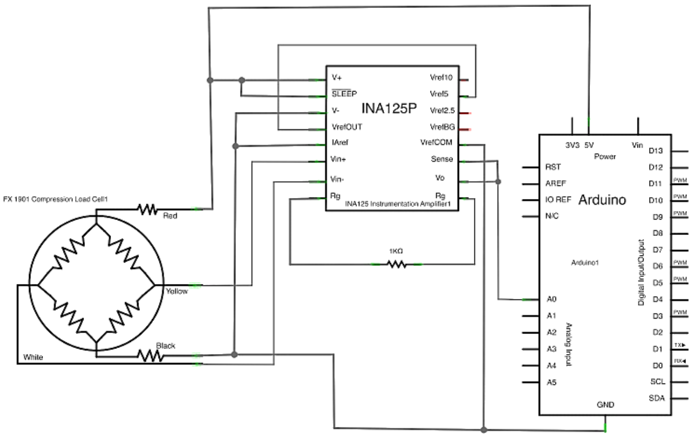

Figure 8: Circuit Diagram for Loading

Figure 8 shown above illustrates the circuit diagram for loading. It comprises of load cell, IC INA 125, Resistor and Arduino Board. Load cell is placed in between the movable jaw of the C- clamp and the hip joint. Loading is given by tightening the C- clamp gradually. The output signal of the load cell is very week to measure. So for the purpose of signal conditioning here signal amplification the IC INA 125 is incorporated. The output signal of the IC INA 125 is given to the microcontroller Arduinouno. Using the code generated in C language the loading is measured in terms of kilograms directly.

Arduino board is an open source computer hardware and software company, project and user community that designs and manufactures kits for building digital devices and interactive objects that can sense and control the physical world. Arduino boards may be purchased preassembled, or as do it yourself kitsat the same time, the hardware design information is available for those who would like to assemble an Arduino from scratch. Table 5 shows the Specification of Arduino Board.

Table 5: Specification of Arduino Board

Microcontroller	**ATmega328**
Operating Voltage	5V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6 – 20 V
Digital input pins	14
Analogue input pins	6
DC current per Input pin	40mA
Flash memory	32 KB
SRAM	2 KB
Clock speed	16 m Hz

VIII. RESULTS OF LAB VIEW

The test on hip joint implant was taken in order to measure the stresses at different locations and validate the results. Here, in this work we have taken trial of static loading on Stainless steel implant for various three positions. The predicted cost for the trial on Titanium and Zirconium material for Hip Joint Implant was too high; because of this high cost constraint we have taken the static loading trial on the stainless steel implant only. The trail was conducted at three different positions that are 0, 40, 90 degrees. Figure 21, 22, 23, 24, 25 and 26 shows the value of different stresses at three different positions in Lab view software.

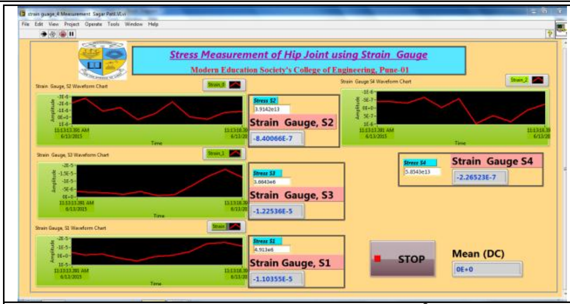

Figure 8: Value of the stress at 0^0 position

Figure 8: Value of the stress at 0^0 position

Figure 9: Value of the stress at 40^0 position

Figure 9: Value of the stress at 40^0 position

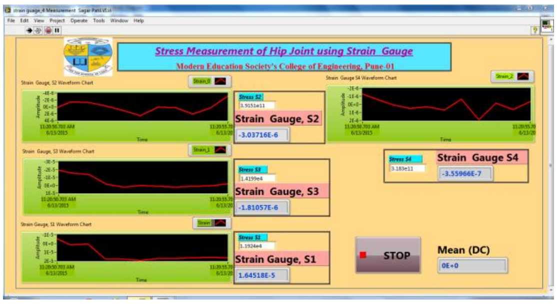

Figure 10: Value of the stress at 90^0 position

Figure 10: Value of the stress at 90^0 position

The above figures illustrate the screen shots of the monitor at the time of loading and the values of respective stresses and strains developed in the strain gauges. Since we can connect the maximum four strain gauges at a time to the data acquisition system, we have repeated the test cycle two times for each position of 0^0, 40^0 and 90^0.

IX. Comparison of Analytical and Experimental Results

Comparison of Analytical and Experimental Results: Table 6, and 8 shows the comparison of analytical and experimental results for different stresses at different positions.

For 0 □ position:

Table 6: Comparison of results for 0˚ Position

For 0^0 Position		
Stresses	**Experimental**	**FEA**
S1	4.913	4.3892
S2	3.9142	4.2834
S3	3.6643	3.4748
S4	5.8543	6.38
S5	4.4341	4.3931
S6	5.187	4.4216
S7	4.882	4.5482

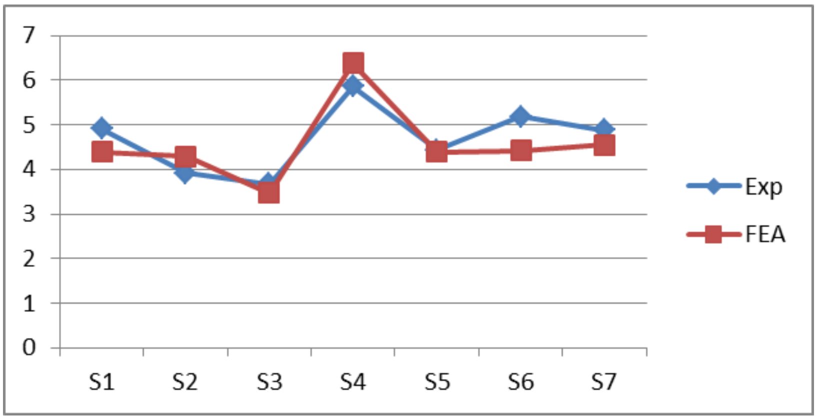

Figure 11: Comparison of stress values for 0˚ position

For 40 ⎕ position:

Table 7: Comparison of results for 40˚ Position

For 40^0 Position		
Stresses	**Experimental**	**FEA**
S1	5.6318	4.8867
S2	1.5834	1.2022
S3	4.3035	4.7074
S4	0.9891	1.0223
S5	11.615	10.131
S6	9.899	10.132
S7	5.128	4.7481

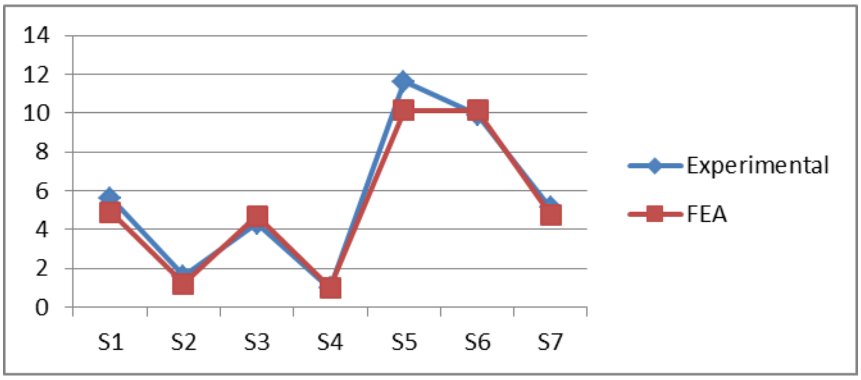

Figure 12: Comparison of stress values for 40˚ position

For 90 ⎕ position:

Table 8: Comparison of results for 90˚ Position

For 90^0 Position		
Stresses	**Experimental**	**FEA**
S1	1.1924	1.3811
S2	3.9151	3.6151
S3	1.4199	1.3699
S4	3.183	3.3119
S5	20.29	20.091
S6	17.85	19.97
S7	15.98	14.794

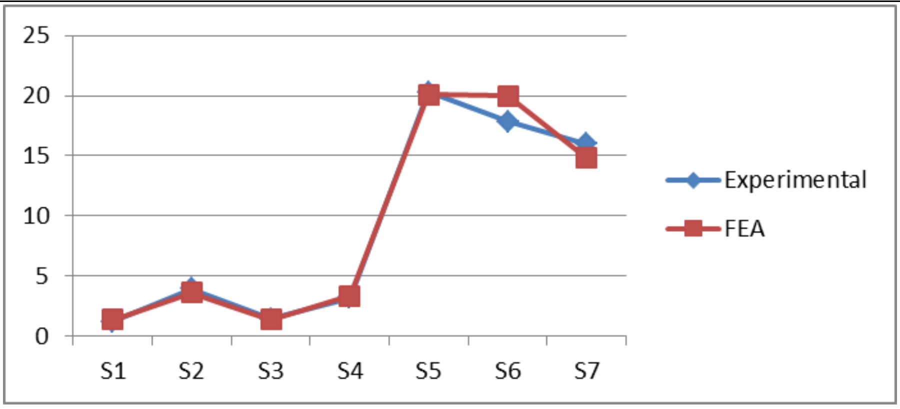

Figure 13: Comparison of stress values for 90˚ position

X. CONCLUSION

Static analysis of the stainless steel hip joint is performed. The numerical static analysis is done using the *ANSYS 14* version. To overcome computational difficulties, the material which is anisotropic, have been assumed to be isotropic. In order to validate the findings required numerical analysis is also done by using *ANSYS* workbench tool and by performing extensive experimentation using data acquisition system. After comparing results of modal analysis as well as static stress analysis it was found that all results are in close agreement. Method can be used for other materials like Titanium, zirconium, Cobalt-chrome which is traditional alloys for hip joint.

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