iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: V Month of publication: May 2018

DOI: http://doi.org/10.22214/ijraset.2018.5405

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue V, May 2018- Available at www.ijraset.com

Effect of different Load Conditions on Artificial Hip Implant using FEM and Taguchi Method

Syed Junaid Ali[1], Prof. (Dr.) Manish Bhargava[2], Mandeep Singh[3]
[1]M. Tech scholar MAIET, (Rajasthan) Jaipur Principal MAIET, Jaipur (Rajasthan)
[2]Assist. Prof. MAIET, (Rajasthan) Jaipur
[3]Mechanical Engineering Department, MAIET, Jaipur (Rajasthan)

Abstract: In present paper artificial implant for hip arthroplasty is simulated using Ansys FEM software via design of experiment technique "Taguchi method". In present work three different factors are selected for simulation. All required experiments are generated using Taguchi mixed method, so each factor required finite levels. First factors is different type of load conditions which are come in due to different movement conditions, this factor has six levels. Second factor is change in design of hip implant, it has three levels and last factor is different type of materials used for manufacturing of hip implant. This factor has also three levels. In this research study mixed array is developed and total 18 experiments are considered. Signal to noise ratio analysis is performed for this study to find optimum factor and its rank. It is found out that forces act as most important factor. Force can fail hip implant. Material is another importance factor.
Keywords: hip implant, ANSYS, taguchi method, Von misses stress, S/N ratio analysis

I. INTRODUCTION

The hip is a synovial joint and is one of two joints which are ball-and-socket joints in the body. The other joint is the shoulder joint and both are fit for different complex movements [1]. In the hip, the femur head fits in the hip bone socket where articular ligament covers the two surfaces. Synovial joints have joint depression where space is loaded with synovial liquid for grease, which brings about low grinding between the bones and for more prominent versatility (figure a,b). The joint is then secured with a capsule with three ligaments which assume a major part for soundness; iliofemoral, pubofemoral and ischiofemoral. Also, there are two different ligaments in the hip joint; ligamentum teres and zona orbicularis. The femur is in the classification of long bones and it is the most grounded and longest bone in the human body. The femur is fundamentally a barrel shaped shaft, yet in the proximal end it has a femoral neck and head (figure 2) which goes into the hip bone socket. The femoral bone composites in two primary materials, cortical and trabecular bone.[02, 03]

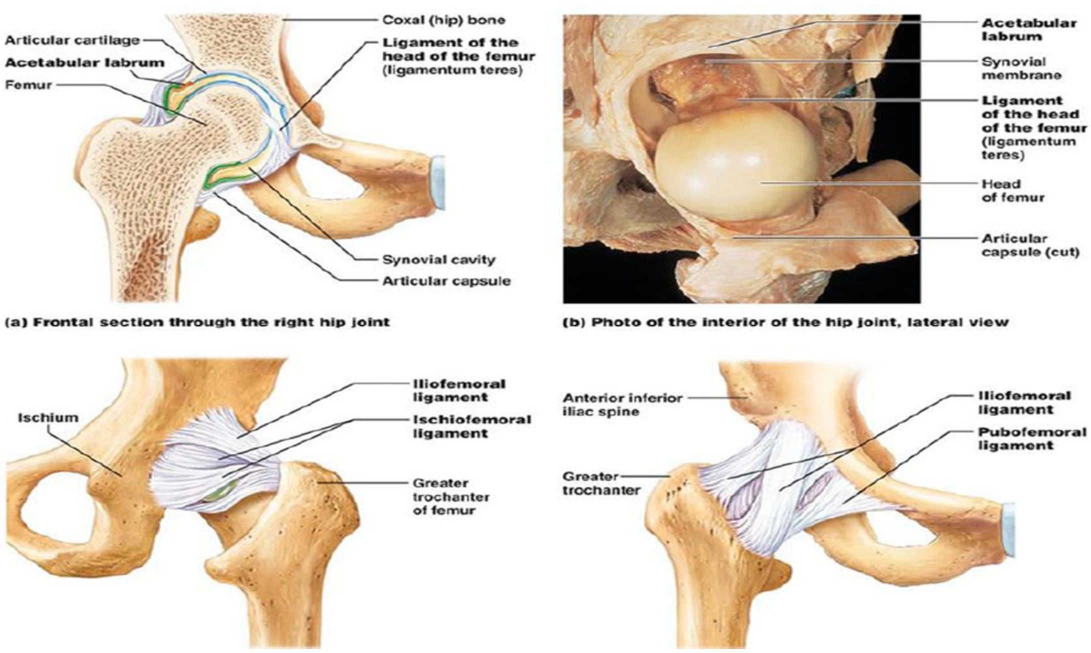

Figure 1 Anatomy of Hip Joint [01]

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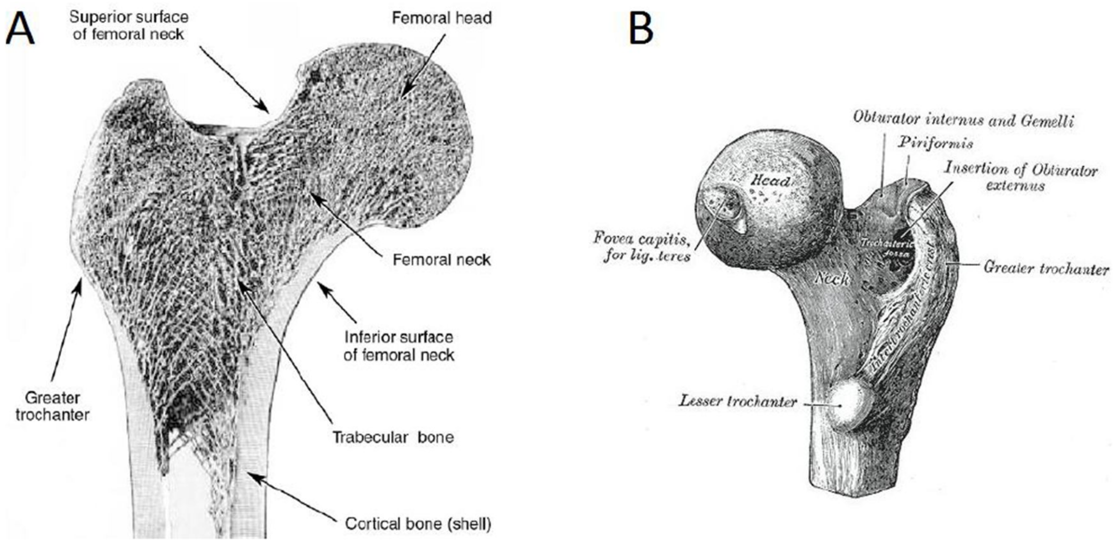

Figure 2 Femur cross-section with text landmarks [02, 03]

Add up to Hip Arthroplasty (THA) is a full of feeling clinical methodology for patients today who are experiencing endless hip agony . There are two techniques utilized today for THA, established and uncemented (squeeze fit). In the two cases the femoral head and the articular ligament in the hip bone socket (figure 3) are supplanted with biocompatible embed segments. The two strategies are for torment diminishing and more prominent versatility, yet influences the patients in various ways.

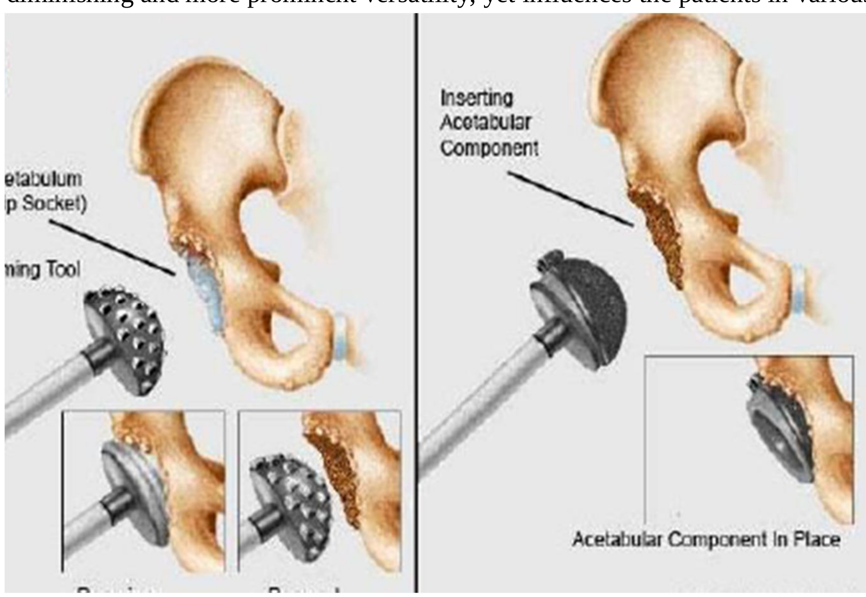

Figure 3 Hip implant methods

There two methods available for hip joint replacement which are cemented and second is press fit methods. In present era various type of artificial hip joints are manufactured due to improvement in design and analysis capabilities of computational software. The prime aim of this research paper is to investigate the design analysis of artificial hip joint for various input boundary conditions like different load conditions, material used in hip joint and last is different type of designs used in hip joint. Design of experiment technique named "taguchi Method" is plan to use in this research work.

A. Factor and Level

In present study three levels are selected for simulation work have uneven levels due to mixed level taguchi method. Table 1 present the factor and their levels for this research work. The design parameters are renamed as factors and they are given in the adjacent column.

Table 1 design parameters and their Levels (Taguchi Method)

Factor	Parameter	Unit	Level					
			L1	L2	L3	L4	L5	L6
A	Load Condition	N	2500	2070	2225	2225	2040	1500
B	Design		Basic	Lower Hole	Full Hole	-	-	-
C	material		Co-Cr	Ti6Al4 V	SS	-	-	-

All factors and their levels are selected on the basis of literature review. There are various other levels conditions are possible but in this research study, the load condition is assumed for 6 feet tale healthy male patient (Approx 100 kg weight). Design is considered from literature review and material is also considered from literature review. Figure 1 present the basic design of hip implant which is modified in this research paper.

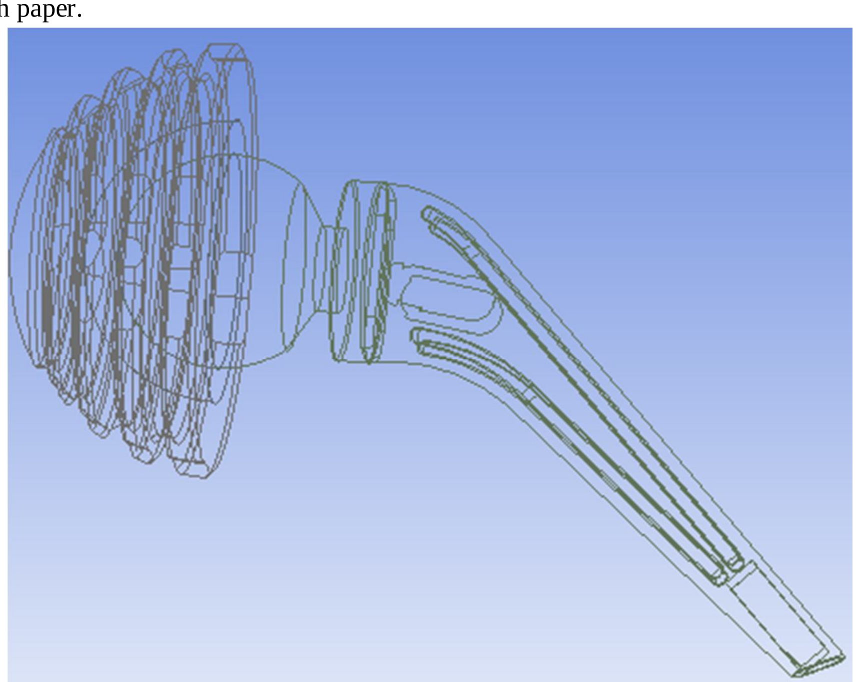

Figure 4 Geometrical line diagram of hip implant

B. *Mixed orthogonal array*

In this research work mixed orthogonal is generated because factor A has six levels whereas other factors has three levels, so mixed orthogonal array which have L 18 is suitable for this research task. The generated table is present in table 2.

Table 2 L 18 mixed OA for analysis of Stress and deformation in hip implant

Sr No	A	B	C	Stress (MPa)	Deformation (mm)
1	1	1	1	210.5	0.189
2	1	2	2	243.7	0.207
3	1	3	3	189.5	0.108
4	2	1	1	152.1	0.092
5	2	2	2	155.1	0.101
6	2	3	3	139.7	0.053

Sr No	A	B	C	Stress (MPa)	Deformation (mm)
7	3	1	2	145.4	0.1
8	3	2	3	154.6	0.052
9	3	3	1	150	0.092
10	4	1	3	156.3	0.052
11	4	2	1	155.1	0.092
12	4	3	2	141	0.101
13	5	1	2	195.3	0.13
14	5	2	3	194.8	0.068
15	5	3	1	176.6	0.12
16	6	1	3	143.2	0.05
17	6	2	1	142.31	0.088
18	6	3	2	129.3	0.096

The material properties for this research work is present in table 3 for three material which is following, first material is ceramic material which is used between head and stem body. It is fixed for all simulation work. Only stem material si changed which is present in table 1.

Table 3 mechanical properties of material used for hip implant FEM simulation

Sr. No.	property name	unit	materials name			
			ceramic(TZP)	cu-cr	Ti6al4v	SS
1	Elastic modulus	GPa	144	117	100	2.4
2	poission ratio		0.45	0.181	0.32	0.25
3	ultimate tensile strength	Mpa	745	655	920	67
4	yield tensile	MPa	500	450	830	35

As seen in figure 5, the basic design has no holes in it but two other design has hole conditions in stem body, like in design second hole is presented in lower section and in third design hole is present in top and bottom section of stem body. Ansys APDL software is used for this research work. The boundary conditions for this research is present in figure 5. In this figure the load and support system is shown for hip implant used in FEM simulation. The same boundary conditions are used for all 18 experiments.

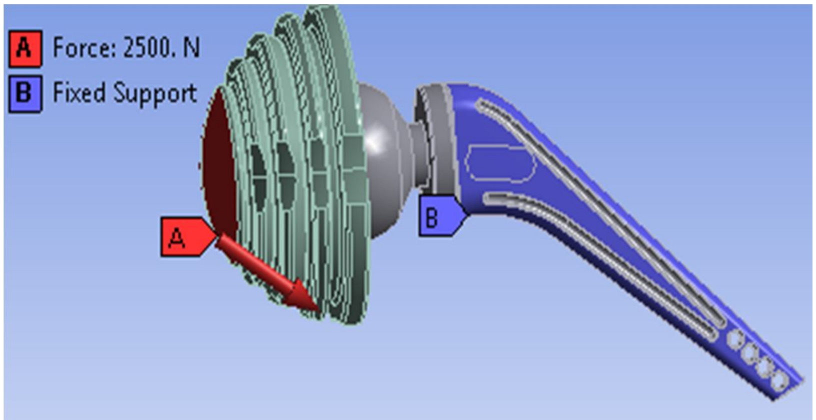

Figure 5 Boundary conditions used in Ansys FEM software

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II. RESULT AND DISCUSSION

In this research paper, signal to noise ratio analysis is performed for stress and deformation analysis. This test help to predict the rank of factor, which improve response parameter. The S/N ratio analysis is presented in table 4 and table 5 for stress and deformation.

Table 4 S/N ratio analysis for stress

Level	A	B	C
1	-46.58	-44.36	-44.24
2	-43.45	-44.67	-44.31
3	-43.52	-43.69	-44.17
4	-43.56		
5	-45.52		
6	-42.81		
Delta	3.78	0.98	0.13
Rank	1	2	3

For analysis of stress, the best ranked factor is load conditions applied on hip implant, whereas materials play very less role in stress minimization. The same analysis is present in figure 6 for stress response.

Table 5 S/N ratio analysis for deformation

Level	A	B	C
1	15.83	20.77	19.36
2	22.05	20.74	18.60
3	22.13	20.71	24.26
4	22.11		
5	19.83		
6	22.50		
Delta	6.67	0.06	5.67
Rank	1	3	2

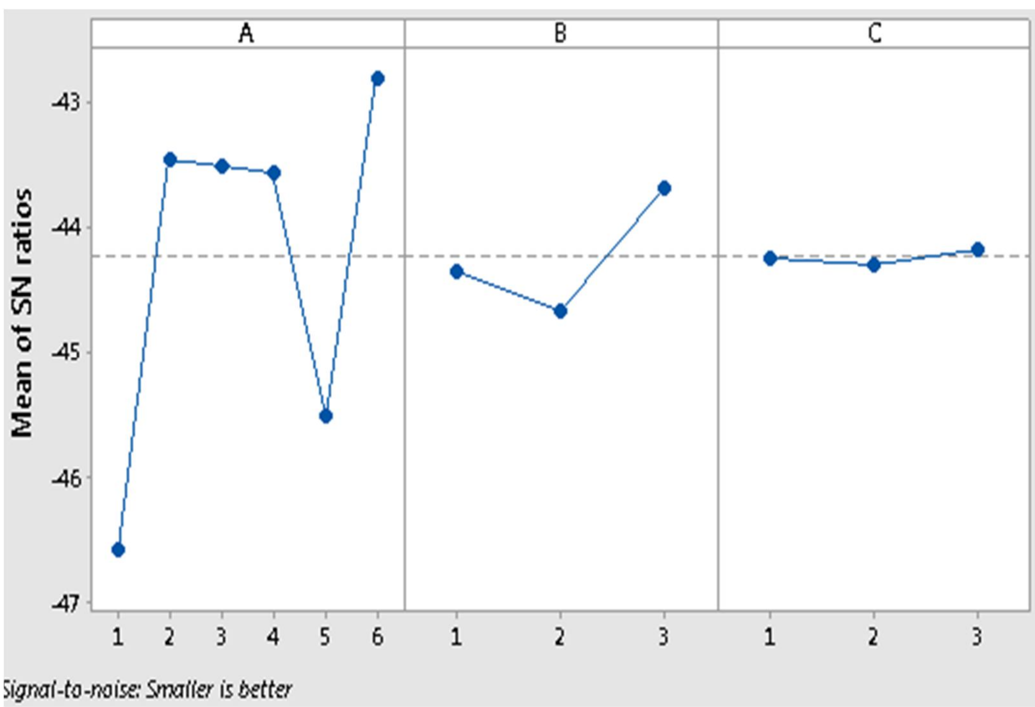

Figure 6 S/N ratio analysis for stress distribution

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As seen in table 5, the best ranked factor is load condition whereas least factor is design of hip implant. The same result is present in figure 7 for deformation response.

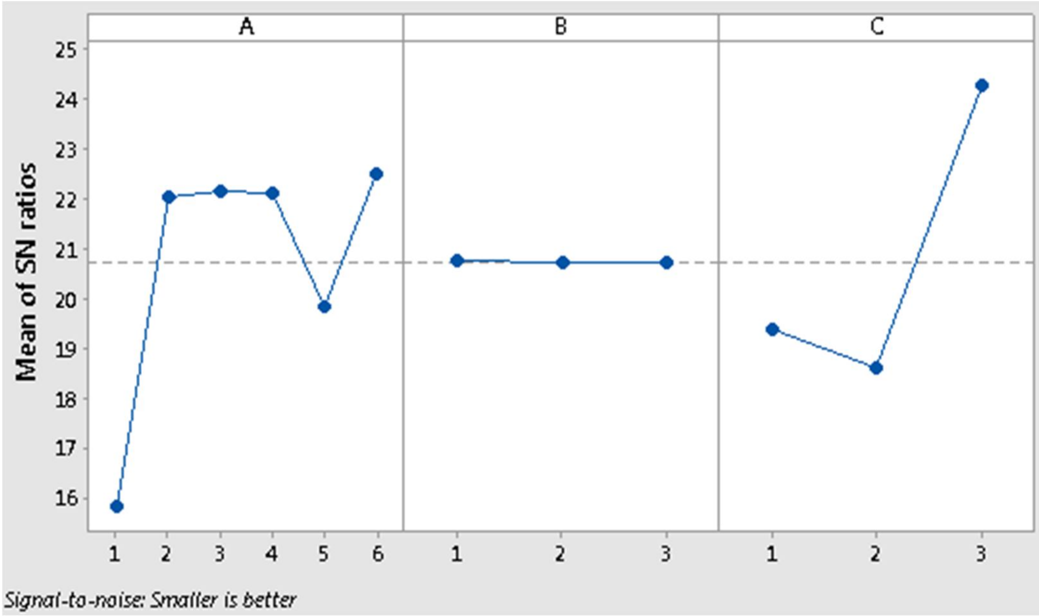

Figure 7 S/N ratio analysis for deformation distribution

Both figures show the best optimal case for present responses and present in table 6 for both responses stress and deformation.

Table 6 Best optimal case for both responses

Response/Factor	A	B	C
Stress	6	3	3
Deformation	6	1	3

Interaction plots for both responses are presented for this research study which are present in figure 8 and figure 9 for stress and deformation respectively.

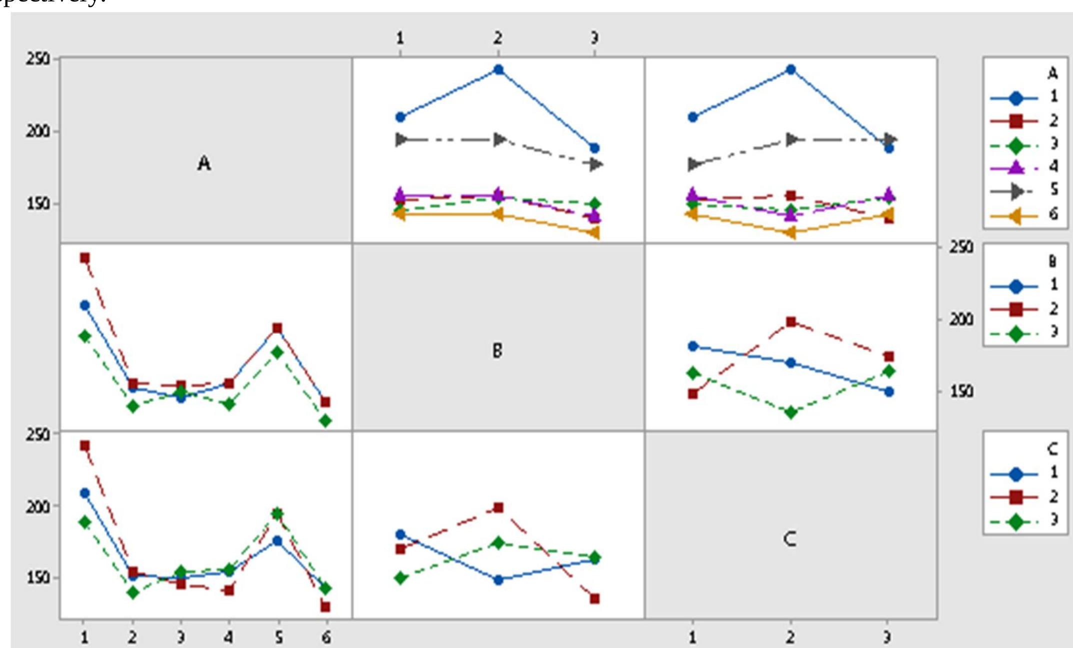

Figure 8 Interaction plot for stress distribution

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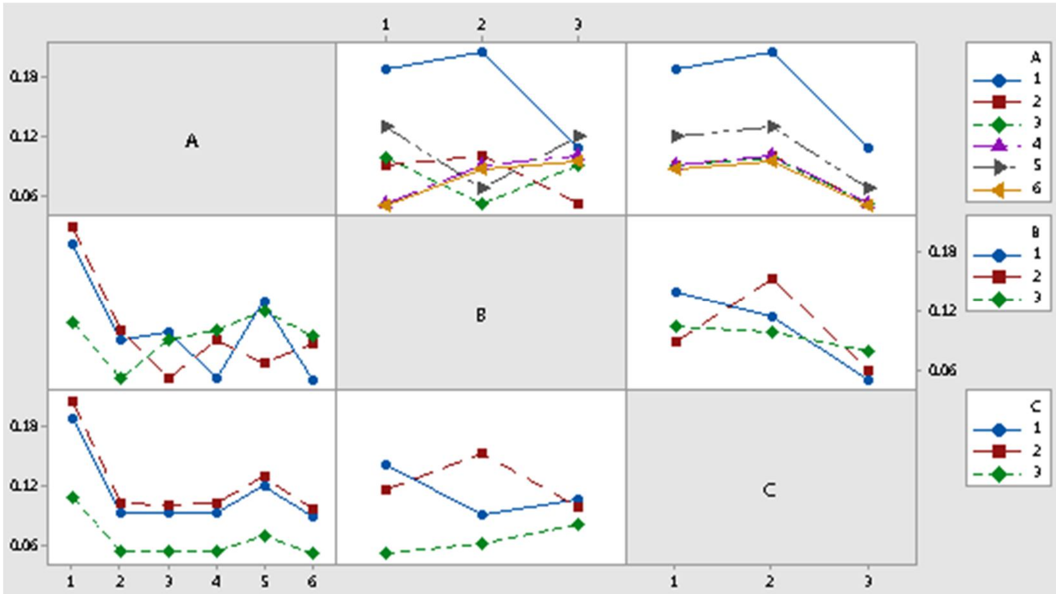

Figure 9 Interaction plot for stress distribution

As seen in figure 8 and figure 9, it is seen that most of the factors show zig zag profiles for hip joint simulation results for both responses. Most important results are show for factor A and C interaction plots available is figure 8 and 9.

Ansys FEM has one important capability, which is visual analysis of stress and deformation. Due to reputation of results some important results are present in figure 10 to figure 11.

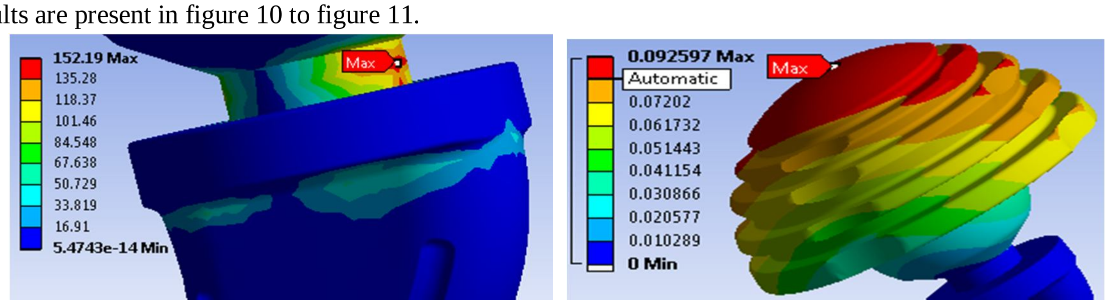

Figure 10 Stress and deformation for case-IV

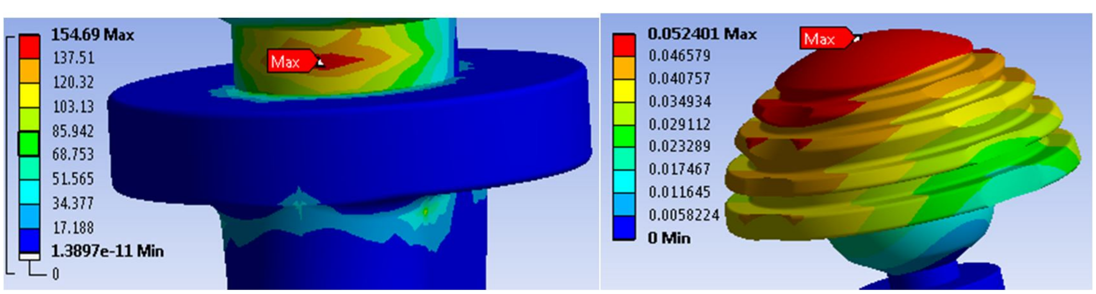

Figure 11 Stress and deformation for case-VIII

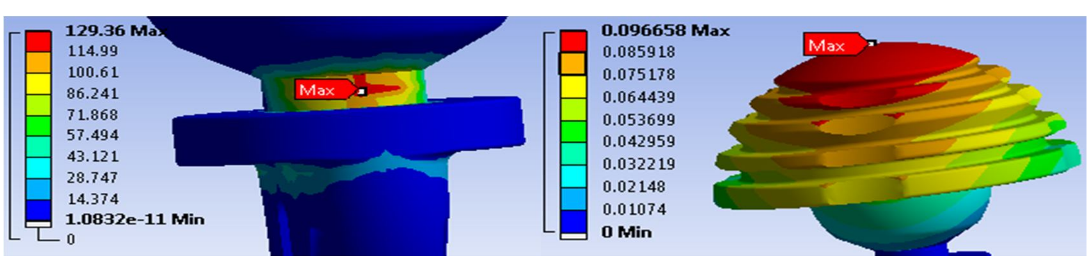

Figure 12 Stress and deformation for case-XVIII

Remaining results of visual analysis is not present due to repetition on same type figures. And already DOE analysis is present in result and discussion of all experiments solved using Ansys FEM software.

III. CONCLUSION

Two response parameters stress and deformation is selected for Ansys FEM simulation of hip implant using Taguchi method. The main conclusion of this study is following:

Three factors having mixed levels are selected and total 18 experiments are generated using mixed orthogonal array using Taguchi metho S/N ratio analysis is performed for both responses stress and deformation and the best rank factor for stress and deformation load condition applied on hip implant. The optimal solution of both response are present in following table which show optimum case using Taguchi S/N ratio analysis.

Response/Factor	A	B	C
Stress	6	3	3
Deformation	6	1	3

Interaction plots are generated to show the effect of factor on each other for response parameters. This study is also performed for both response stress and deformation.

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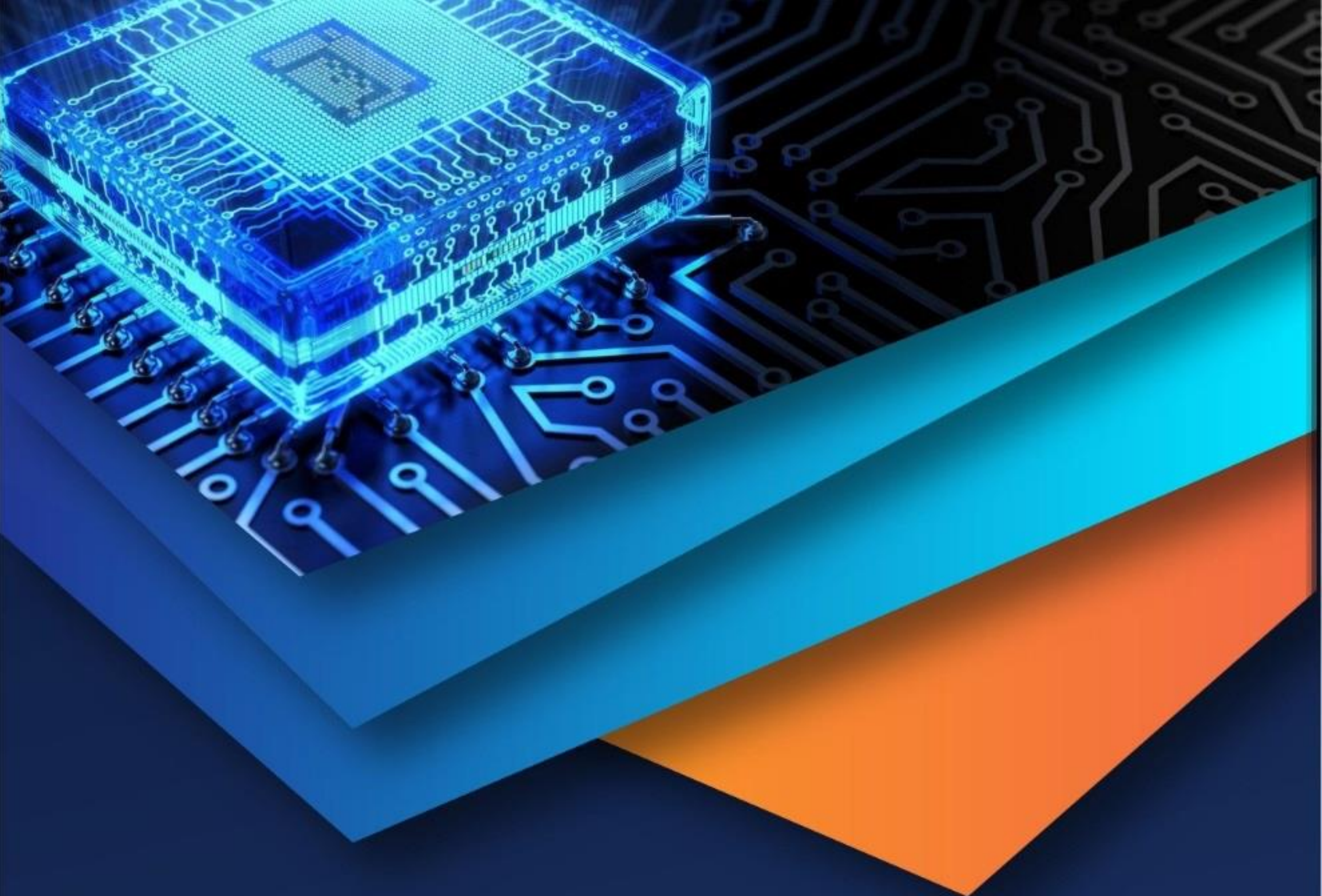

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