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PROSTHESIS KNEE JOINT OPTIMIZATION USING FEM AND TAGUCHI METHOD FOR DIFFERENT LOAD AND MATERIAL CONDITIONS

Lokesh Sihag[1], Gajendra Singh[2]
Mechanical Department, Shekhawati institute of engineering and technology, Sikar

Abstract: In present research study prosthesis knee joint is optimized using design of experiment method called Taguchi method. In present era, knee joint replacement is one of the main medical issue found in Indian male patients. There are various designs are available for this task but each design has its benefits and disadvantage also, so in present study optimum design is plan to investigate by changing its dimensional variables of knee joint. The dimensional variables are set as per given in encyclopedia of knee joint made by G.W. Hastings. In present study four parameters are selected for input variable which are load applied on knee joint, load direction applied on knee joint, material of knee joint upper part and last parameter is material applied to lower part of knee joint. All experiments are designed as per Taguchi guidelines and finally 16 experiments are selected for research. Then experiments are conduct on FEM simulation software made by ANSYS company. Signal to noise ratio analysis is performed for stress applied on knee joint with FEM visual results.
Keywords: FEM, Prosthesis knee joint, Taguchi method, Signal to noise ratio, interaction plots

I. INTRODUCTION

The human knee joint is a weight bearing joint which is classified as synovial, diathrosis complex joint. The knee is essentially made up of femur, tibia, fibula and patella. When the knee moves, it does not just bend and straighten, there is also a slight rotational component in this motion. The knee muscles which go across the knee joint are the quadriceps and the hamstrings. The quadriceps muscles are on the front of the knee, and the hamstrings are on the back of the knee. The ligaments are equally important in the knee joint because they hold the joint together. In review, the bones support the knee and provide the rigid structure of the joint, the muscles move the joint, and the ligaments stabilize the joint. Statistical design of experiments (SDE) has been rigorously developed over the past several years and are being widely used in the CNC-milling industry to optimize the machining parameters and in understanding the relationsknee between machining parameters and material properties. These experimental designs represent a plan for constructively changing process parameters in order to determine their effect on the machining qualities. A variety of statistical design of experiment (SDE) strategies are available to obtain information within the selected test matrix. These include Taguchi methods, evolutionary operation, central composite designed experiments and full and fractional factorial experiments The effectiveness of each technique will depend on the objectives of the experiment, i.e. higher efficiency or reduced variability; on the availability of pre-existing knowledge of the process and on the environment under which the information must be obtained, e.g. production or development. The aim of present research is to optimize the prosthesis knee joint using FEM and Taguchi method for different boundary conditions. Very less research is available on this knee joint work in which DOE method is used for analysis.

II. BASE DESIGN OF PROSTHESIS KNEE JOINT

It is required to start a research on base model for find the research outcome, so in present research study the base model is made with the help of medical practitioner whose research work is prosthesis knee joint. So final base design of this research study is show in figure 1.

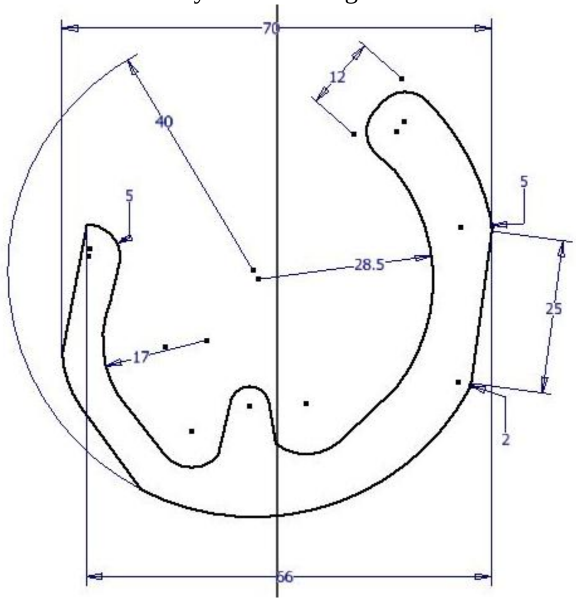


Figure 1 Dimensional line diagram of knee joint

Factor and Levels selection

In present research study the final selective input parameters and their levels are present in table 1 with proper indication.

Table 1 factor and Levels for base model optimal solution

Factor	Name	L-1	L-2	L-3	L-4
A	Load	800	1000	1200	1400
B	Direction	0	15	30	45
C	Material-F	1	2	3	4
D	Material-T	1	2	3	4

The mechanical properties of materials selected for present research work is present in table 2 to table 5 for present study.

Table 2 Mechanical Properties of titanium Alloy

Ti-6Al-4V		
Density	4400	Kg/m3
Young Modulus	1.1E+05	MPa
Shear Modulus	4.16E+10	Pa
Yield Strength	880	MPa
Tensile Ultimate Strength	950	MPa
Poisson Ration	0.32	NA

Table 3 Mechanical Properties of Chromium Alloy

Co-Cr-Alloy		
Density	8500	Kg/m3
Young Modulus	2.2E+05	MPa
Shear Modulus	8.46E+10	Pa
Yield Strength	450	MPa
Tensile Ultimate Strength	655	MPa
Poisson Ration	0.3	NA

Table 4 Mechanical Properties of Stainless Steel

SS		
Density	7750	Kg/m3
Young Modulus	1.93E+05	MPa
Shear Modulus	7.36E+10	Pa
Yield Strength	207	MPa
Tensile Ultimate Strength	586	MPa
Poisson Ration	0.31	NA

Table 5 Mechanical Properties of UHMWPE

UHMWPE		
Density	931	Kg/m3
Young Modulus	1000	MPa
Shear Modulus	3.57E+08	Pa
Yield Strength	21.4	MPa
Tensile Ultimate Strength	38	MPa
Poisson Ration	0.4	NA

Orthogonal Array generation

Taguchi method is used for generation of experiment table for this research work and the generated orthogonal array in present inn table 6. Total 16 experiments are generated in this work. The MINITAB software is used for this task.

Table 6 L-16 orthogonal Array

Run	A	B	C	D
1	800	0	1	1
2	800	15	2	2
3	800	30	3	3
4	800	45	4	4
5	1000	0	2	3
6	1000	15	1	4
7	1000	30	4	1
8	1000	45	3	2
9	1200	0	3	4
10	1200	15	4	3
11	1200	30	1	2
12	1200	45	2	1
13	1400	0	4	2
14	1400	15	3	1
15	1400	30	2	4
16	1400	45	1	3

All these 16 experiments are then simulated using Ansys WB 14.5 version software, which is FEM simulation software. All simulations are conduct in static FEM environmental conditions for present research study.

III. RESULT AND DISCUSSION

All 16 experiments are simulated using FEM software and the final two response parameters measured for this research study which are Von misses stress and shear stress for planer direction. And the final results are present in table 7.

Table 7 Response and factor for Knee joint research work

Run	A	B	C	D	Von-Stress (MPa	Shear-Stress (MPa)
1	800	0	1	1	7.43	1.58
2	800	15	2	2	12.35	2.62
3	800	30	3	3	16.02	3.45
4	800	45	4	4	17.43	3.93
5	1000	0	2	3	9.64	2.00
6	1000	15	1	4	14.70	3.32
7	1000	30	4	1	28.79	4.09
8	1000	45	3	2	23.52	5.06
9	1200	0	3	4	11.92	2.27
10	1200	15	4	3	27.21	3.75
11	1200	30	1	2	24.38	5.06
12	1200	45	2	1	27.43	6.17
13	1400	0	4	2	20.76	2.74
14	1400	15	3	1	21.07	4.61
15	1400	30	2	4	28.53	6.17
16	1400	45	1	3	32.95	6.92

Signal to noise ratio analysis for Von misses stress are present in table 8 and figure 2. The same results are present for Shear stress ad present in table 9 and figure 3.

Table 8 S/N ratio for Von Misses Stress

Level	A	B	C	D
1	-22.04	-21.24	-24.72	-25.46
2	-24.91	-25.09	-24.85	-25.84
3	-26.68	-27.53	-24.88	-25.71
4	-28.07	-27.84	-27.26	-24.7
Delta	6.02	6.6	2.54	1.14
Rank	2	1	3	4

As seen in table 8, the best ranked factor is load direction and least important factor is material allot to lower body of knee joint.

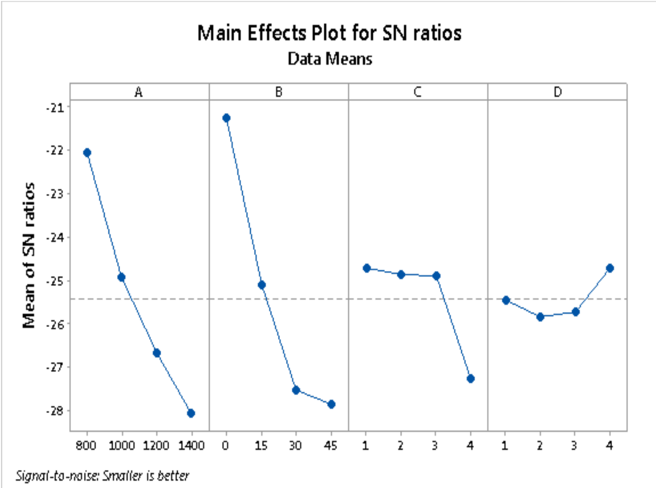


Figure 2 S/N ratio for Von misses Stress

As seen in figure 2, the optimal solution for Von Misses stress are (A-800, B-0, C-1, D-4).

Table 9 S/N ratio for Shear Stress

Level	A	B	C	D
1	-8.752	-6.472	-11.327	-11.324
2	-10.689	-10.886	-11.492	-11.317
3	-12.121	-13.215	-11.305	-11.266
4	-13.655	-14.644	-11.092	-11.31
Delta	4.903	8.172	0.4	0.058
Rank	2	1	3	4

The smaller is better option is selected for calculation of S/N ratio for both response parameters and the result for shear stress are present in table 9 and as seen in table 9 the best factor is direction of load and least factor is material of lower part of knee joint.

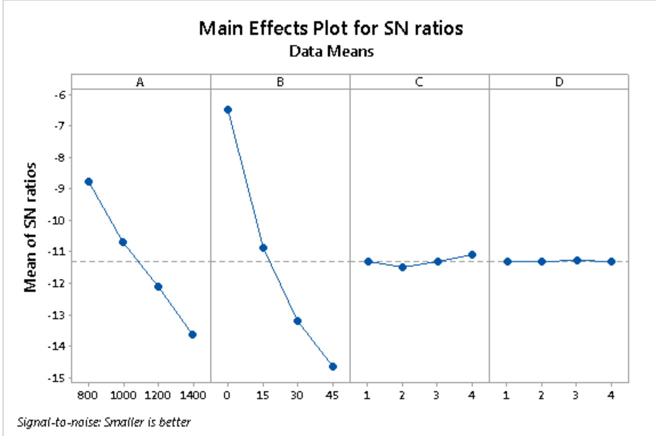
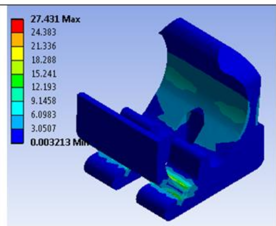
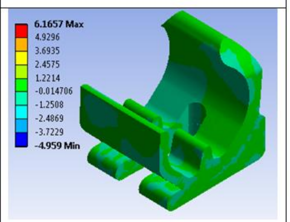
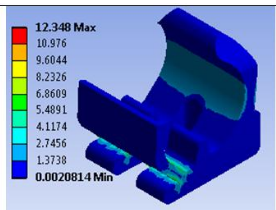
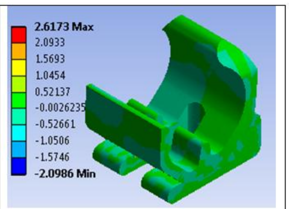
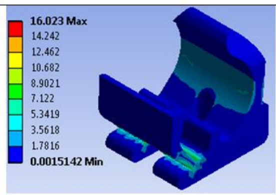
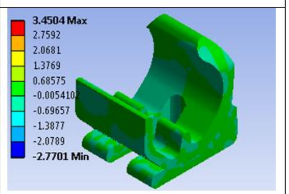
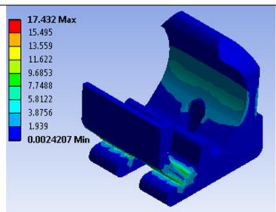
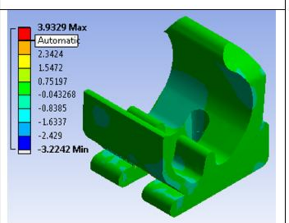


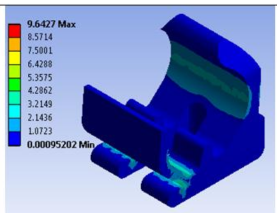
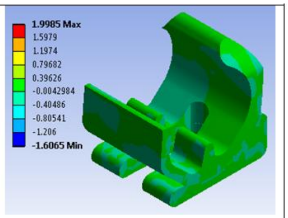
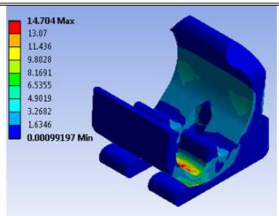
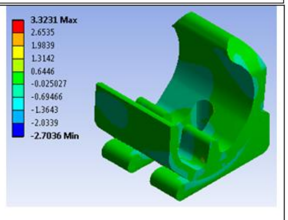
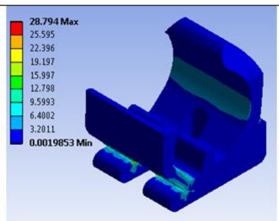
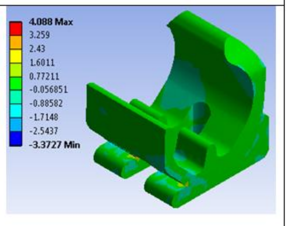
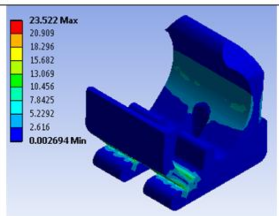
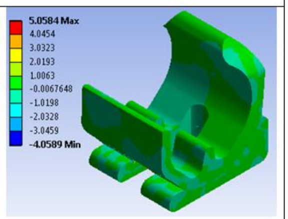
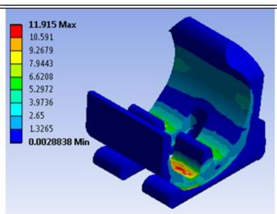
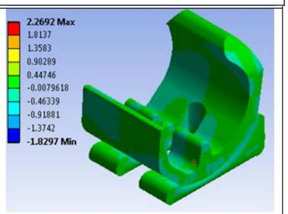
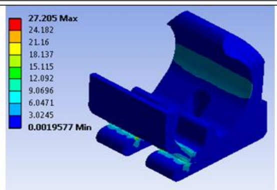
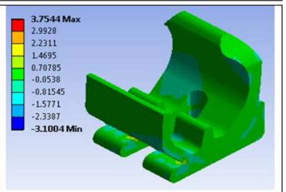
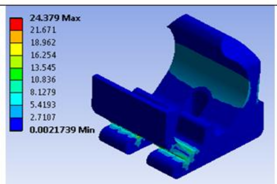
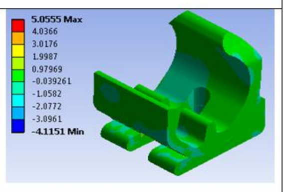
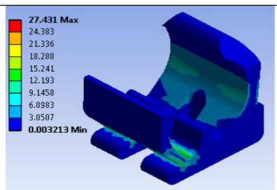
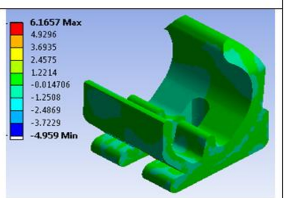
Figure 3 S/N ratio for shear Stress

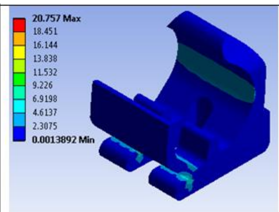
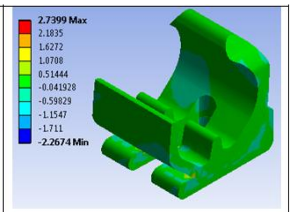
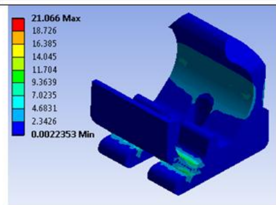
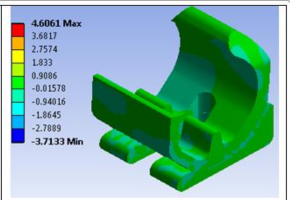
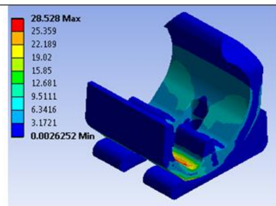
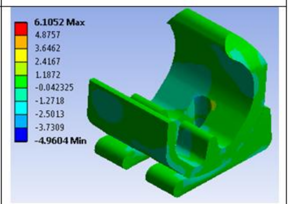
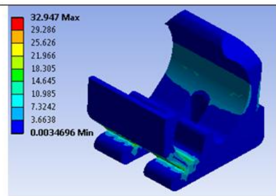
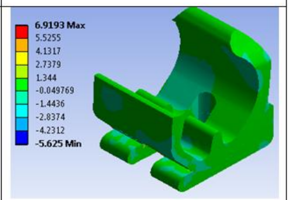
As seen in figure 3 the materials play a role are very low in the case of shear stress response parameters. The optimal solution for shear stress are (A-800, B-0, C-4, D-3)

In final result the FEM visual for these 16 experiments are present in table 10.

Table 10 FEM visual results for von and shear stress

Case No.	Von-Misses Stress (MPa)	Shear Stress (MPa)
1		
2		
3		
4		

5		
6		
7		
8		
9		
10		
11		
12		

13		
14		
15		
16		

IV. CONCLUSION

In present study 16 experiments are solved for optimization of knee joint base design using FEM and Taguchi method. Two response parameters Von Misses and shear stress are solved using Signal to noise ratio and visual analysis of knee joint which is discussed in result and discussion of this paper.

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