

FEA of Mechanism for Hip Manipulation

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ABSTRACT: In this paper a mechanism for hip joint manipulation has been designed and analysed using finite element analysis. The designed mechanism can manipulate the abduction, adduction, extension and flexion of hip joints. Four bar mechanism has been synthesised based on two position synthesis method to achieve desired manipulations. The analysis has been done for various thicknesses of linkages. C20 carbon steel and FG150 grey cast iron materials have been considered for the analysis. Based on the Finite Element (FE) analysis results for all the 4 linkages, C20 carbon steel material has been found to be safe and optimum thickness values have been selected.

KEYWORDS: Artificial Hip Joint, Four Bar Mechanism, Finite Element Analysis (FEA), ANSYS.

I. INTRODUCTION

Every human body consists of two hip joints in lower part of the body, each on either side of the vertebral column. In mechanical terms hip joint is nothing but a ball and socket joint with three degrees of freedom. It also connects the pelvis to the thigh bone or femur which is the longest bone in the human body [1]. The acetabulum acts as a socket and femoral head acts as a ball. Hip joint not only gives stability to entire human body, but also plays a major role in all routine activities like walking, running, step climbing, sitting in various positions, car entry and exit, bath tub entry and exit, etc.[2]. Due to some reasons natural hip joint fails to execute its regular function and producing pain in the hip portion of the body. The various types of defects and diseases which cause pain in the hip joint are injuries due to accidents, femoral head fracture, femoral neck fracture, abnormal joint geometry, damage in cartilage, osteoporosis, necrosis, osteoarthritis, inflammatory arthritis, rheumatoid arthritis, etc. [2]. The failed natural hip joint can be replaced by a surgery which involves either partial replacement like resurfacing of femoral head or replacement of cartilage or replacement of entire joint by artificial hip joint with a surgery known as Total Hip Arthroplasty (THA) [3, 4]. The artificial hip joint involves stem, ball, liner and cup. The stem is fitted into the femur, ball is fitted on top of the stem and the cup acts like socket which houses the ball with liner between them. The types of artificial hip joint include metal on metal (MOM), metal on ceramic (MOC), ceramic on ceramic (COC), ceramic on metal (COM) etc. [5, 6]. Currently many of the researchers have conducted the tests on the natural and artificial hip joints by applying the static load exactly at the centre of the ball by fixing the bottom portion of the stem. This is similar to a compression test on any mechanical component. Almost all tests are conducted in the standard loading machines like UTMs, compression and fatigue test machines. The basic objectives of many tests are to check the feasibility and sensitivity of various types of signals to hip joint failure. Based on the study of the reported test setups of artificial hip joint, it can be said that there is a need for a simple test setup to capture the signals of artificial hip joint during various manipulations required for routine activities. [1-8].

The main goal of this work is synthesis, design and analysis of the mechanism in order to study the common motions occurring in the hip joint. In this paper, section 1 gives the introduction, section 2 presents the selection of mechanism for hip joint manipulation, synthesis and force analysis of the selected mechanism followed by finite element analysis, section 3 presents the results of FEA and section 4 presents the conclusion.

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II. MECHANISM FOR HIP JOINT MANIPULATION

SELECTION OF MECHANISM

The healthy hip joint should be able to perform minimum of four motions namely abduction (50°), adduction (30°), flexion (120°) and extension (30°) [9]. The angles represent the degree of motion between the cup (socket) and ball axis. In order to simulate the hip implant motion under different conditions, a mechanism is needed which facilitates the motion of the hip implant in different ways. The selection of mechanism should be such that, the output motion should be of oscillatory type and to obtain this, different mechanisms have been considered for the study which includes Leva mechanism, Nuova Pagina mechanism, etc. There is no customized design procedure available for these mechanisms, a 4 bar mechanism is considered for the study as shown in Figure 1. The reasons behind the selection 4 bar mechanism are simple to design and standard procedures are available for synthesis of mechanism. In the mechanism the crank rotates by 360° through an external source. The rotational motion is converted into an oscillatory motion at the rocker arm by the coupler link. This oscillatory motion is given to the femur of the hip joint through an external link.

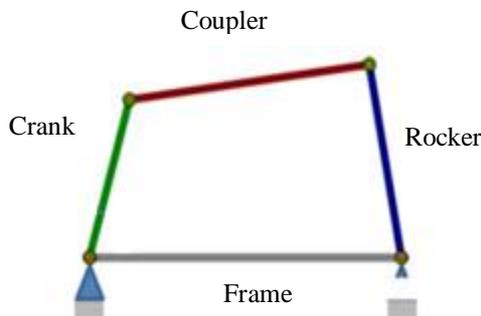


Figure 1: 4 bar Mechanism

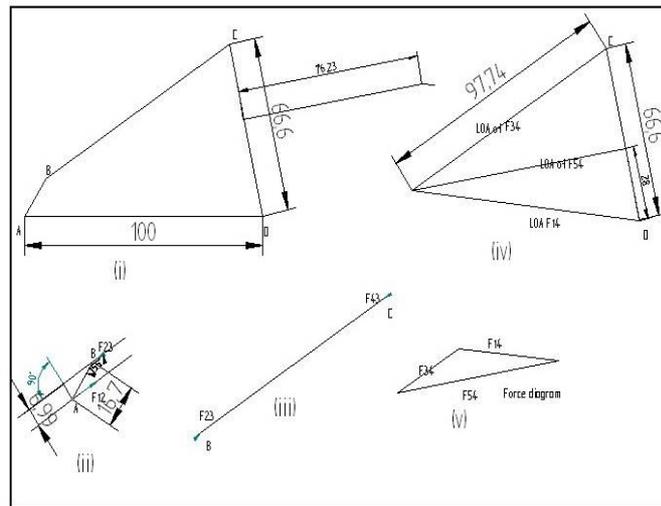


Figure 2: static force analysis for output angle $\theta=30^\circ$

SYNTHESIS OF 4 BAR MECHANISM

Synthesis of mechanism deals with the method of graphic kinematic design of mechanism according to specified kinematic and dynamic principles. A standard 2 position synthesis of 4 bar mechanism is adopted for synthesis of mechanism to simulate the hip motions for 30° , 50° and 120° given by Hall and Soni [10]. The distance between the crank and rocker is taken as 500mm. In synthesis of mechanism for adduction and extension the output angle (θ) of motion should be 30° . It means that the range of motion allowed for rocker is 30° . The obtained dimensions after the synthesis of mechanism are as shown in table 1. In order to have at least 1 revolving link we have to verify the Grashof's Law. It states that a four bar mechanism showed have at least 1 revolving link, if the sum of the shortest and longest link lengths must be less than or equal to the sum of the lengths of remaining 2 links. In the table we can see 583.885 is less than 796.01. Hence the synthesized dimensions agree with Grashof's law and the crank moves by 360° .

Table 1: Dimensions of Synthesised Mechanism

Sl. No.	Motion	Angle (θ)	Links (mm)				Grashof's Law
			Frame	Crank	Coupler	Rocker	
1.	Extension and Adduction	30°	500	83.885	462.94	333.07	$583.885 < 796.01$
2.	Abduction	50°	500	93.86	503.64	227.89	$597.5 < 727.89$
3.	Flexion	120°	500	295.99	536.09	366.96	$832.08 < 866.96$

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FORCE ANALYSIS AND MATERIAL SELECTION

For the mechanism to work in safe mode, forces acting on the various parts are important factors to be considered, so the static force analysis has been done on the 4 bar mechanism for the design of components. The input motion is given to the crank by a RHS-14 6003DC servo motor. The motor gives the output torque, output power, and output speed of 5.4Nm, 34W, 60 rpm respectively. Figure 2 shows the static force analysis for output angle of 30 degree. The force generated from the input torque is calculated as shown below.

$$T = F_{23} \times h = F_{12} \times h$$

$$5.4 = F_{23} \times 0.0035 = F_{12} \times 0.0035$$

$$F_{23}=F_{12}=154.28N.$$

The obtained forces from the force analysis are, $F_{23}=F_{43}=F_{32}=154.28N$, $F_{54}=344N$ and $F_{14}=211N$. The direction these force can be seen in the static force diagram shown in Figure 2. Similarly force calculations are done for abduction and flexion motions using same input external DC source.

The material properties of the two materials considered for the analysis are given in Table 2.

Table 2: Material Properties

Material	Properties		
	Density(Kg/m ³)	Young's modulus (MPa)	Yield strength (MPa)
C20 Carbon steel	7500	1,80,000	250
FG150 Grey Cast iron	7200	1,10,000	130

FINITE ELEMENT ANALYSIS OF LINKS

FEA has been carried on all the links to obtain the stress and deformation values using ANSYS workbench 14.5. The load values obtained in static force analysis are used for the FEA. By taking constant width as 30mm and thickness of links are varied depending on the stress values. Figure 3 shows the stress plots for the crank, coupler, rocker and external link for extension and adduction motions.

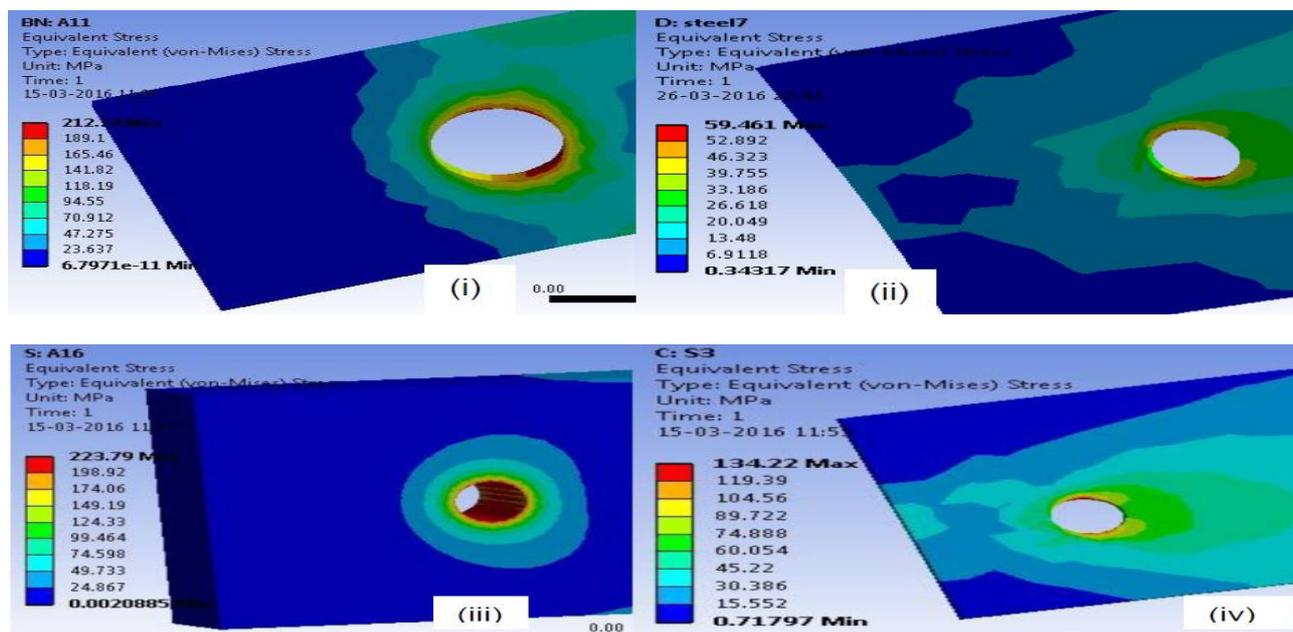


Figure 3: Stress plot for the i) crank, ii) coupler, iii) rocker and iv) external link

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III. RESULTS AND DISCUSSION

Table 3 to 6 shows the results of analysis based on varying the thickness for crank, coupler, rocker and external link connecting to the hip joint. The optimum thickness has been selected based on the Von Mises stress value, which has considerable lower value compared to the yield strength of material. For all the four links, C20 carbon steel has given better stress values compared to FG150 grey cast iron. For crank, from Table 3 it can be observed that the optimum thicknesses for extension and adduction, abduction and flexion have been found to be 2.2mm, 2.3mm and 0.7mm respectively. For coupler, from Table 4 it can be observed that for 0.5mm thickness, the link is safe in all the 4 cases. Even though the coupler link is safe for 0.5mm thickness, minimum thickness of 1mm is selected for extension, adduction and abduction by considering the thickness of crank link. And for flexion 0.7mm thickness is chosen. It is also observed that the stress values for the coupler are well below the yield strength as it experiences lesser load. For rocker, from Table 5 it can be observed that the optimum thickness for extension and adduction, abduction and flexion have been found to be 18mm, 6.3mm and 2.1mm respectively. For external link, from Table 6 a minimum thickness of 1mm and 0.7 mm for extension, adduction, abduction and flexion are selected by considering the thickness of other links respectively. In all the 4 cases, for flexion motion 4 bar mechanism with least thickness values for the linkages is obtained.

Table 3: Stress and deformation values for crank

Manipulation	Materials	Thickness (mm)	Von Mises (MPa)	Yield Strength (MPa)	Deformation (mm)
Extension and Adduction	C20 Carbon steel	1.8	265.5	250	0.7280
		2	245.14		0.6928
		2.2	212.7		0.6617
	FG150 Grey Cast iron	3.5	140.81	130	0.6807
		3.8	129.9		0.6269
		4.2	117.37		0.5672
Abduction	C20 Carbon steel	1.9	273.3	250	0.8876
		2	255.28		0.8432
		2.3	227.86		0.7331
	FG150 Grey Cast iron	3.9	142.8	130	0.7086
		4	129.8		0.5707
		4.2	113.21		0.4191
Flexion	C20 Carbon steel	0.5	328	250	2.1617
		0.6	270		1.7922
		0.7	227.9		1.3898
	FG150 Grey Cast	1.2	139.7	130	1.4741
		1.3	123.3		1.3606
		1.4	118.47		0.8087

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Table 4: Stress and deformation values for coupler link

Manipulation	Materials	Thickness (mm)	Von Mises (MPa)	Yield Strength (MPa)	Deformation (mm)
Extension and Adduction	C20 Carbon steel	0.5	117.34	250	0.083
		1	59.46		0.041
	FG150 Grey Cast	0.5	117.34	130	0.115
		1	59.461		0.067
Abduction	C20 Carbon steel	0.5	103.29	250	0.084
		1	52.27		0.042
	FG150 Grey Cast	0.5	103.29	130	0.137
		1	52.27		0.068
Flexion	C20 Carbon steel	0.5	16.36	250	0.013
		0.7	11.72		0.009
	FG150 Grey Cast	0.5	16.36	130	0.022
		0.7	11.72		0.016

Table 5: Stress and deformation values for rocker arm

Manipulation	Materials	Thickness (mm)	Von Mises (MPa)	Yield Strength (MPa)	Deformation (mm)
Extension and Adduction	C20 Carbon steel	16	265	250	0.5039
		17	250		0.3361
		18	223		0.2953
	FG150 Grey Cast	29	146.38	130	0.8876
		33	130.05		0.8432
		36	120.02		0.7331
Abduction	C20 Carbon steel	5.3	267.23	250	0.3576
		5.6	251.12		0.3385
		6.3	226.77		0.3009
	FG150 Grey Cast	10.5	136.42	130	0.2954
		10.8	130.48		0.2872
		12.2	118.18		0.2542
Flexion	C20 Carbon steel	1.8	263	250	0.6379
		1.9	249.16		0.6043
		2.1	225.4		0.5467
	FG150 Grey Cast	3.5	147	130	0.535
		3.7	127.98		0.5078
		4	118.4		0.4697

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Table 6: Stress and deformation values for external link

Manipulation	Materials	Thickness (mm)	Von Mises (MPa)	Yield Strength (MPa)	Deformation (mm)
Extension and Adduction	C20 Carbon steel	0.5	260.86	250	2.679
		0.6	223.34		1.960
		1	134.22		1.717
	FG150 Grey Cast	0.5	134.2	130	1.925
		1.1	119.89		1.750
		1.2	106.19		1.604
Abduction	C20 Carbon steel	0.5	60.46	250	0.061
		1	58.74		0.053
	FG150 Grey Cast	0.5	60.46	130	0.088
		1	58.74		0.079
Flexion	C20 Carbon steel	0.5	44.29	250	0.055
		0.7	16.91		0.021
	FG150 Grey Cast	0.5	44.29	130	0.091
		0.7	16.91		0.034

IV. CONCLUSION

Based on the literature it can be concluded that there is a great need for design and development of mechanism for hip joint manipulation. In this paper four bar mechanism has been designed for imparting extension, adduction, abduction and flexion manipulations for hip joint. Based on the FEA results the final link lengths, thicknesses and material have been selected. For all the 4 linkages C20 carbon steel material is found to be safe. The future work will be connection of external link to the femur on which hip joint will be attached. The development of a column to hold the entire mechanism and a base resulting in a test rig, to manipulate the hip joint.

REFERENCES

- [1] Sharad Shrivastava, Ravi Prakash, "Assessment of bone condition by acoustic emission technique", A review. J. Biomedical Science and Engineering 2, 144-154.
- [2] Total hip replacement, OrthoInfo.ORG, American Academy of Orthopaedic surgeon, pp 1-12.
- [3] Maria Strantz, Olivia Louis, Frans Boulpaep, Demosthenes Polyzos, Danny Van Hemelrijck, Dimitrios. G. Aggelis, "Acoustic Emission on Human Femur Tissue Fracture", 31st Conference of the European Working Group on Acoustic Emission, www.ewgae2014.com/portals/131/bb/fr3a3.pdf.
- [4] Krames Patient Education, Hip replacement Surgery, 2010, <http://www.galwayclinic.com/files/pdfs/Total%20Hip%20Replacement.pdf>.
- [5] Uwe Holzwarth, Giulio Cotogno, "Total Hip Arthroplasty", JRC Scientific and Policy Report, 2012, https://www.google.co.in/?gfe_rd=cr&ei=aYGVVpLqA_CK8Qe866PYCg#q=Total+Hip+Arthroplasty%2C+JRC+Scientific+and+Policy+Report.
- [6] Nieuwenhuijse, M. J Nelissen, R. G. H. H. Schoones, J. W Sedrakyan, "Appraisal of evidence base for introduction of new implants in hip and knee replacement: a systematic review of five widely used device technologies", 9 Sep 2014.
- [7] Leonard C Pastrav, Siegfried VN Jacques, Ilse Jonkers, Georges Vander Perre, Michiel Mulier, "In vivo evaluation of a vibration analysis technique for the per-operative monitoring of the fixation of hip prostheses", Journal of Orthopaedic Surgery and Research, 2009, pp 1-10.
- [8] Catherine Ruther, Ulrich Timm, Hartmut Ewald, Wolfram Mittelmeier, Rainer Bader, Rico Schmelter, Armin, Lohrengel and Daniel Kluess, "Current Possibilities for Detection of Loosening of Total Hip Replacements and How Intelligent Implants Could Improve Diagnostic Accuracy", 2012, <http://cdn.intechweb.org/pdfs/26870.pdf>.
- [9] <https://www.google.co.in/search?q=flexion+and+abduction+angle&biw=1242&bih=606&tbn=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwifxOKa-JnKAhVQjo4KHarQDiYQsAQIHQ#imgrc=hMQQdfOgRHjFM%3A>.
- [10] Joseph Edward shigley, John joseph uicker, Theory of Machines and Mechanisms, McGRAW-HILL INTERNATIONAL publications, Edition 1995, pp 338-350.
- [11] Kazuo Giguchi, Akira Yamashita, Makoto Sasaki, Masaru Ueno, Tsuneyuki Kobayashi, Masaaki Mawatari, and Takao Hotokebuchi, "Control of an Artificial-Hip-Joint Simulator to Evaluate Dislocation", International Conference on Control, Automation and Systems, 14-17 Oct. 2008, Seoul, Korea, pp 1942 – 1945.
- [12] www.harmonicdrive.net/hd/.../rh-rhs-rfs-dc-servo-catalog-0905.pdf.