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Design, Analysis and Rapid prototype of Hip Simulator

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***Abstract* - Universally more than 2lakhs people are ailing from hip failure every year and the remedy for this is replacement. In India, the percentage of people getting handicapped due to hip fractures is high. For that, the people are going for replacements of the hip using artificial hip prosthesis. The artificial prosthesis is imported from the foreign countries which are costlier than the custom-made Indian prosthesis. For that, the Indian people are going for Indian custom-made prostheses. To evaluate the custom made for patients of Indian prostheses, many institutes are working on the prostheses simulators. In this work the walk simulator or hip simulator for Indian customized prostheses is designed. Using this simulator, the prostheses life period can be evaluated with the existing data available from the literature and with the data acquiring from the simulator.**

***Index Terms* - Hip simulator model, stainless steel and aluminium alloy material, Fatigue and wear analysis.**

1.INTRODUCTION

Once a suitable implant configuration was achieved, initial bench testing was repeated with the simple load to failure test using a hydraulic jack and donated polyurethane foam femurs from Pacific Research Laboratories The information from these initial tests was valuable to develop a qualitative understanding of failure modes. For example, it was noted that the head of the compression screws migrated superiorly as the construct approached failure. This was addressed with a plate designed to fit between the interlocking screw and the posterior compression screw to serve as a buttress. Although prominence of the plate was originally problematic, this was resolved with successive iterations of the design. Furthermore, early testing demonstrated the distinct advantage of having the threaded screw heads for fixation into the lateral cortex. Overall, the load-to-failure testing system was invaluable in comparing early design iterations of the hip construct. Ultimately, it was recognized that although early bench testing was helpful, a more sophisticated testing apparatus was needed before using the implant clinically. This testing was achieved through a collaborative effort between SIGN, Program for Appropriate Technology in Health (PATH) (an international on-profit organization), and Allan Tenser from the University of Washington Orthopedic Science Laboratory. Although load-to-failure testing was valuable in the early design process of the SHC, fatigue testing was necessary to understand the failure modes associated with more physiologic loading.(Ref 1,4 and 7)

Maturation of the fitness movement has brought with it an increasingly sophisticated consumer who has become concerned with the stress that activities such as Walking or running impose on the body. In order to maintain and improve their level of fitness, many in this group have sought out new modalities that provide the desired training stimulus but with reduced wear and tear.

To meet this demand, manufacturers first introduced treadmills with impact absorbing suspension systems. Later, the entire nature of weight-bearing cardiovascular exercise was altered with the introduction of gait simulators. These devices mimic walking and running by keeping the user suspended on two moving footplates. Unlike treadmills, however, gait simulators impart no jarring forces on the user, by virtue of the fact that the foot never leaves the support platform.

The degree to which gait simulator induces joint stress is entirely a function of its design. The initial design utilized an elliptical path of motion and was referred to as an elliptical cross trainer. A new class of gait simulator is designed around an accurate path of motion and has, thereby, been designated an arc trainer. The purpose of this investigation is to examine the kinematics and biomechanics of these gait simulators and to compare them to normal ambulatory conditions.(Ref 3,4 and9)

Observation of adult human walking suggests that coordination of this task is seemingly simple. After all, walking 'appears' quite graceful. Nevertheless, how individual muscles fulfil the mechanical requirements of the Loco motor task remains controversial even though studies of gait have a long history. One of the major issues in the biomedical engineering field is creating mathematical models that resemble the human body, in a manner that gives us the opportunity to recreate, simulator analyze movements like walking, running or stepping over obstacles.

Adaptation to bipedal walking challenges the human body from the moment we are born. Walking is achieved through a learning process that trains muscles to control the body for bipedal standing and walking. Researchers believe that human walking is not under conscious control of the central nervous system (CNS); it is assumed that the walking pattern has a low-level control in the spinal cord (Ref 10 and14)

1.1 Fundamentals of biomechanics What is biomechanics?

As you can probably guess biomechanics is the application of mechanics to biology. Mechanics is branch of applied mathematics that deals with movement and tendency to movement; it is also the science of mechanics in practice there is no difference between biomechanics and mechanics except what is studied. Certainly, in terms of underlying theory there is no difference whatsoever. However common usage of the term varies slightly from this rigid definition .biomechanics is often interested in the physiology underlying movements and also biological role of the movement. Additionally certain aspects of mechanics are rarely of interest such as quantum mechanics and relativity.

1.2 Brief history of biomechanics

Formal mechanics in the modern sense data back to Sir Isaac Newton in the 17thcentury but studying objects in motion dates back to the ancient Greeks. Biology has always had a strong influence on design. If one way batter then another, that you may be sure is nature's way.

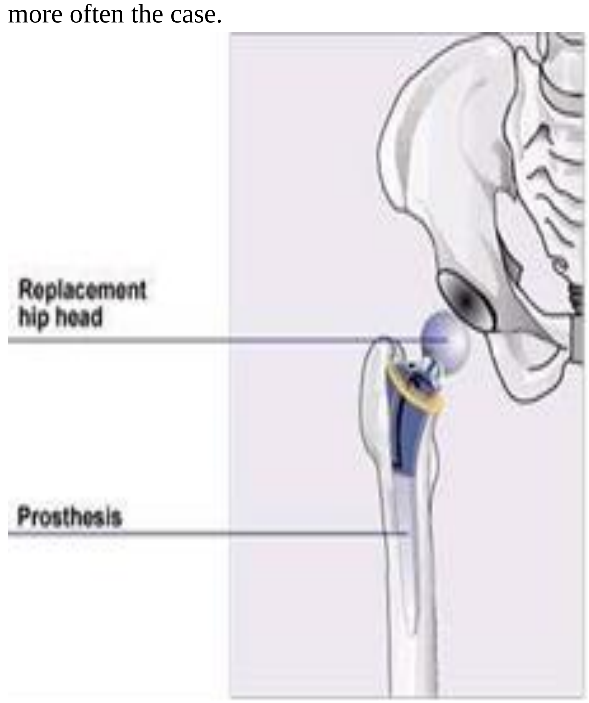
Aristotle, fourth century B.C.E Human ingenuity may make various inventions, but it well never devise any inventions more beautiful, nor more to the purpose than nature does; because in her inventions nothing is wanting and nothing is superfluous.

Leonardo ad Vinci, fifteenth century sources of hydraulic contrivances and of mechanical movements are endless in nature; and if machinist would but study in her school she would lead them to the adoption of the best principles, and the most suitable modifications of them in every possible contingency.

Thomas Embank, mid-nineteenth century one handbook that has not yet gone out of style and predictable never will is the handbook nature. Here in the totality of biological and biochemical systems the problem mankind faces have already been met and solved and through analogues met and solved optimally.

1.3 What is an artificial hip?

The idea of replacing the hip joint, with its relatively simple construction, originated in 1890. Now, around 800,000 artificial hips are implanted annually around the world and about120,000 in Germany. Artificial hips can be sub- divided into partial and total prostheses. With partial prostheses, only the hip head and the neck of the thigh bone are replaced. The natural hip socket is preserved. With total prostheses, the hip head, the neck of the thigh bone and also the hip socket are replaced by a total prosthesis. This is more often the case.



2.HIP SIMULATORDESIGN

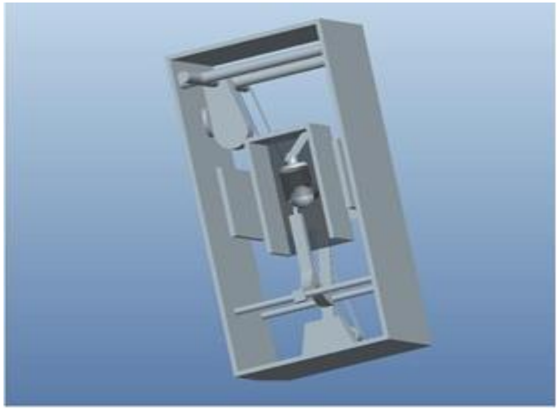


Fig2.1.Hip simulator Model

There has been a progression of innovations in treating hip fractures from the Smith-Petersen and Jewett nails to the sliding hip screw (SHS) and more recently, to intramedullary devices. Despite these advances, internal fixation devices for hip fractures have yet to find the optimal approach for all fracture configurations. Each of these implants is an attempt to balance collapse of the fracture with rigid stability. Fracture collapse has the benefit of inter fragment apposition and compression whereas rigid stability is the traditional goal of internal fixation. We have learned that achieving this balance is critical to successful treatment of hip fractures. The SHS was an attempt to attain this balance by allowing collapse of the fracture to create compression between the proximal and distal fragments.5 The design works well for stable fractures, but unstable fractures are prone to excessive collapse, resulting in leg length discrepancy and implant cut out. The intramedullary hip screw (IMHS) utilizes the nail itself to prevent excessive collapse, but cut-out from the femoral head remains problematic. Regardless of their Efficiency, both the SHS and the IMHS rely on real-time image guidance to be placed safely, which makes them unfeasible for the resource limited hospitals of the developing world.

2.1.COMPONENTS OF HIP SIMULATOR

1.FRAME:

It is the outer body of the Hip Simulator. It can be constructed of Stainless Steel, Alloy Steel, and Aluminum Alloy.

2.LINKSTAND:

It is the supporting stand for the Simulator Arm. It is the movable stand and it can be constructed of Stainless Steel, AluminiumAlloy.

3.LINKROD:

It transfers motion from the Motor to the Link Stand.

4.ACETABULARCUP:

It is fixed to the Simulator Arm. It holds the Prostheses. It can be constructed of Metal, Ceramic, Plastic depends upon the Prosthesis material.

5.CAM:

It provides horizontal motion to the Link stand. It can be constructed of Stainless Steel, AluminiumAlloy.

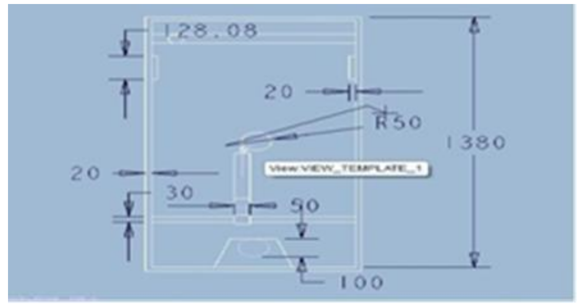


Fig 2.2.1. Main frame

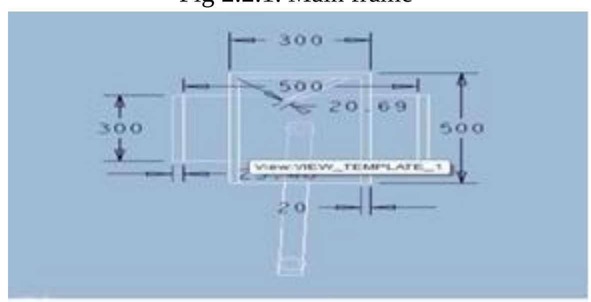


Fig 2.2.2. Link stand

2.2.HIP SIMULATOR ARMMODEL

ARM:

- Holding part of the Hip Simulator
- Holds the prosthesis and provides various motions such as Spherical Horizontal Reciprocating
- The Arm obtains motions through the link rod from the motor.

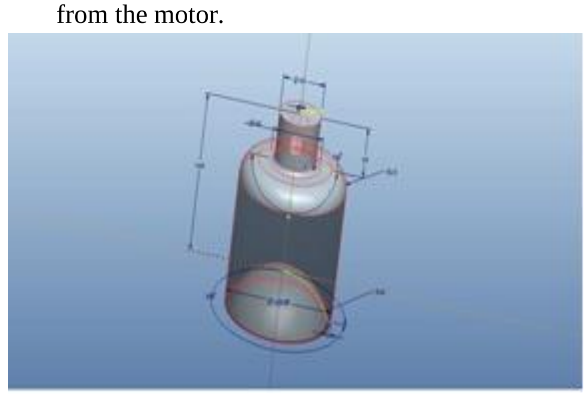


Fig 2.2.1 Prosthesis Holder

Arm diameter=50mm Arm length=300mm Acetabular Cup: Dia=46mm Length=23mm

FRAME and CAM LINK ASSEMBLY:
Cam link provides motion from motor to arm.

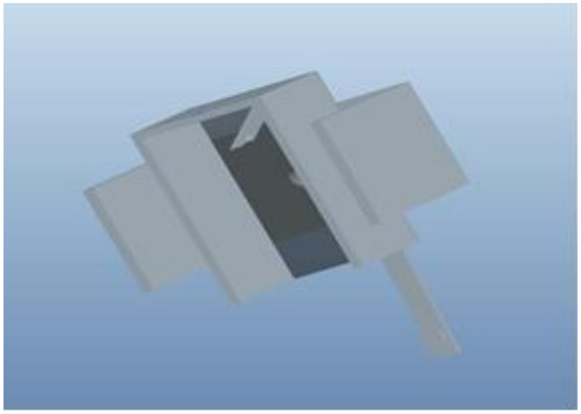


Fig 2.2.2 Link Stand Assembly

Arm Holder – 300 * 500 * 20mm Prosthesis ball dia. – 50mm Prosthesis height – 200mm

3.ANALYSIS OF HIP SIMULATOR ARM (ALUMINIUMALLOY)

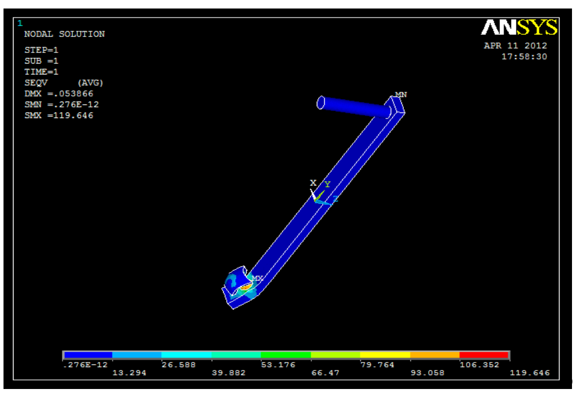


Fig 3.1.Stress analysis of link rod

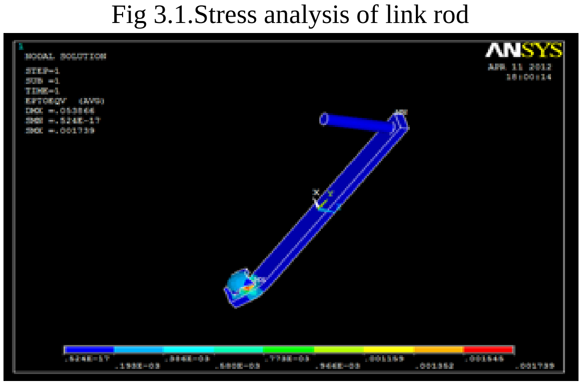


Fig 3.2. Strain analysis of link rod

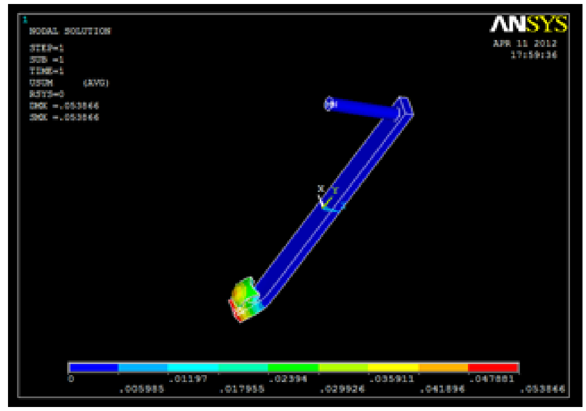
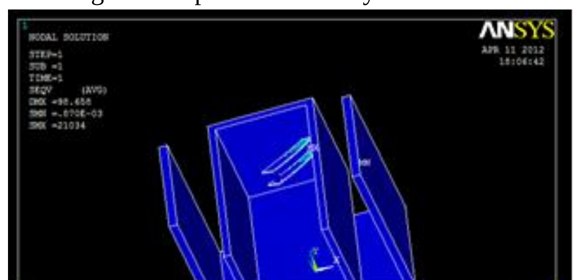


Fig 3.3. Displacement Analysis of link rod



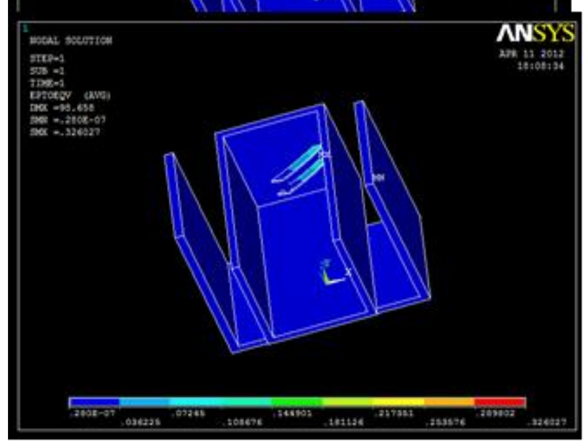


Fig 3.4. Stress analysis of link stand Fig 3.5. Strain analysis of link stand

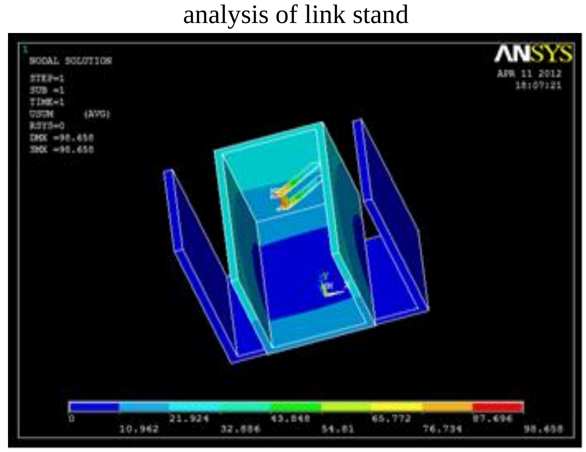


Fig 3.6 Displacement analysis of link stand

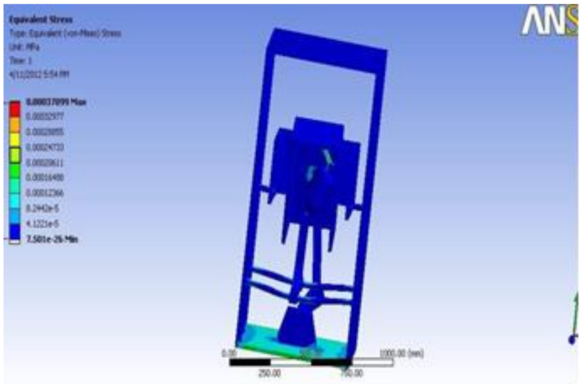


Fig 3.7 Stress Analysis of Aluminium

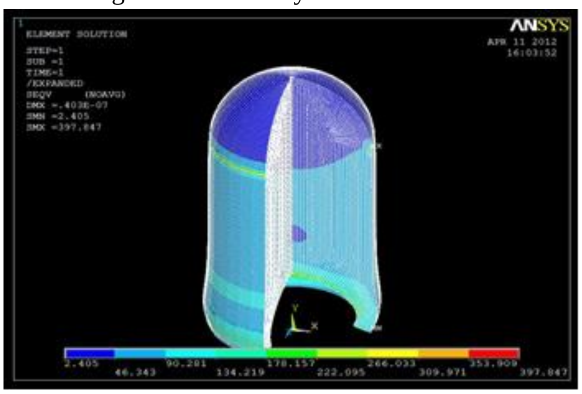


Fig 3.8 Stress Analysis of Arm

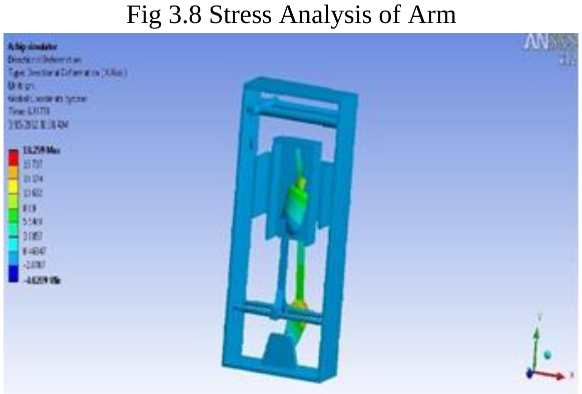


Fig 3.9 Analysis of hip simulator design

4.MATERIAL SELECTION

4.1STAINLESS STEEL MATERIAL

All standard grades of stainless steel contain iron, carbon and a minimum of 11.5% chromium, the element responsible for the inherent corrosion resistance of the alloy. All stainless steels resist corrosion, although the degree of resistance to attack by many common chemicals, food products and other materials is variable. To enhance or supplement the effect of chromium, other alloying elements are added to straight chromium stainless steels.

Physical properties

In terms of physical properties, stainless steels are markedly different from carbon steels in some respects. There are also appreciable differences between the various categories of stainless steels

STAINLESS STEEL 316 L COMPOSITION

CHROMIUM	-	17 %
NICKEL	-	11 %
OTHERS	-	2.0 Mo%
CARBON UPTAKE	-	1.0%
NITROGEN	-	≤0.10%
SCALINGTEMPERATURE -	850°C	SCALINGTEMPERATURE -

4.2COMPARISONOFMATERIALS

	STAINLESS STEEL	ALUMINUM
Young's modulus (Mpa)	200000	70000
Tensile strength (Mpa)	615	70-700
Melting point(°C)	1375-1400	660
Yield strength (Mpa)	245	200-600
Thermal conductivity (W/mK)	16.2	0.5
Poisson ratio	0.27-0.3	0.33

Arm is differentiated by these Material Properties

General characteristics of structural materials

Characteristics	Ceramics	Metal	Polymers
Density	Low to High	Low to High	Low
Hardness	High	Medium	Low
Tensile Strength	Low to Medium	High	Low
Compressive Strength	High	Medium to High	Low to Medium
Young's Modulus	Medium to High	Low to High	Low
Melting Point	High	Low to High	Low
Dimensional Stability	High	Low to Medium	Low
Thermal Expansion	Low to Medium	Medium to High	High
Thermal Conductivity	Medium	Medium to High	Low
Thermal Shock	Low	Medium to High	High
Electrical Resistance	High	Low	High
Chemical Resistance	High	Low to Medium	Medium
Oxidation Resistance	Medium to High	Low	Low
Machinability	Medium	Low	Medium

Ceramic material:

Ceramics and glasses are inorganic, nonmetallic materials consisting of metallic and nonmetallic elements bonded primarily with ionic and covalent bonds. These high strength bonds give rise to the special characteristics of these materials. They occupy a unique place in the spectrum of engineered materials offering many desirable alternatives to the metals and polymers in common usage.

Characteristics:

- Low to moderate density compared to metals
- High modulus of elasticity (stiffness)
- Good strength retention at elevated temperatures
- Resistant to high temperature creep
- Dimensional stability
- High compressive strength
- Low to moderate tensile and shear strength
- High hardness
- Corrosion and oxidation resistant
- Good electrical insulation properties
- Wide range of thermal conductivity

Nylon materials:
Nylon is one of the most common plastics, first produced at DuPont. Two common grades of nylon are Nylon 6 and Nylon 6/6.

Nylon Properties
Nylon has several advantageous properties:

- Heat resistance
- Chemical resistance
- Wear resistance
- Resilience
- Abrasion resistance
- Flexibility
- Durability
- Resistance to fungi and animals, molds, mildew, chemicals
- Low friction

Plastic Properties of Nylon (Polyamide)
Nylon (Polyamide), invented in 1928 by Wallace Carothers (DuPont) is considered to be the first engineering thermoplastic. It is one of many heterochain thermoplastics which have atoms other than C in the chain. Commercially Nylon is commonly used in the production of tire cords, rope, belts, filter cloths, sports equipment and bristles. It is particularly useful when machined into bearings, gears, rollers and thread guides.

Nylon Resistance:

- Excellent resistance (no attack) to Oils, Bases and THF
- Good resistance (no attack) to Solvents, Formaldehyde and Alcohols
- Limited resistance (moderate attack and suitable for short term use only) to Dilute Acids
- Poor resistance (not recommended for use with) Phenols, Alkalis, Iodine and Acids

Nylon Fabrication:

- Excellent material for machining
- Tough, strong, and impact resistant material
- Very low coefficient of friction
- Abrasion resistant

Polymers:
The word polymer literally means "many parts." A polymeric solid material may be considered to be one that contains many chemically bonded parts or units which themselves are bonded together to form a solid. Two industrially important polymeric materials are plastics and elastomers. Plastics are a large and varied group of synthetic materials which are processed by forming or molding into shape. Just as we have many types of metals such as aluminum and copper, we have many types of plastics such as polyethylene and nylon. Plastics can be divided into two classes, thermoplastics and thermosetting plastics, depending on how they are structurally and chemically bonded. Elastomers or rubbers can be elastically deformed a large amount when a force is applied to them and can return to their original shape (or almost) when the force is released.

Thermoplastics
Thermoplastics can be softened as often as they are reheated. Thermoplastics are not as rigid as thermosetting plastics but tend to be rougher.

Thermosetting Plastics (Thermosets)
Thermosetting plastics undergo a chemical change during moulding a can never again be softened by reheating. The chemical change in the moulding process is triggered by temperature and pressure and is called *curing.* Thermosetting plastics are harder and more brittle than thermoplastic materials.

5.RAPIDPROTOTYPING

Before fabricating the original simulator, it is necessary to make a prototype of the product to test the stability of that product material and so, the Rapid prototyping (RP) has been adopted as the technique to test the product material first.

MATERIAL USED INRP
Durable Polyamide (Nylon)

OTHER SUGGESTED MATERIALS
Polycarbonate (PC)-white, Black, Translucent
Polyphenylsulfone (PPSF) ABS-M30i (ivory color)

- Once the RP model has been developed, the sample prosthesis can be tested on that, else, the RP model can be used as a mould for the real Simulator model casting.
- On the real simulator model, the real prosthesis materials can be tested.
- The following tests can be performed over the real hip simulator model.
- Prosthesis model is implemented for developing the original model after analyzing.

6.DESIGNCALCULATION

Pressure=100N/mm^2 P=Load /Area
100=Load/(-)
L=196.3*10^3N
Stress= Load/ Area
= 196.3*10^3 / (-)
Stress= 61.019N/mm^2
Theoretical Stress (in Ansys) = 307.32N/mm^2
Theoretical Stress (in Calculation) =61.019N/mm^2

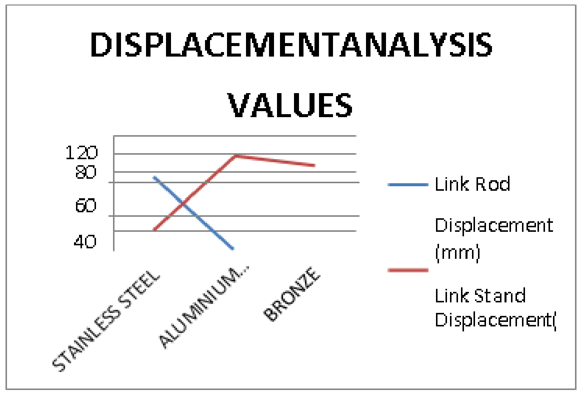
The maximum allowable stress for material=515*10^6 N/mm^2
= (515*10^6)/ (10^3) ^{2}
=515N/mm^2

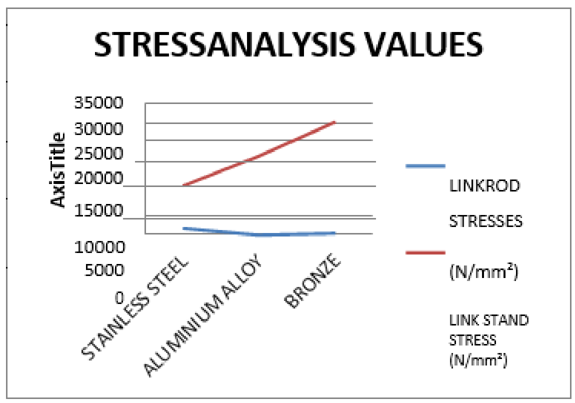
Factor of Safety= Maximum allowable stress/ Working stress
= 515/307.32
=1.66
Hence, the design is safe.

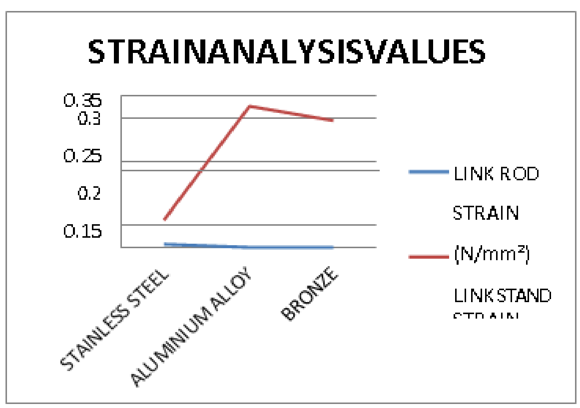
7.RESULT

- TheRP model of the simulator is developed.
- This model can be used for the casting of real simulator.
- Testing has been done computationally over the hip simulator and the data are obtained.
- Using these data the life period of the prosthesis material can be calculated.

SCOPE FOR FUTURE WORK
- This RP model can be used as a mould for casting the real simulator using different materials.
- Using the real arm, the stress values for different postures can be obtained.







Stress analysis of Arm=397.847N/mm^2

7.COSTESTIMATION

USED MATERIAL (PROTOTYPE):

Material -	NYLON
Materialcost -	Rs.15500.00
Manufacturingcost-	Rs.5500.00
Tax &otherexpenses-	Rs.3500.00
Transportation -	Rs.2200.00
TOTAL -	Rs.26700.00

8.CONCLUSION

- The RP model has been made from the design.
- The simulator can be operated under different loading conditions and different postures.
- The stress values can be taken from the plots.
- Using the stress values obtained, the fatigue, wear and contact analysis will be done for finding the life period of the materials.
- Analysis can be done over different biomaterials and suitable material can be found for the prosthesis which is to be used on the patient.
- The life period can be calculated using this simulator.

9. PHOTOGRAHIC VIEW

Fig:9.1. Front View of Hip Simulator

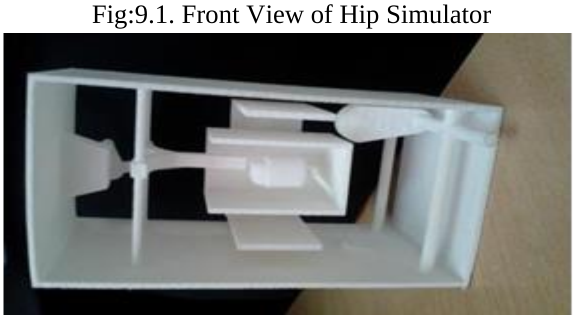


Fig:9.2. Rear View of Hip Simulator

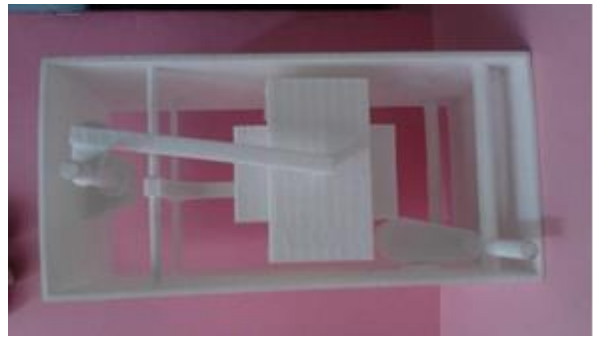


Fig 9.3. Arm Design

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