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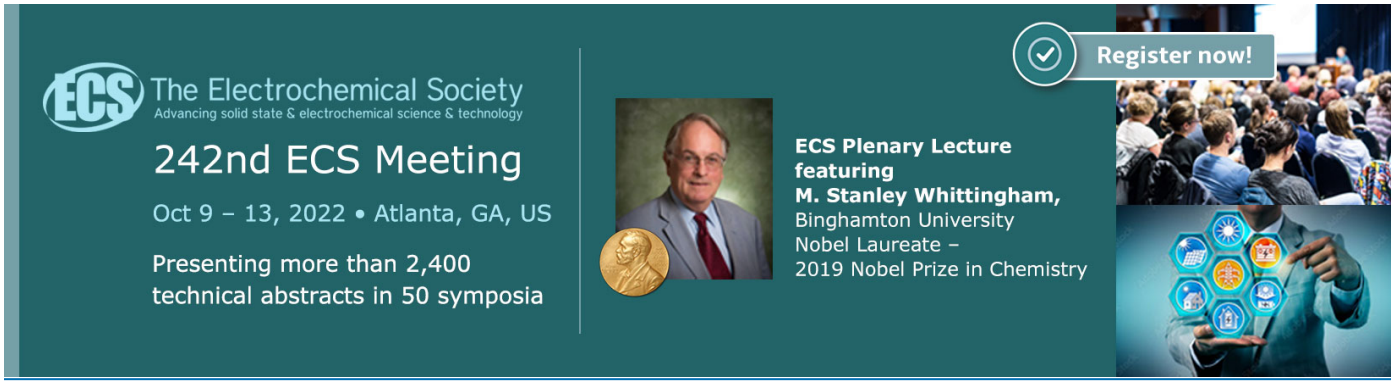

Design of biped hip simulator using SolidWorks

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Abstract. The increasing number of people who underwent both hip implant surgery based on World Health Organization (WHO) has received massive attention from researchers lately to develop various types of hip simulators in order to test the hip implant. Various number of hip simulator have been developed with different functions and capabilities. This paper presents the design development of biped hip simulator using SolidWorks software by taking into consideration some improvement and modifications. The finite element method is used to test the design whether it is safe to be used or not. The biped hip simulator has been successfully designed and ready to be fabricated as the endurance testing shown a positive results. The von Mises stress induced in the material is an alloy steel which is 2,975,862.3 N/m^2 lower than the yield strength. Thus, the design is safe to be used as it obey the safety criterion.

1. Introduction

A few last decades, hip joint prosthetics have been widely used in world's orthopedic surgery where 400 000 operations were performed every year and more than 100 designs of orthopedic construction have been proposed. Based on that, the development of hip simulator has received massive attention from researchers. A simulator generally described as machine that used to test a joint replacement under condition approximating the motion that occur in human body. Simulator test can be used to conduct protocol that replicates particularly extreme conditions and establishing the performance limit of the material [1].

There are few simulators that have been developed in order to achieve similarity between simulation and in-vivo conditions [2]. The simulators are differ from each other from a lot of parameters such as movements, number of channels, degree of freedom, configuration of the femoral head and acetabular component, and loading condition. Wear and dislocation of the artificial hip joint are still serious problems to be solved in hip joint replacement [3].

Basically, there are a lot of hip simulators that have been developed and differ in their sophistication level and plays a crucial role in the pre-clinical validation of biomaterials used for hip implants. Most of them were focused on testing wear and load on hips implant in which unfortunately, the metal-on-metal hips articulation suffers from friction due to the moving metal surface thus, shortening the surviving of the joint [4-5].

What is a biped hip simulator? Generally, the biped hip simulator is a simulator for testing both right and left hip implant as it is built in pair (consist of both right and left hip joint). This is because, both right and left performances is assumed to be symmetrical, but some research reported there are

differences in the action of lower extremities although in able-bodied. Unfortunately, it actually affect the performance of both right and left hip joints since the wear mechanism were difference between them. Therefore, biped hip simulator is designed that able to be used to test for wear rate and load effect on hip implant especially for both hip replacement surgery. This paper introduces biped hip simulator design and simulation by using SolidWorks software. Finite element method for design endurance testing will also be discussed further in this paper.

2. Design Methodology

Biped hip simulator design was drawn using SolidWorks sofware and the design is based on the current available hip simulator with some improvement in term of size and performance.

2.1. Design selection process

The selection criteria are based on manufacturability, complexity, stability, cost, maintenance, compact size, light weight, and lubrication space. Design selection is important as it will results to a competitive design, better product-process coordination, and minimizing product fabrication.

In selection concept, there are two-stage design selection methodology in which the first stage is called concept screening and the second stage is called concept scoring. Each is supported by a decision matrix, which is used to rate, rank, and selects the concepts. Concept selection is often performed in two stages as a way to manage the complexity of evaluating dozens of design concepts. Furthermore, the design of biped hip simulator is an improvement and modification made from various available hip simulator that have been developed. Therefore, a correct procedure will ensure smooth design process.

2.2. Design Concept Screening

Concept screening is based on a method developed by Struart Pugh in the 1980 and is often called Pugh design concept selection [6-7]. The purpose of this stage is to narrow the number of design concept quickly and to improve the concepts. Six design concepts were chosen from others work in literature which are wobble plate, actuator (reference), hydraulic, compressor, pumping and linear concept.

Table 1. The concept-screening matrix for the biped hip simulator design concept.

	Design					
Selection Criteria	A (wobble plate)	B (actuator) Reference	C (linear)	D (hydraulic)	E (compressor)	F (pumping)
Manufacturability	+		+	+	+	+
Complexity	0	D	+	-	-	-
Stability	+	A	+	0	-	0
Cost	0	T	0	0	-	0
Lubrication space	+	U	0	+	+	-
maintenance	0	M	0	0	0	0
Small size	-		0	-	-	+
Light weight	+		-	-	-	-
Sum +’s	4	0	3	2	2	2
Sum 0’s	3	8	4	3	1	3
Sum -’s	1	0	1	3	5	3
Net score	3	0	2	-1	-3	-1
Rank	1	3	2	4	5	4
Continue?	YES	YES	YES	NO	NO	NO

The design A (wobble plate), C (linear) , D (hydraulic), E (compressor) and F (pumping) are compared to reference design B (actuator) in order to narrow down the number of design concept as to make it easy to select the best concept. Symbol (+) means better than, (0) means same as and (-) means worse than reference design concept as shown in table 1. Based on table 1, it can be seen clearly that, the chosen design concept are design A, B and C due to the highest net score results from the subtraction of Sum of (+) and Sum of (-). The net score result of the design A, B and C are 3, 0 and 2 respectively.

2.3. Design Concept Scoring

Concept scoring is used when increased resolution shows a better differentiation among the competing concept. In this stage, it goes to weight the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion. The design concept scores are determined by the weighted sum ratings. In this part, there are three concepts design (A, B and C) which will be rated to choose the biped hip simulator design concept for developing a new biped hip simulator design.

Based on table 2, it can be seen clearly that, the best selection of the design concept of biped hip simulator is design C (linear concept). This is because, design C has the highest weighted score compared to design A and B with 3.95 score. It is based on the rating given as depicted in table 3 to each selection criteria after considering some aspect or factors. Design C is the chosen design concept and will be realized into a real design by using SolidWorks software.

Table 2. The concept-scoring matrix of the biped hip simulator design.

		Design					
		A (wobble plate)		B (actuator) Reference		C (linear)	
Selection Criteria	Weight (%)	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Manufacturability	10	3	0.3	1	0.1	3	0.3
Complexity	10	3	0.3	3	0.3	3	0.3
Stability	10	3	0.3	3	0.3	3	0.3
Cost	15	2	0.3	5	0.75	5	0.75
Lubrication space	5	2	0.1	3	0.2	3	0.2
maintenance	15	2	0.3	4	0.6	5	0.75
Small size	20	3	0.6	1	0.2	3	0.6
Light weight	15	2	0.3	3	0.45	5	0.75
	Total score		2.9		2.9		3.95
	Rank		3		2		1
	Decision		NO		NO		YES

Table 3. Performance rating of for the design concept

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

3. Results

3.1. Biped hip simulator design

The biped hip simulator is designed with some improvement and modification made based on specification that are obtained from literature on others work. The system of simulator is expected to imitate the motions and loads seen by the human hip joint and able to test the contact load and wear on the artificial hip for pitted surface filled with lubricant in order to prolong the lifespan. The simulator can be used to test the lifespan of hip implant especially for both hip joint replacement surgery, to investigate the different of contact load and wear on human dominant and non-dominant limb apart from reducing the manufacturing cost as it is developed in compact size. Figure 1 shows the design of biped hip simulator that was drawn using SolidWorks from the chosen design C after undergo the design selection process. SolidWorks software is a solid modeller and utilizes a parametric feature based approach to create models and assemblies that easy to use, affordable, and available on the Windows desktop. Based on that features, SolidWorks software is used to draw and simulate the biped hip simulator design.

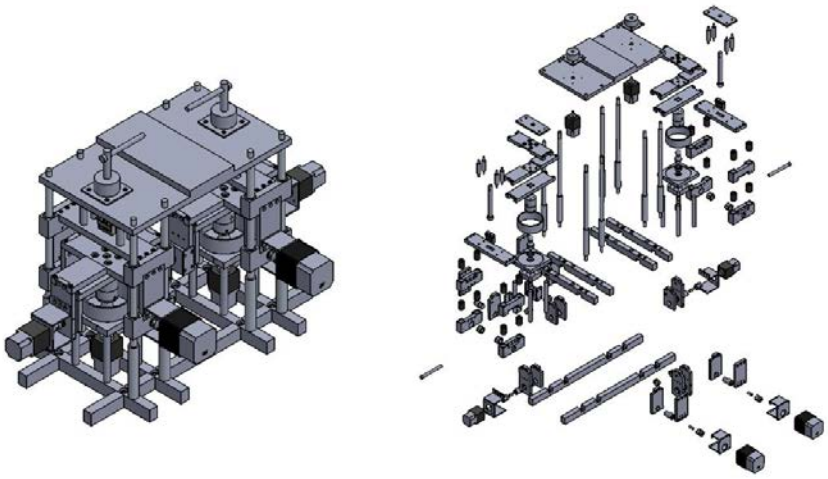

Figure 1. Design of biped hip simulator before and after assemble

Designing of the biped hip simulator design is tedious as it need to be designed part by part as each part plays a crucial role in making it completely functioning as desired. From each part then, it need to be assembled to make a complete design as shown in figure 1. Figure 2 shows the illustration of the main frame in the biped hip simulator design. The hip implant part is embedded in innermost of the frame and become the fixed geometry of the whole main frame. The design consists of 6 stepper motor in which it will be controlled by design control system to make it run as illustrated in figure 2. This is because, the simulators provides the motions of flexion-extension, abduction-adduction, and internal-external rotation.

Besides, the load will be applied manually by rotating the handle at the top of the design as shown in figure 1 and the load cell sensor will read the applied load value. The maximum load applied for the simulator is up to 3 kN. In addition, the simulator can be reconfigured in term of the load exerted and angle of movement by controlling the speed of the motor to imitate human daily life motion. In addition, the biped hip simulator design is based on the ISO standard 14242-1 and applicable to the human normal walking cycles during the gait cycles [8].

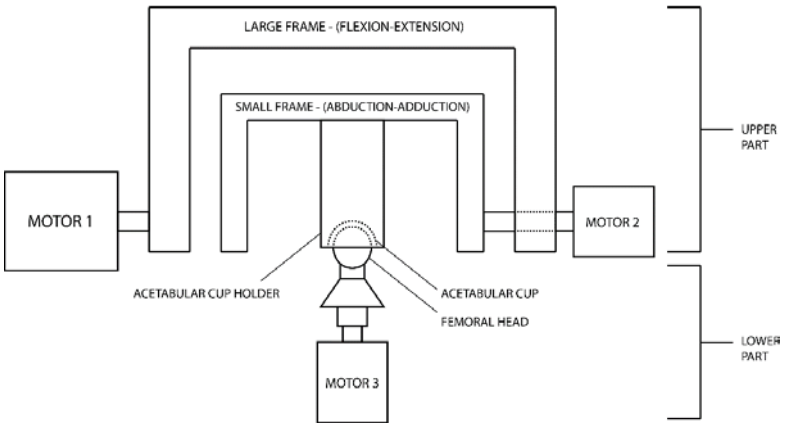

Figure 2. Illustration of the main frame.

3.2. Design endurance simulation

Endurance simulation is performed by using SolidWorks SimulationXpress for finite element method (FE) [9]. This is really important to determine whether the design are successfully done and can be fabricated. All aspects of a design have some degree of uncertainty and for the reasons, a factor of safety (FOS) is employed. The FOS of unity means that failure is eminent and it does not mean that a part or assembly is safe to be used or being fabricated. In current practice, it is advisable to justify $1 < FOS < 8$ and FOS must be greater than 1 in order to make sure that the design is safe and functioning properly as desired. Von Mises stress is used in the simulation to check whether the design can withstand a given load condition (3kN for biped hip simulator). The design is considered fail, if the maximum value of von Mises stress induced in the material is more than the strength of the material.

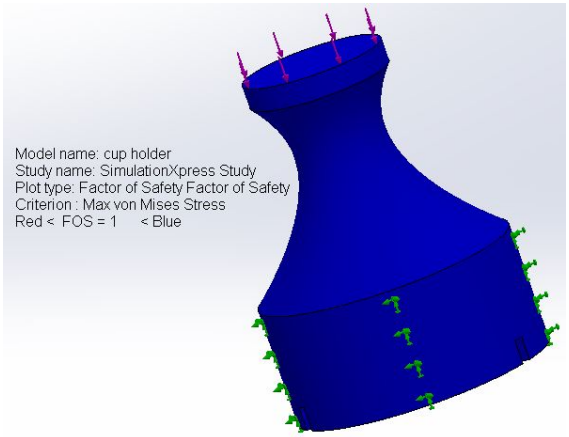

Figure 3. Simulation result of a part of biped hip simulator design using SolidWorks

The design was simulated part by part in order to obtain a safe and good final product. Every single part of the design need to be simulated as it can help to predict how the part will perform under load condition and help to detect potential problems early in the design stage before it is being fabricated. Materials used for this simulation design is alloy steel and force exerted is 3 kN as it is the maximum load that the human hip joint can withstand. Figure 3 shows a simulation result of a part of biped hip simulator design using SolidWorks. The FOS must be more than 1 in order to have a safe design and if it is less than 1, then some readjustment must be made in terms of material selections, design size and others.

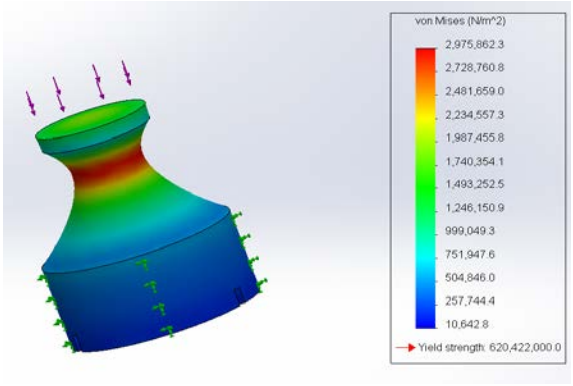

Figure 4. Von Mises stress induced in the biped hip simulator hip cup and the yield strength.

In figure 4, it can be seen clearly that von Mises stress induced in the material lower than the yield strength which means that the design is safe to be used as it is obeyed the safety criterion. The value of von Mises at red area is 2,975,862.3 N/m^2 in which red represents the highest deformation followed by yellow, green and blue However, if the von Mises stress induced in the material exceeds the yield strength, some adjustments need to be done in term of the material selections, size of the defect part of the design and other related factors. The steps are repeated for other part of the design so that the overall design is safe to be fabricated.

4. Conclusion

Biped hip simulator has been successfully designed and simulate using SolidWorks software. Designing biped hip simulator has been done carefully as it deals with a very small components and parts. Based on the results, the design capable to provide the motions of flexion-extension, abduction-adduction, and internal-external rotation. It is found that, the biped hip simulator design is ready to be fabricated as the endurance testing shown a positive results.

5. Acknowledgments

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