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FINAL YEAR PROJECT 2

Development of Waist Power Assistive Suit to Prevent Lower Back Pain

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“Development of Waist Power Assistive Suit to Prevent Lower Back Pain”

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A report submitted in partial fulfillment of the requirements for the degree of

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I hereby declare that I have read through this report entitle “Development of Waist Power Assistive Suit to Prevent Lower Back Pain” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering.

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Date : …………………………………………..

I declare that this report entitle “Development of Waist Power Assistive Suit to Prevent Lower Back Pain” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signature : ....

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Dedicated to my beloved family and friends

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First and foremost, praise to Allah the Almighty for it countless blessings and guidance throughout the hard times I have endured. I would like to thank for many people that always support me until the end of the project.

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ABSTRACT

Waist assistive power suit will be develop to prevent lower back pain for workers in industry. The significant of this research are this product can use by industry worker especially for carries heavy load and also can be used by the patient with a problem to do task normally. The exoskeleton spine are design to follow the 3 different types of DOF such as spine flexion(forward bending), spine lateral flexion(sideways bending, left or right) and spine rotation(rotation around the vertical axis). Each movement has each angle stress limitation on human body, thus the design are created to ensure that the waist assistive suit can protect the posture of human body while help to increase productivity by created a suit that give enough force to do their work productively. The objective of the project is to design and develop waist assistive suit while able to validate the design of waist assistive suit. Waist assistive power suit will use concept of human spine which can move in three degree of freedom (flexion, lateral flexion, and rotation). Hence the design will be concentrate into making a waist assistive suit that are reliable and mathematically proven in weight ratio in required torque to lift a load. The design will start by draw a model by using Solidworks software and the model will be simulate using a simulation in Solidwork software. Then the prototype will be fabricate and the analysis on the mechanism will be take place regarding weight, stress, strain, assistive torque using the spring, motor and material selection. From the result, we know that the maximum yield strength for alloy steel is 54 kg if applied direct force to material. The assistive torque that the spring correspond to the 7 kg load is 2.94 Nm. From the graph it shows that the increase of load and distance will increase the assistive torque produced by spring.

ABSTRAK

Jaket pembantu pergerakan pinggang akan dibangunkan untuk mencegah sakit belakang yang dialami oleh pekerja dalam industri berat. Perkara yang penting dalam kajian ini ialah produk ini boleh digunakan oleh pekerja industri terutama untuk membawa beban berat dan juga boleh digunakan oleh pesakit dengan masalah untuk melakukan tugas-tugas seperti biasa. Jaket pembantu pergerakan pinggang akan menggunakan konsep tulang belakang manusia yang boleh bergerak dalam tiga darjah kebebasan (akhiran, akhiran sisi, dan putaran). Setiap pergerakan mempunyai setiap sudut had tekanan pada badan manusia, dengan itu reka bentuk yang dicipta untuk memastikan bahawa jaket bantuan pinggang boleh melindungi postur badan manusia manakala bantuan untuk meningkatkan produktiviti dengan mencipta satu jaket yang memberikan daya yang cukup untuk melakukan kerja mereka secara produktif. Objektif projek ini adalah untuk mereka bentuk dan membangunkan jaket pembantu pinggang manakala dapat mengesahkan reka bentuk jaket bantuan pinggang. Jaket kuasa bantuan akan menggunakan konsep tulang belakang manusia yang boleh bergerak dalam tiga darjah kebebasan (akhiran, akhiran sisi, dan putaran). Oleh itu reka bentuk akan menjadi menumpukan perhatian ke dalam membuat jaket bantuan pinggang yang boleh dipercayai dan terbukti dalam matematik terbukti dalam nisbah berat dalam tork diperlukan untuk mengangkat beban. Reka bentuk ini akan bermula dengan dengan menggunakan perisian Solidworks dan model akan disimulasikan menggunakan simulasi dalam perisian Solidwork. Kemudian prototaip akan dianalisis mengenai mekanisme akan dilakukan mengenai berat badan, tekanan, ketegangan, tork bantuan menggunakan spring, motor dan pemilihan bahan. Dari keputusan, kita tahu bahawa kekuatan maksimum untuk keluli aloi adalah 54 kg jika digunakan kuasa terus kepada material. Daya kilas bantuan yang tork sesuai dengan beban 7 kg 2.94 Nm. Daripada graf ini menunjukkan bahawa peningkatan beban dan jarak akan meningkatkan tork bantuan yang dihasilkan.

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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

The economic development in Malaysia evolve through commercialize of car manufacturing industry in 1983. In 2013 the number of worker that are involve with the car manufacturing industry are 26 367 workers [1] compare to 2007 statistic that show that 24 146 workers [2] that worked in motor vehicle manufacturing that year.

Car manufacturing industry recorded third-highest number of Cumulative Trauma Disorder (CTD) related injuries compared to other industry with the incidence rate of 963.5 per 10,000 cases of repeated trauma workers [3]. A study conducted among employees working on the assembly line in the automotive industry shows that 39% of musculoskeletal disorders suffered by the employee is at the bottom spine, followed by the head-neck-shoulder with 18% and the lower body region by 16% [4].

In Malaysia, the occupational diseases problem began to get the attention of various parties. In 2006 there were 14 cases of musculoskeletal injury reported by the Social Security Organization (SOCSO) [5].Exoskeleton upper limb power suit is develop as the waist power assistive robot to prevent lower back pain and can enhance strength and endurance of people especially when they are work.by having this suit it will increase the productivity of the workers.

The idea to develop waist power assistive robot to prevent lower back pain are from the idea to help worker in the industrial manufacturing. This concept helps workers especially on the industrial to work longer without hurt their back. These waist power assistive suits will use concept of human spine which can move in three degree-of-freedom (flexion, lateral flexion and rotation).

From the result obtained, the percentage of people suffers from lower back is increasing with 57.9% in 12 months, 49.5% in one month and 35.1% in 7 days[2]. Due to this, a waist power assist suit to prevent a lower back pain is needed especially to worker industry.

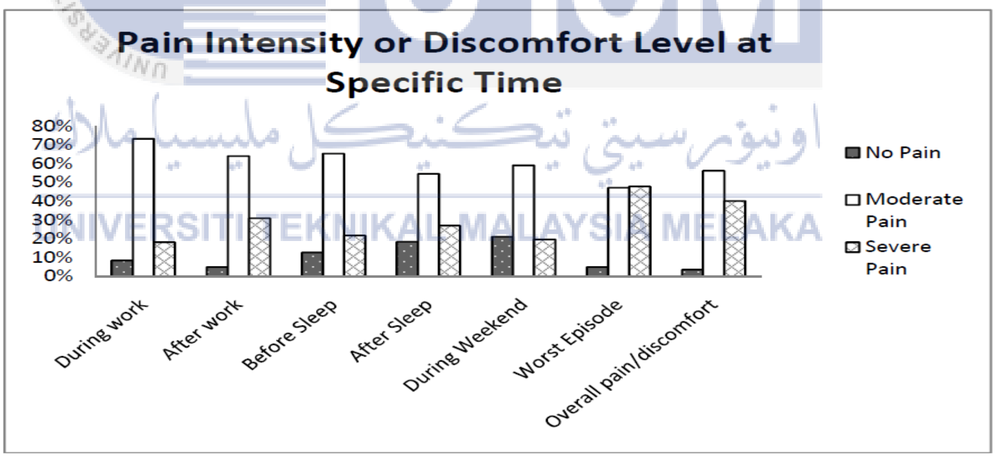


Figure 1.1: Pain Intensity or Discomfort Level at Specific Time [2]

1.2 PROBLEM STATEMENT

This project of designing an electrical exoskeleton is to improve the size and weight of exoskeleton for an ideal operation condition for the user. The problem rise with the mentality to create an exoskeleton that are small but are wise in weight to power ratio considering that there are a lot of machine induced in helping human to carry a heavy weigh. The exoskeleton spine are design to follow the 3 different types of DOF such as spine flexion(forward bending), spine lateral flexion(sideways bending, left or right) and spine rotation(rotation around the vertical axis). Each movement has each angle stress limitation on human body, thus the design are created to ensure that the waist assistive suit can protect the posture of human body while help to increase productivity by created a suit that give enough force to do their work productively.

The first components is modeling the 3 degree-of freedom of lower back suit mathematically in term of dynamics analysis. In this part we will calculate the motor torque that are required at the help. We will see the relationship between motor torque and the load that human can carry versus the angle with regards to the gravity of earth. The second components is to design the assistive torque that can help to distribute the required torque. We will study on the relationship between the distances (angle) of the spring to the assistive torque that the spring can produced. The last components is to analyze the structure of the in term of stress, strain analysis. We will use the simulation in solid work to see the break point of the material use, in this case alloy steel. From that we can see the relationship between the load uses to the break point of the material use.

In terms of actuator, in previous study there are some that incorporated hydraulics and pneumatics system to actuate their exoskeleton but in terms of usage the electrical actuated system is more popular usage of researches. There are some problem regarding the using of hydraulics and pneumatics system. One of the main reason is because of its system complexity, there are need of both hydraulics and pneumatics system for the actuators while the control and sensors system are rely on electrical system. Other than that, in terms of hydraulics and pneumatics system, the oil leakage may occur that reduce the performance and comfortable of the user. [6, 7] Besides that the air compressor produce noise that can distracted the user that need to be fully focused in their field of work. [21, 22]

Even though electrical actuated system are more popular in research studies there are downside that needs to be overcome. The motor that will be used is be minimal in size and weight but can produce a high number of torque. The problem is to find this kind of motor with the price range that are within the budget of the project Exoskeleton upper limb power suit is develop as the waist power assistive robot to prevent lower back pain and can enhance strength and endurance of people especially when they are work. Lower back pain may occurred due to the compression force to the lumbar which exceed a threshold of 3400N [8]. Thus to overcome this, the purposed of waist power assistive suit should be design to hold 100Nm torque. It's possible to find motor that can produce 100Nm but considering the size, weight and price range of the motor it is difficult to overcame this problem.

In the case of considerable lifting heights, high velocity devices are applied with the purpose of shortening cycle duration and increasing the capacity. In the paper, they analysis the relevant influence such as variation of the rope free length, slipping of the elastic rope over the drum or pulley and damping due to the rope frictional friction[9]. The system combining the pulley system and rope system to increase the volume of the weight that the motor can carry at certain time. The length of the rope effect the load that can be carry by the motor. If the load is near the motor, thus the system can lift a heavy load compare a system that has a long rope system that reduce the amount of the load that the motor can carry.

1.3 OBJECTIVE

- To design and develop waist assistive suit in terms of strength of structure and mechanism of the suit versus the torque required and assistive torque to assist the movement of the user
- To validate the design of waist assistive suit using the dynamics analysis

1.4 SCOPE OF RESEARCH

This project mainly on the development of waist assistive power suit. The design will be conducted using the Solid Works software in the Mechatronics Lab before been fabricate. The average of weight of Malaysians people is 61.8 kg, thus with regard of this the human body should support up to 100kg using the normal strength without any help [10].

The waist assistive suit will be actuated by electrical actuator that available on the market. The motor that will be used is be minimal in size and weight but can produce a high number of torque. The problem is to find this kind of motor with the price range that are within the budget of the project. The experiment will been conduct after the prototyping product is done. The experiment is mainly on the measurement of force on the waist assistive suit that will lift loads of 1 kg, 2 kg, 3 kg, 4 kg, 5 kg, 6 kg and 7 kg with the addition of the upper limb of human weight.

The design will consists a pulley system and spring system that will help to reduce the torque needed in the assistive torque provided by the DC motor and spring. In Hooke Law Theory state that if an object applies a force to spring, the spring will generates an opposite force to the object. The theory is valid if the elastic limit is not over than it should. If the spring is pushed or pulled more that it should it should, it will loss it stretchy ability.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Background

Exoskeleton upper limb power suit is develop as the waist power assistive suit to prevent lower back pain and can enhance strength and endurance of people especially when they are work. Lower back pain may occurred due to the compression force to the lumbar which exceed a threshold of 3400N [8]. Thus to overcome this, the purposed of waist power assistive suit should be design to hold 100Nm torque. Rosen et al. stated that when human perfuming daily tasks the gravitational component of the support forces accounts more than 90% of the total force [11].

As the name suggested, the upper limb exoskeleton will be focused on the waist to the neck because of the main objective of the project is to prevent lower back pain by develop a waist power assistive suit. There are other type of exoskeleton that are well known in the industry such as Hybrid Assistive Limb (HAL) develop by Cyberdyne. The suit are develop as a full body exoskeleton to help in nursing home [12, 13, 14, 21, 22].

There are many type of exoskeleton that surfaced this past year, thus to design a suitable waist power assistive suit to prevent lower back pain and can enhance strength and endurance of people especially when they are work many aspects much be taken care such as suitable components and design that are compatible with the system and user.

2.2 State of Art

2.2.1 Biomechanics of Human

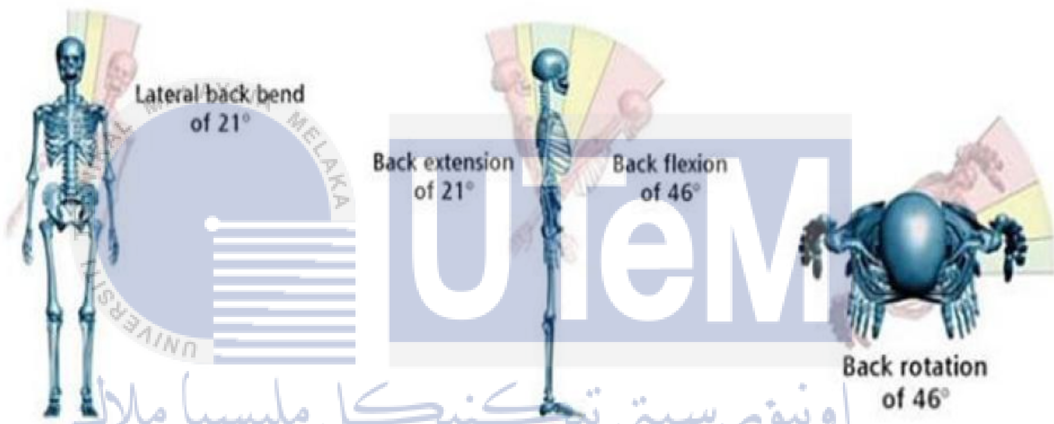


Figure 2.1: Motion Movement of Back Side of Human [8]

There are 4 types of zone that human will encounter while standing or sitting. The first zone is Zone 0 (Green Zero), zone that encounter most of the movement while puts minimal stress on muscles and joints are same with the condition of Zone 1 (Yellow Zone). The 3rd zone is Zone 2 (Red Zone) that gives extreme position for limbs, puts high strain on muscles and joints.While Zone 3 (Beyond Red Zone is the most extreme position for limbs that should be avoided while lifting or repetitive tasks [8].

Table 2.1: Back Range Motion [8]

		Range of Motion			
	Movement	Zone 0	Zone 1	Zone 2	Zone 3
	Flexion	0-10	11-25	26-45	46+
BACK	Extension	0-5	6-10	11-20	21+
	Rotational	0-10	11-25	26-45	46+
	Lateral Bend	0-5	6-10	11-20	21+

The exoskeleton spine are design to follow the 3 different types of DOF such as spine flexion(forward bending), spine lateral flexion(sideways bending, left or right) and spine rotation(rotation around the vertical axis)

- Spine flexion

Spine flexion is most important DOF to lifting while extend total flexion range and allow natural bending postures

- Spine lateral flexion

This motion is to lift up or put down objects that tilted sideways. The required forces always toward neutral position with the consideration to balance the weight of the wearer and the load as their center mass.

- Spine rotation

Rotation motion are used to move the objects sideways or to extend the reach.to prevent large rotation, the supporting torque towards neutral position must been take consideration

2.2.2 Dynamics Analysis

In this section will be focused on the theoretical parts that are related to the dynamics mechanism of the design. The main objective of this art is to find the required torque at the hip and to find the assistive torque that help distributed the load to the power to weight ratio.

Parameter $F_{UP,pulley}$ is the friction component during downward flexion. This similar for $F_{dwn,A4}$, $F_{up,A1}$, and $F_{up,A4}$ with up indicating upward flexion. Parameter $F_{UP,pulley}$ is the friction components relatively to the torque that drive the cables,T_{pulley}, which the sum of the T_{motor} and at the T_{spring}. [12].

$$T_{pulley} = T_{motor} + T_{spring} \tag{1}$$

T_{motor} is calculated as follows when flexing down:

$$T_{motor} = -2 + \frac{M_{hip} - F_{dwn,A1} - F_{dwn,A4}}{TR} - T_{spring} \tag{2}$$

And when flexing up:

$$T_{motor} = 2 + \frac{M_{hip} - F_{up,A1} - F_{up,A4} - F_{UP,pulley}}{TR} - T_{spring} \tag{3}$$

In the figure show the dynamics variable to find the torque at the hip. This part is very important because by using the equation given in [15, 16], we can find the required torque corresponding to the load and the angle of the waist assistive suit that built according to upper limb of human body. The design are consider the ergonomics structure of human spine because the purpose of the waist assistive suit is to prevent lower back pain. Thus we must consider the limitation of human spine according to [8].

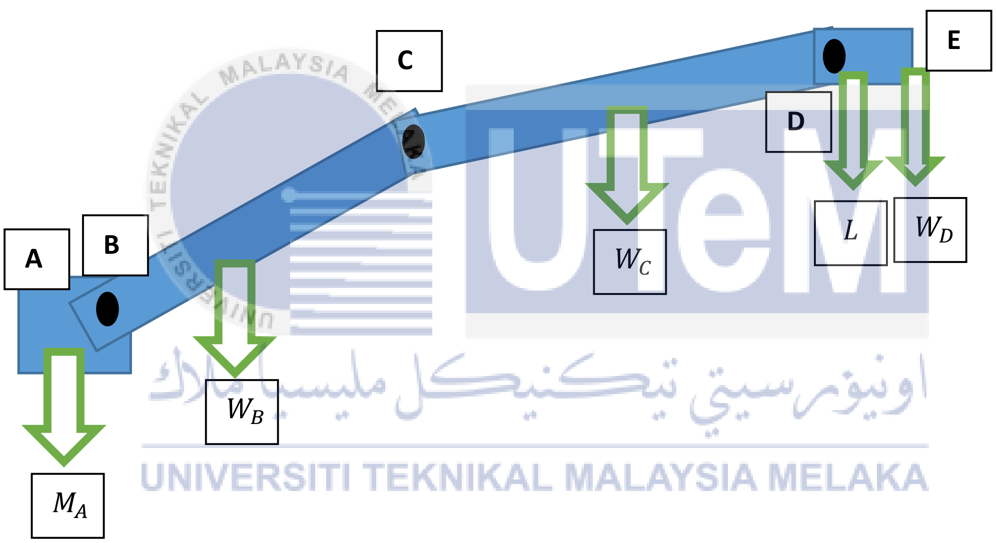


Figure 2.2: Dynamics Variable [15,16]

$M_A = weight\ of\ motor$

$W_B = weight\ of\ link\ AB$

$W_C = weight\ of\ link\ BC$

$W_D = weight\ of\ link\ CD$

$L = load$

$L_{BC} = length\ of\ link\ BC$

$L_{CD} = length\ of\ link\ CD$

$L_{DE} = length\ of\ link\ DE$

Taking the sum of forces in Y axis, using the load, find the force in the B_Y and C_Y and the torque of the motor at M_B:

$$\sum F_Y = (L + W_D + M_A + W_C)g - C_Y = 0 \tag{4}$$

$$\sum F_Y = (L + W_D + M_A + W_C + W_B)g - B_Y = 0 \tag{5}$$

$$\sum M_B = -L(L_{BC} + L_{CD} + L_{DE}) - W_D\left(L_{BC} + L_{CD} + \frac{L_{DE}}{2}\right) - W_C\left(L_{BC} + \frac{L_{CD}}{2}\right) - W_B\left(\frac{L_{BC}}{2}\right) + M_B = 0 \tag{6}$$

2.2.4 Weight and Pulley

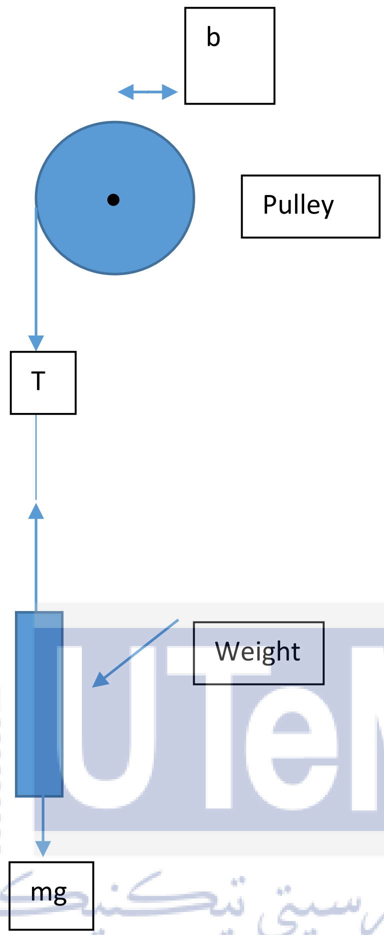


Figure 2.3: Weight and Pulley Diagram [17]

Let v be the instantaneous downward velocity of the weight, ω the instantaneous angular velocity of the pulley, and T the tension in the cable. [17]

$$mv = mg - T \tag{7}$$

The angular equation of motion of the pulley is written

$$I\omega = \tau \tag{8}$$

Where I is its moment of inertia, and τ is the torque acting on the pulley. While b, represent the radius of the pulley. Hence,

$$\tau = Tb \tag{9}$$

If the cable does not slip with respect to the pulley, then its downward velocity, must match the tangential velocity of the outer surface of the pulley, $b\omega$. Thus,

$$v = b\omega \qquad 10)$$

The above equations can be combined to give

$$T = \frac{mg}{1 + mb^2 / I} \tag{11}$$

Now, the moment of inertia of the pulley is $I = (1/2)Mb^2$ .Hence, the above expressions reduce to

$$T = \frac{mg}{1 + mb^2 / I} = \frac{mg}{1 + mb^2 / I} \tag{12}$$

2.3 Gap of knowledge and Hypothesis

2.3.1 Actuators

Actuators are device that provide motion and support for the exoskeleton and hence help with the wearer limb motion. Actuator can be operated by types of energy source such as electric current, hydraulics fluid pressure and pneumatic pressure by converting that energy into motion.

In [18, 19], the DC motor are chosen its high in torque ratio. DC motor or direct current motor use electrical energy to convert to mechanical energy. The speed of DC motor can be controlled using either variable supply voltage or changing the number of windings in its current field inside the motor.

DD motor is well known for its full power that comes from the motor because it transfer power without any reduction. DD motor is popular to the weight reduction and size wise compare to other type of actuator [20]. Because of its mechanism that are direct attached to the motor it's give faster and precise positioning because of it feedback sensor that contribute to the precise angular position.

Figure 2.4: Direct Drive Motor Mechanism [20]

In [21, 22], the pneumatic rotary motor give a flexible joints that are support by the micro-compressor that reduce the size and weight. The benefit using pneumatic rotary motor system the system itself is very clean because the source of energy is from air that cheap and obtainable compare to hydraulic that can easily leaked by the oil. But the biggest disadvantage is the noise that come from the compressor. Thus it will make the user feel uncomfortable to wear it also the people surrounding that are worked together.

Table 2.2: Actuator Specification

	DC motor	DD motor	Pneumatic rotary motor
Advantages	-high torque -easy speed -torque control	-Increased efficiency -reduced noise -high torque -longer lifetime	-clean -relatively fast -air is cheap -no magnetic field
Disadvantages	-physically larger	-need precise control mechanism	-noise problem from the compressor

2.3.2 Drive System

In [17] cable pulley drive system is used to transmit power for actuation. The system combining the pulley system and rope system to increase the volume of the weight that the motor can carry at certain time. The length of the rope effect the load that can be carry by the motor. If the load is near the motor, thus the system can lift a heavy load compare a system that has a long rope system that reduce the amount of the load that the motor can carry.

In [23]. Gear drive is chosen to be the drive system in the exoskeleton. Gear drive provided definite velocity ratio from the gear teeth. It possesses the advantages in the reduced number of parts required. However, gear drive system are expensive to fabricate and the lubrication requirement is not suitable for exoskeleton application.

In [20], direct drive used the mechanism by taking power from motor without any reduction. DD motor is popular to the weight reduction and size wise compare to other type of actuator [study on waist]. Because of its mechanism that are direct attached to the motor it's give faster and precise positioning because of it feedback sensor that contribute to the precise angular position.

In [6, 24], harmonics drive system is chosen because it can improve certain characteristic compared to traditional gearing system. Its decrease the output speed as well increase the output torque thus reduce the motor in size. The reason that harmonics that are chosen as mechanism system because of its advantages of no backlash, excellent positional accuracy and high torque ratio. The disadvantages of the harmonics drive system is the system itself is very expensive compare to other type of drive mechanism.

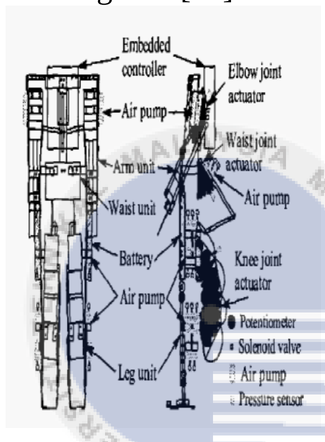
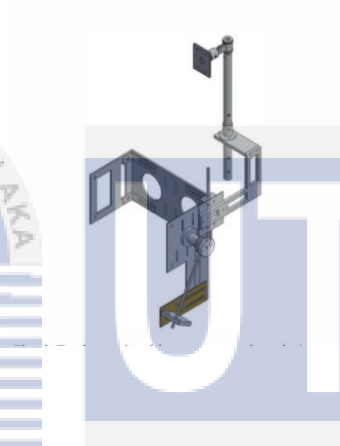
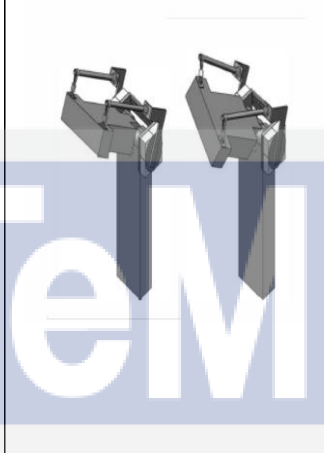
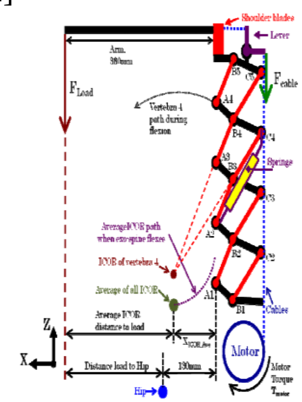
Table 2.3: Drive System Specification

	Cable pulley drive	Gear drive	Direct drive	Harmonics Drive
Feature	-Transmit power over long distance -speed reduction	-definite velocity ratio from the gear teeth	-taking power from motor without any reduction	-short distance power transmission -speed reduction
Advantages	-no backlash -no friction	-reduced number of parts required	-Increased efficiency -reduced noise -high torque -longer lifetime	-compact -no backlash -excellent positional accuracy -high reduction ratio
Disadvantages	-Limited range of motion -Takes space	-expensive	-need precise control mechanism	-expensive

2.4 Summary on Related Method

In the table below are the summary for different journals on their method on their study on exoskeleton as assistive to human. In this table show different method such as their type of motor, motor torque, assistive torque (spring), and their advantages and disadvantages.

Table 2.4: Summary of Related Journal

Method	Development of Stand Alone Wearable Power Assisting Suit [21] 	Mechanism Design of power Assist Suit For Caregiver By using Torsion Springs [18] 	A Study on a Waist Power Assist Suit for a caregiver To prevent Lower Back Pain [20] 	Exoskeleton Spine and Shoulders for Full Body Exoskeleton in Health Care [12] 
Type of actuator	Rotary Pneumatics Actuator	NA	DD motor	DC motor
Torque motor	35 Nm	100 Nm	54 Nm	14.5 Nm
Spring	NO	YES	NO	YES
Advantages	-clean -relatively fast -air is cheap	-Lightweight -High torque -Assistive Spring	-High Torque -Increased efficiency -reduced noise -high torque -longer lifetime	-Assistive Spring -Pulley System -no backlash -no friction

Disadvantages	-noise problem from the compressor		-need precise control mechanism	-Limited range of motion -Takes space

2.5 Summary of Review

The challenge of this research is in designing and developing the three degree of freedom motion of lateral, flexion, extension and rotation. In developing the suits, the design will be divided into three main components. This project of designing an exoskeleton is to improve the size and weight of exoskeleton for an ideal operation condition for the user. The problem rise with the mentality to create an exoskeleton that are small but are wise in weight to power ratio considering that there are a lot of machine induced in helping human to carry a heavy weight. The movement will be control by the user but will limited based on the ergonomics condition of lower back spine

The first components is modeling the 3 degree-of freedom of lower back suit mathematically in term of dynamics analysis. In this part we will calculate the motor torque that are required at the help. We will see the relationship between motor torque and the load that human can carry versus the angle with regards to the gravity of earth. The second components is to design the assistive torque that can help to distribute the required torque. We will study on the relationship between the distances (angle) of the spring to the assistive torque that the spring can produced. The last components is to analyze the structure of the in term of stress, strain analysis. We will use the simulation in solid work to see the break point of the material use, in this case alloy steel. From that we can see the relationship between the load uses to the break point of the material use.

CHAPTER 3

METHODOLOGY

3.1 Flowchart of the Project

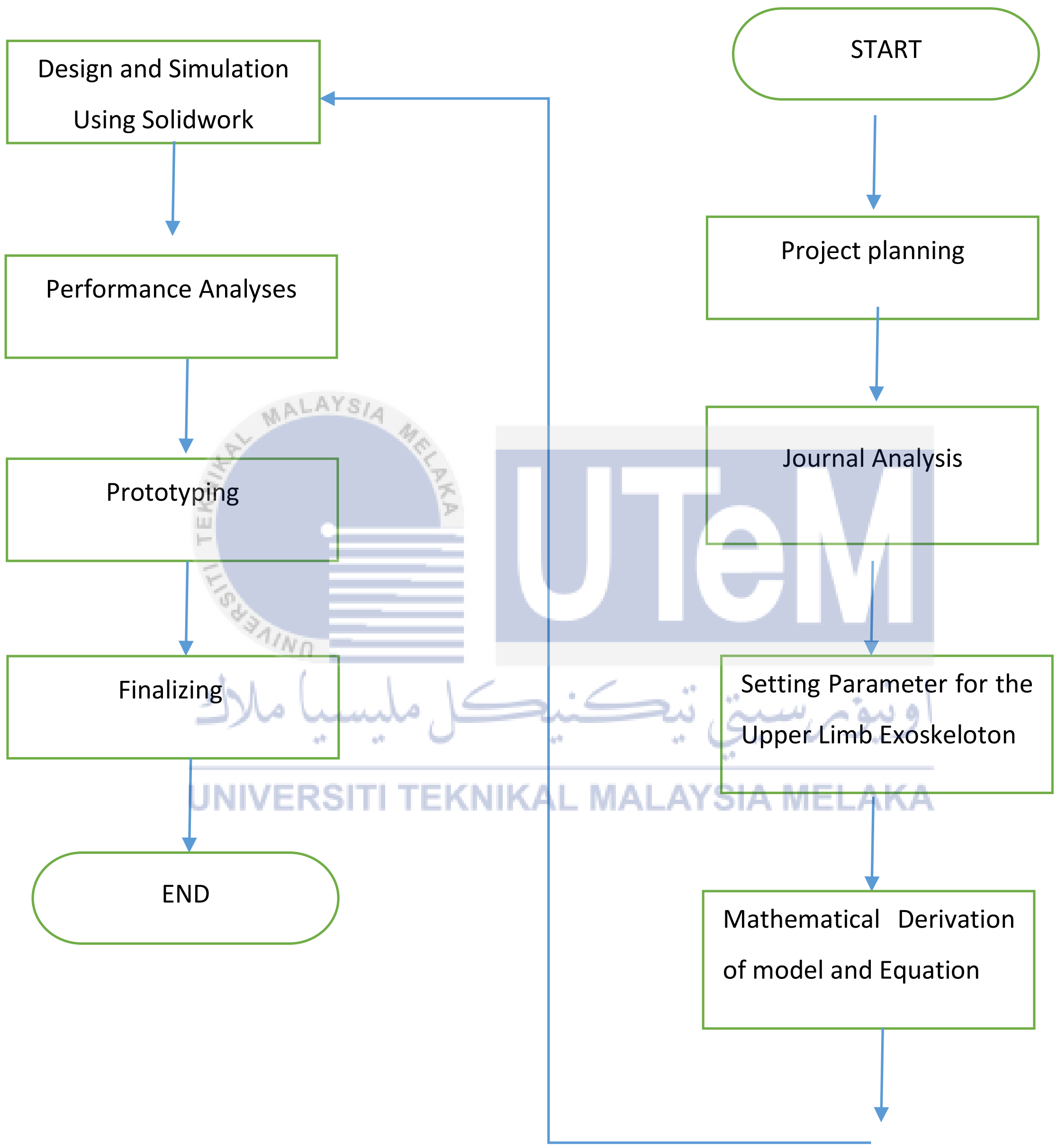


Figure 3.1: Flowchart

3.2 K-chart of the Project

K-chart shown in figure below is used to show the stage of planning for this project. This K-chart will included all stages starting from the title selection, scope, methodology, result, and analysis of the project. The main subject in this project is exoskeleton and will be sub-project to upper Limb. From there the actuator will be divided into actuated by electricity and actuated by either hydraulics or pneumatics. For this project the actuator that will be selected is actuated by electricity. From there it will sub-section into theory, software, and hardware. In the theory section mathematical modeling and kinematic equation are been calculated using the structure of the prototype design using solidworks. The system will be using open loop system simply by movement flexing up and flexing down. In the hardware section, for the mechanical part, it will be divided into two section prototyping and solidworks design and simulation.

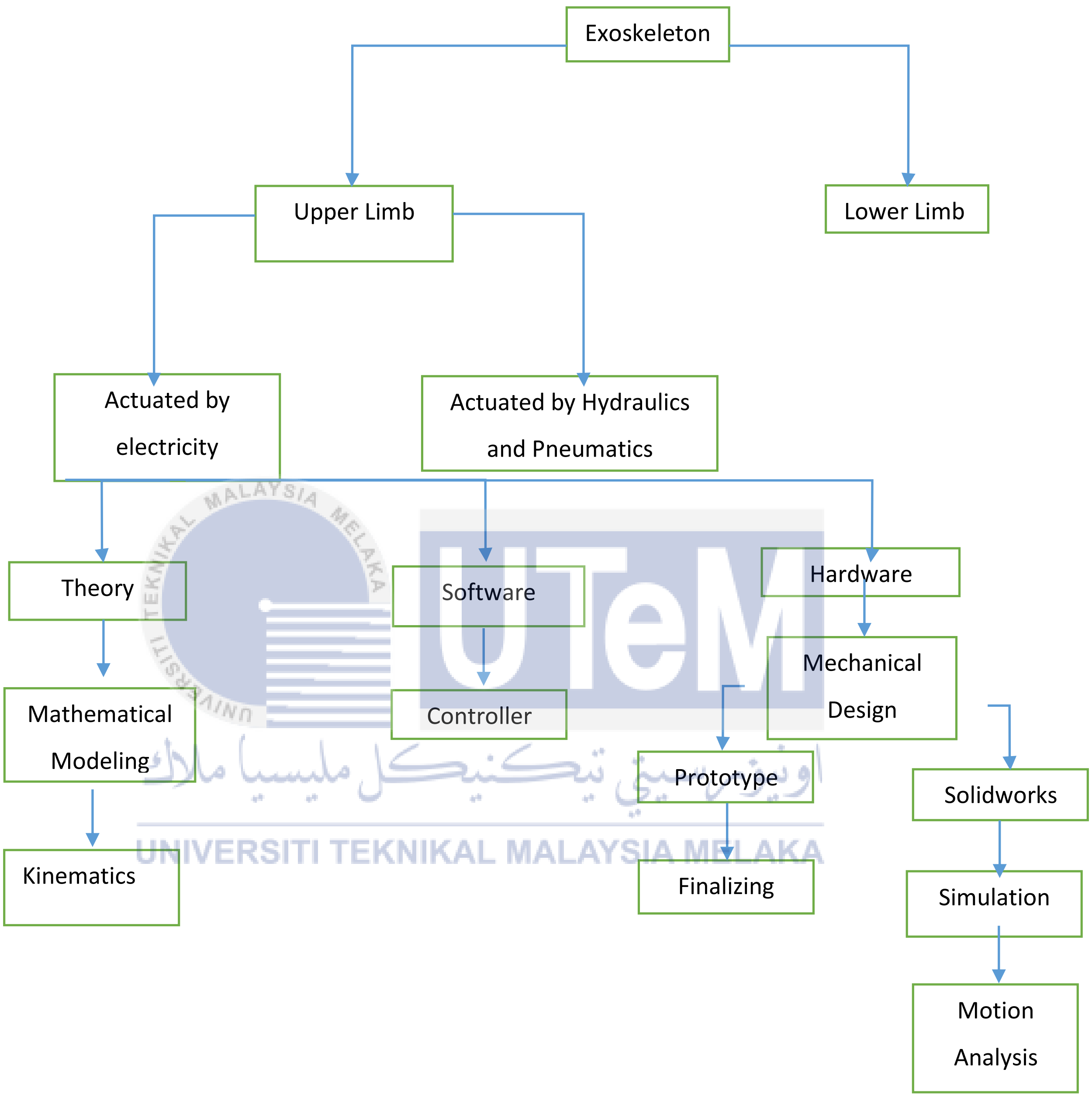


Figure 3.2: K-Chart

3.3 The Mechanism of the Design

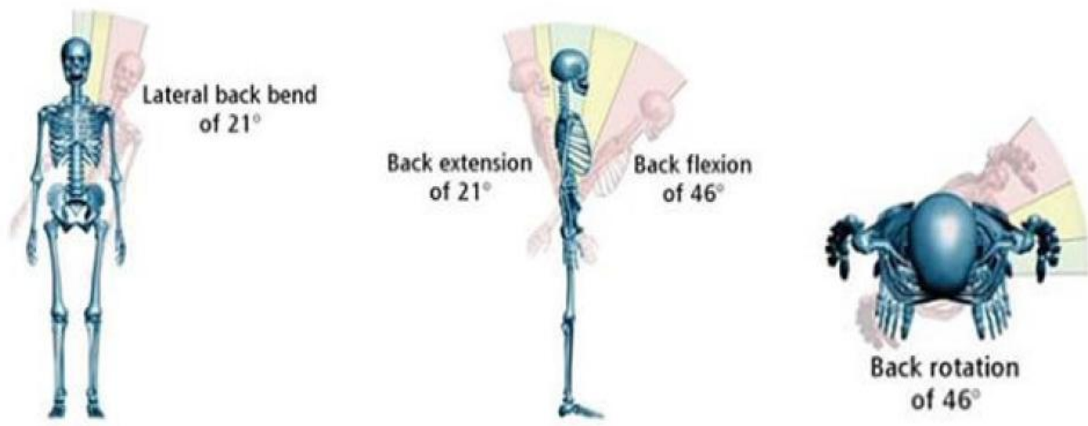


Figure 3.3: Motion Movement of Back Side of Human [8]

There are 4 types of zone that human will encounter while standing or sitting. The first zone is Zone 0 (Green Zero), zone that encounter most of the movement while puts minimal stress on muscles and joints are same with the condition of Zone 1 (Yellow Zone). The 3rd zone is Zone 2 (Red Zone) that gives extreme position for limbs, puts high strain on muscles and joints.While Zone 3 (Beyond Red Zone is the most extreme position for limbs that should be avoided while lifting or repetitive tasks [8].

To create same movement of the human upper body, the design will refer to the mechanism of motion movement of back side of human. The maximum of angle required are from the back rage motion of human biomechanics[8]. The motion that are related to this experiment is spine flexion, Spine lateral flexion, Spine rotation. Spine flexion is most important DOF to lifting while extend total flexion range and allow natural bending postures. Rotation motion are used to move the objects sideways or to extend the reach.to prevent large rotation, the supporting torque towards neutral position must been take consideration

The waist assistive suit is designed to mimicked the movement of human spine by developing a 3 degree of freedom which are for motion spine flexion(forward bending), spine lateral flexion(sideways bending, left or right) and spine rotation(rotation around the vertical axis)

The design process will was conducted using Solidworks CAD a design tool that help determined the movement of the spine model using the motion study. Before the prototype is develop the Solidworks helps to test the strength of each types of material that are needed to develop the exoskeleton.

Figure 3.5: Waist Assistive Suit

3.3.1 Spine Lateral Flexion Motion

Spine lateral flexion motion is to lift up or put down objects that tilted sideways. The required forces always toward neutral position with the consideration to balance the weight of the wearer and the load as their center mass. In figure below there are 3 part that are mimicked this type of movement. This motion are very important because it will determine whether the user can be move sideways or not. In the design there are 3 connectors that are responsible to this mechanism.

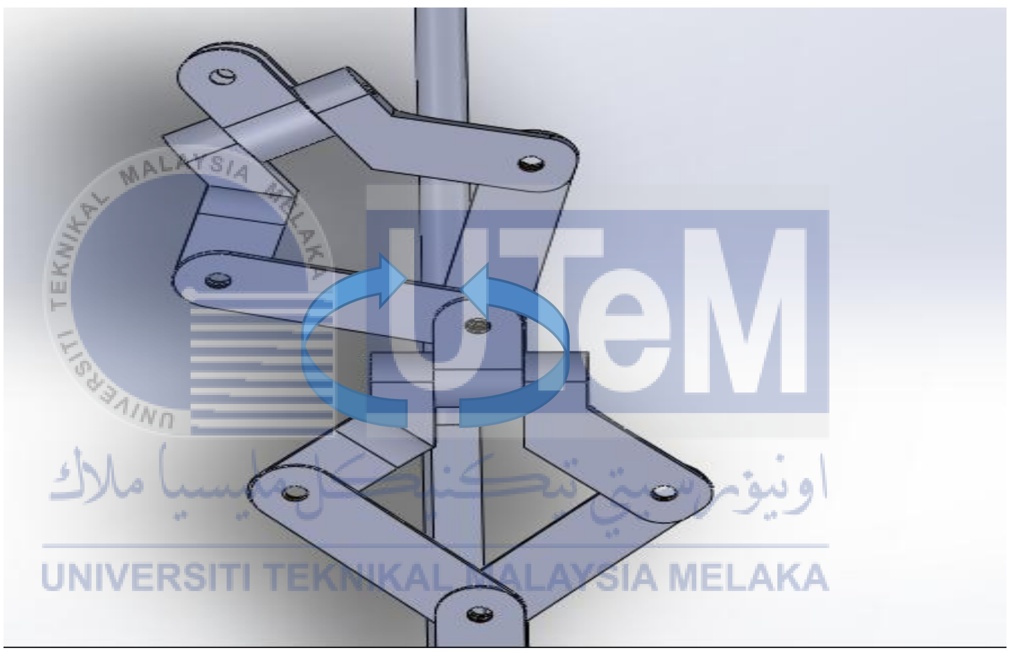


Figure 3.6: Front View

3.3.2 Spine Flexion Motion

Spine flexion is most important DOF to lifting while extend total flexion range and allow natural bending postures. This movement are the main part of the mechanism because the experiment will be depending to this movement. The weight testing experiment will be test regarding the angle of the bending postures to carry weight of 1 kg, 2 kg,3 kg, 4 kg, 5 kg, 6 kg, and 7 kg. This motion will be supported by using the pulley system. The pulley will connected to the actuator and will be connected to the end of the suit that will point at the neck.

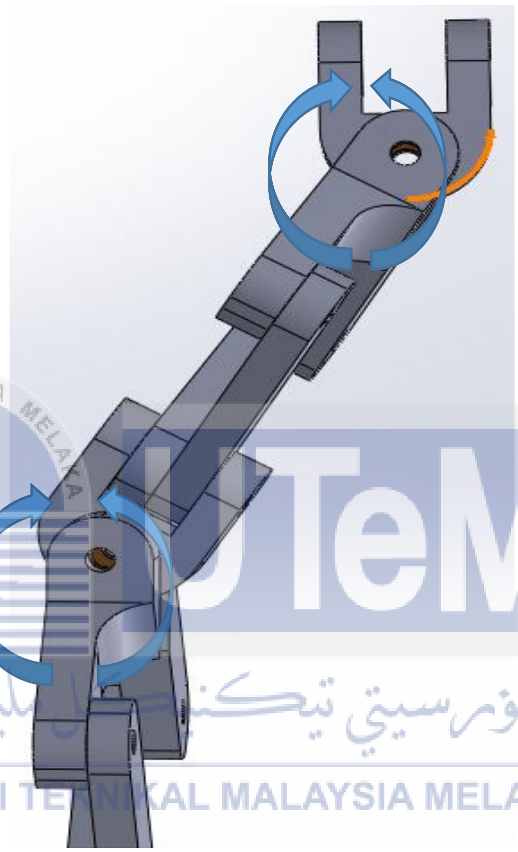


Figure 3.7: Side View

3.3.3 Rotation Motion

Rotation motion are used to move the objects sideways or to extend the reach.to prevent large rotation, the supporting torque towards neutral position must been take consideration. This motion is contribute whether the user can move the body in rotation motion. The maximum angle that human body can withstand is 46˚, thus the mechanism must rotate according to the user motion.

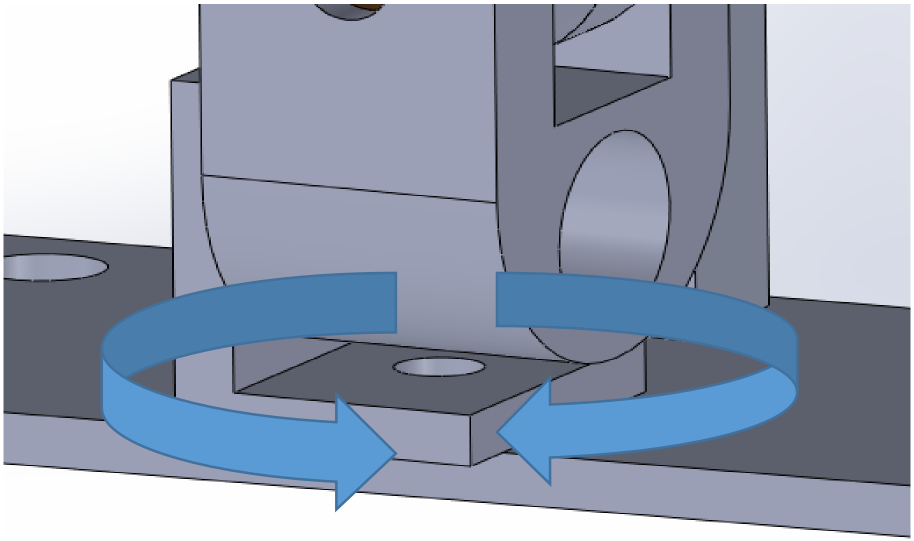


Figure 3.8: Front View

3.3.4 Extended and Assistive Motion

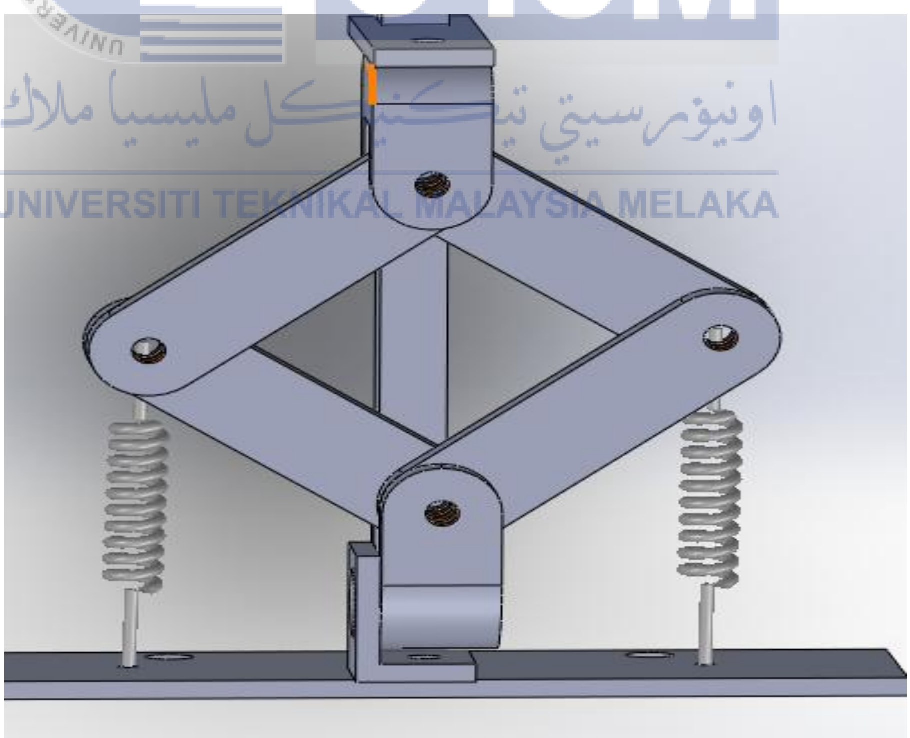


Figure 3.9: Assistive Torque

The torque that produced by motor and drive system are not enough compare to the calculated torque. Thus to solve this, the assistive torque must be applied. The spring can produce a large number of torque corresponding to the spring constant. Thus the selection of the spring is very important to the design. In this design the value of the extended spring is estimated because there are no specific ways to determine the accuracy of the extended value of the spring.

3.4 Properties of the Design

This section will be focused on the properties of the design. It will be divided into 3 components. First is the mass properties of the design, second components is the material properties of the design, and the last component is the lists of parts of the design.

Table 3.1: Mass properties of the design

Mass	1202.64 grams
Volume	496579.66 cubic millimeters
Surface area	178168.92 square millimeters
Center of mass: (millimeters)	X = -206.44 Y = 166.23 Z = 377.72
Principal axes of inertia and principal moments of inertia: (grams * square millimeters) Taken at the center of mass.	Ix = (0.15, 0.05, 0.99) Px = 1062776.57 Iy = (0.97, -0.20, -0.14) Py = 24289485.76 Iz = (0.19, 0.98, -0.08) Pz = 25077758.38
Moments of inertia: (grams * square millimeters) Taken at the center of mass and aligned with the output coordinate system.	Lxx = 23779933.56 Lxy = 30591.34 Lxz = 3498707.65 Lyx = 30591.34 Lyy = 24987942.65 Lyz = 1198656.16 Lzx = 3498707.65 Lzy = 1198656.16 Lzz = 1662144.49

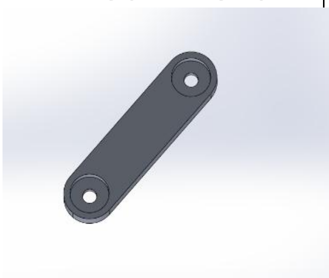
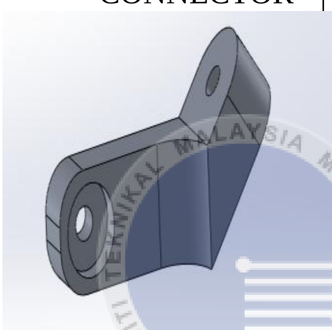
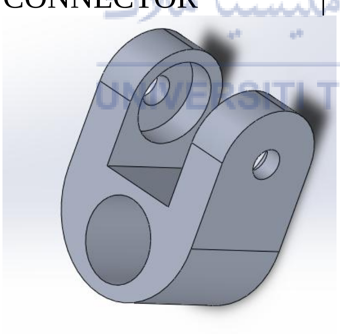
Moments of inertia: (grams * square millimeters) Taken at the output coordinate system.	Ixx = 228593768.25 Iyx = -41241116.76 Izx = -90279665.37	Ixy = -41241116.76 Iyy = 247823878.62 Izy = 76711135.89	Ixz = -90279665.37 Iyz = 76711135.89 Izz = 86150082.64

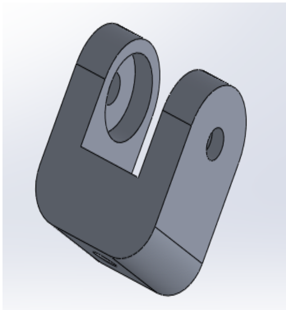
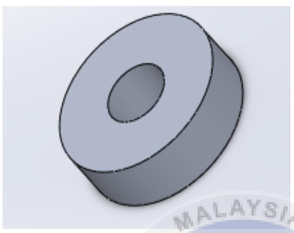
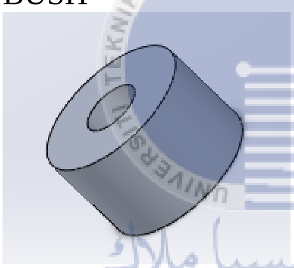
Table 4.2: Material Properties

	Name: **1060 Alloy Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.75742e+007 N/m^2** Tensile strength: **6.89356e+007 N/m^2** Elastic modulus: **6.9e+010 N/m^2** Poisson's ratio: **0.33** Mass density: **2700 kg/m^3** Shear modulus: **2.7e+010 N/m^2** Thermal expansion coefficient: **2.4e-005 /Kelvin**

]

Table 4.3: List of parts

	PART (Solidworks)	Fabrication	Volumetric Properties	APPENDICES NO
	CONNECTOR 		Mass:0.053861 kg Volume:1.99485e-005 m^3 Density:2700 kg/m^3 Weight:0.527838 N	B
	CONNECTOR 		Mass:0.0737127 kg Volume:2.7301e-005 m^3 Density:2700 kg/m^3 Weight:0.722384 N	C
	SIDEWAYS CONNECTOR 		Mass:0.0602593 kg Volume:2.23183e-005 m^3 Density:2700 kg/m^3 Weight:0.590541 N	D

	UPSIDE DOWN CONNECTOR 		Mass:0.0610583 kg Volume:2.26142e-005 m^3 Density:2700 kg/m^3 Weight:0.598372 N	E
	BEARING 		Mass:0.00396972 kg Volume:1.47027e-006 m^3 Density:2700 kg/m^3 Weight:0.0389032 N	F
	BUSH 		Mass:0.00793943 kg Volume:2.94053e-006 m^3 Density:2700 kg/m^3 Weight:0.0778064 N	G
	CONNECTOR 3 		Mass:0.046977 kg Volume:1.73989e-005 m^3 Density:2700 kg/m^3 Weight:0.460375 N	H

3.5 Dynamics Analysis

In this section will be focused on the theoretical parts that are related to the dynamics mechanism of the design mainly joint torque analysis. The main objective of this art is to find the required torque at the hip and to find the assistive torque that help distributed the load to the power to weight ratio.

Parameter $F_{UP,pulley}$ is the friction component during downward flexion. This similar for $F_{dwn,A4}$, $F_{up,A1}$, and $F_{up,A4}$ with up indicating upward flexion. Parameter $F_{UP,pulley}$ is the friction components relatively to the torque that drive the cables,T_{pulley}, which the sum of the T_{motor} and at the T_{spring}. [12].

$$T_{pulley} = T_{motor} + T_{spring} \tag{1}$$

In the figure below show the dynamics variable to find the torque at the hip. This part is very important because by using the equation given in [15, 16], we can find the required torque corresponding to the load and the angle of the waist assistive suit that built according to upper limb of human body. The design are consider the ergonomics structure of human spine because the purpose of the waist assistive suit is to prevent lower back pain. Thus we must consider the limitation of human spine according to [8].

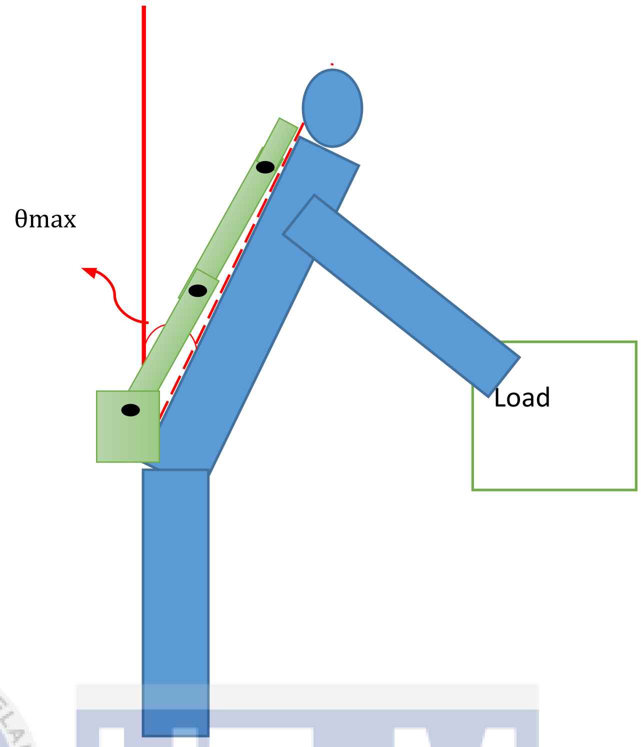


Figure 3.10: Dynamic diagram on human body

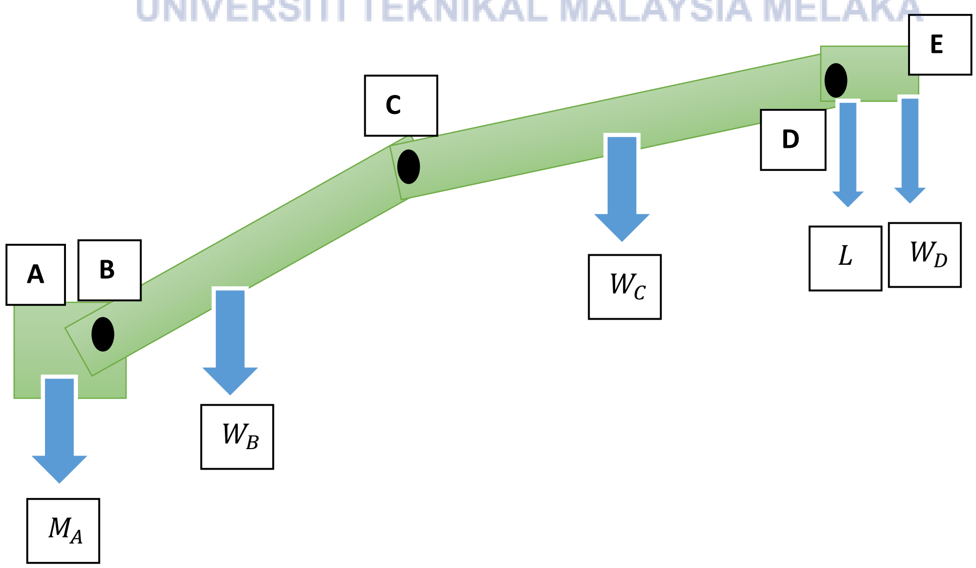


Figure 3.11: Dynamics Variable

$M_A = weight\ of\ motor$

$W_B = weight\ of\ link\ AB$

$W_C = weight\ of\ link\ BC$

$W_D = weight\ of\ link\ CD$

$L = load$

$L_{BC} = length\ of\ link\ BC$

$L_{CD} = length\ of\ link\ CD$

$L_{DE} = length\ of\ link\ DE$

By using free body diagram (FBD),

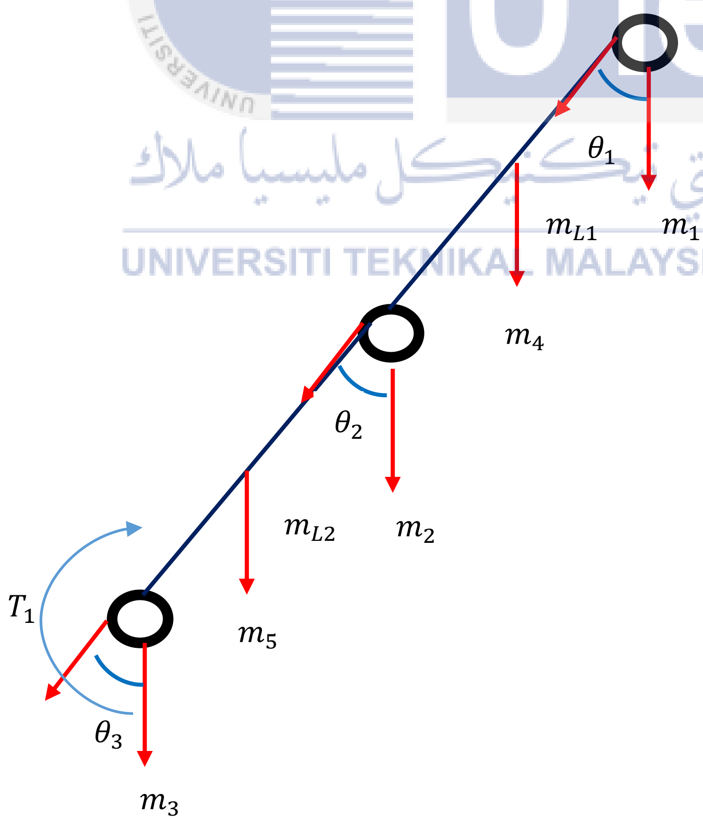


Figure 3.12: Free body Diagram

Taking the sum of forces in Y axis, using the load, find the force in the B_Y and C_Y and the torque of the motor at M_B:

$$\sum M_B = -L(L_{BC} + L_{CD} + L_{DE}) - W_D\left(L_{BC} + L_{CD} + \frac{L_{DE}}{2}\right) - W_C\left(L_{BC} + \frac{L_{CD}}{2}\right) - W_B\left(\frac{L_{BC}}{2}\right) + M_B = 0 \tag{6}$$

3.5 Design an open loop control algorithm for the waist assistive robot movement in 3 DOF motion

In this part, open loop system will be used to control the movement of waist power assistive suits in three motion. The motion of the power assistive suit is control based on the movement of the limitation of human motion as shown in table:

Table 3.6: Back Range motion [8]

		Range of Motion			
	Movement	Zone 0	Zone 1	Zone 2	zone 3
	Flexion	0-10	11-25	26-45	46+
BACK	Extension	0-5	6-10	11-20	21+
	Rotational	0-10	11-25	26-45	46+
	Lateral Bend	0-5	6-10	11-20	21+

The assistive suit will give a negative feedback to a wearer. The negative torque will support the wearer or user in the motion is in one 2 and zone 3 to avoid back pain. The negative torque requirement is based on the force given by the shoulder

Figure 3.13: Microcontroller

Figure shows Arduino UNO. Arduino UNO is chosen as microcontroller because it is a high performance, cost effective and can runs on operating system (OS) that easy to use tool chain and compatible with the Arduino ecosystem such as arduino shield and open source projects.

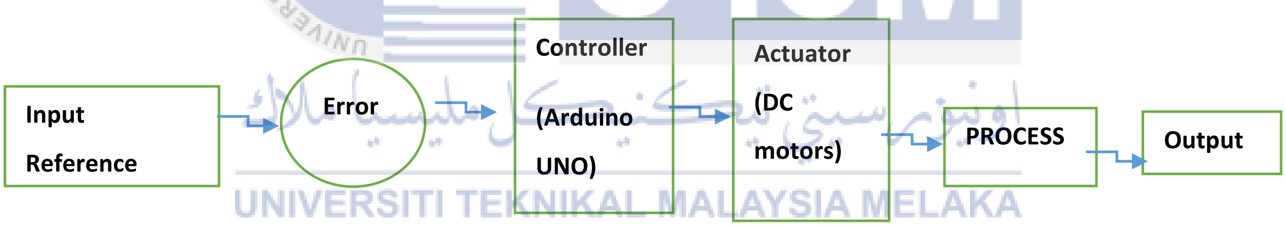


Figure 3.14: Block Diagram of Exoskeleton Spine

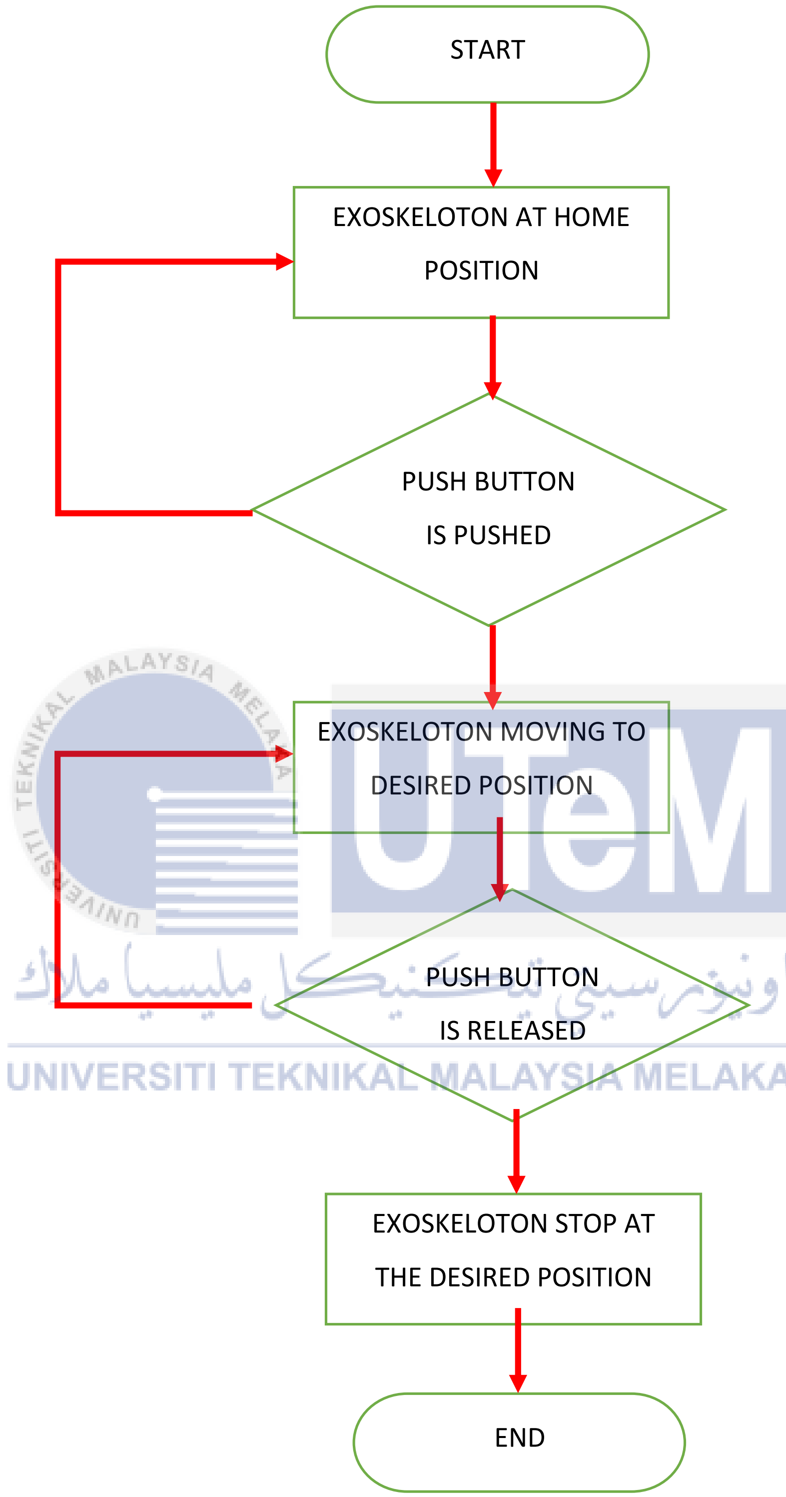


Figure 3.10: Waist Power Assistive Suit System Flowchart

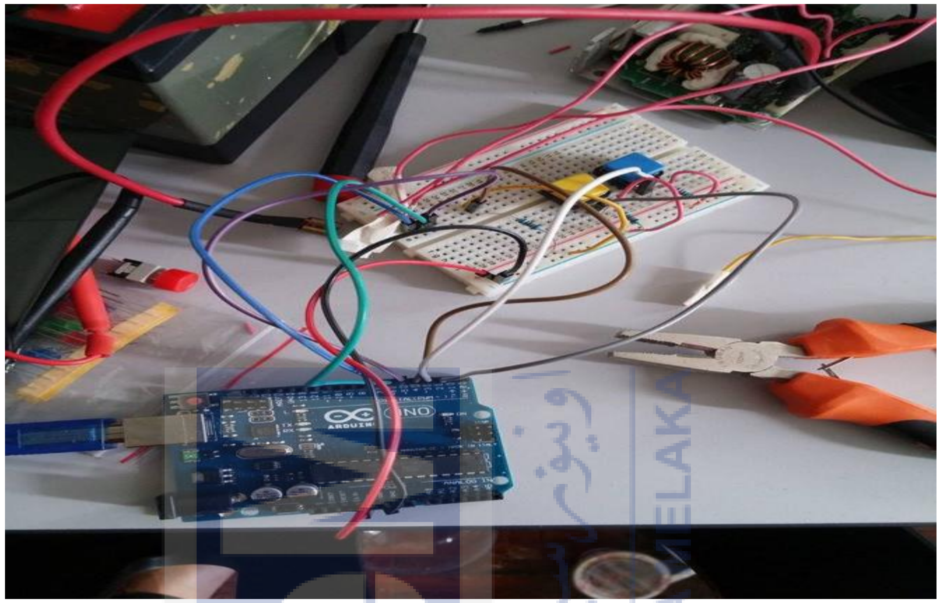


Figure 3.16: Designing Circuit

In this simulation, we are using 3 push button to design the actual controller, the first one is for the start and stop button, while the other two is for direction of the motor in clockwise and anti-clockwise direction. In the simulation the motor is been substitute by using LED because it easier to indicate the functionality of the programming.

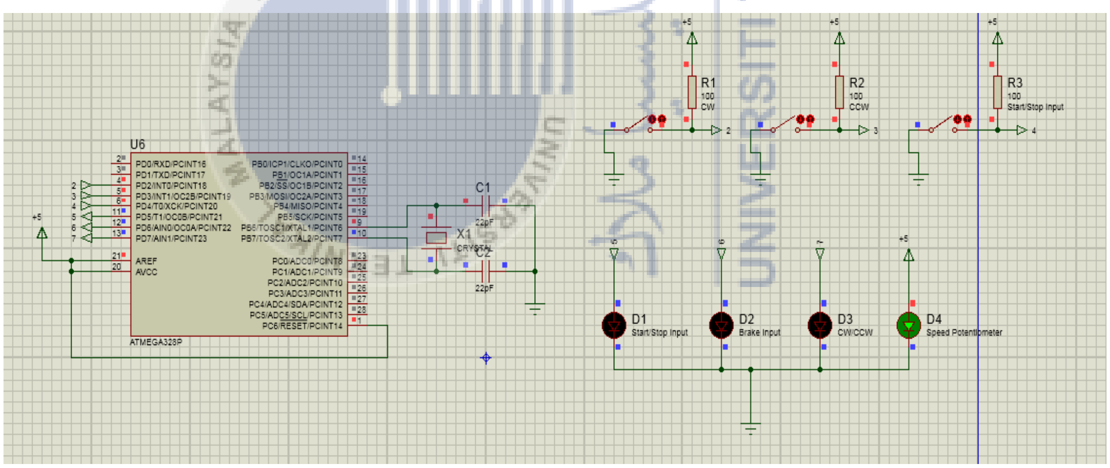


Figure 3.17: Waist Assistive Suit Circuit 1

In the figure above, show the circuit in the state where no button is been push, thus the light of LED CW/CCW, BRAKE, and push button STOP/START will turn OFF, the only LED that will light is the speed potentiometer because the pin must always turn ON to use the internal potentiometer function, if the LED is turn OFF then the speed controller will be in external potentiometer state where it will be control by programming. In this state the BRAKE function is active because the input is 0 from both CW and CCW.

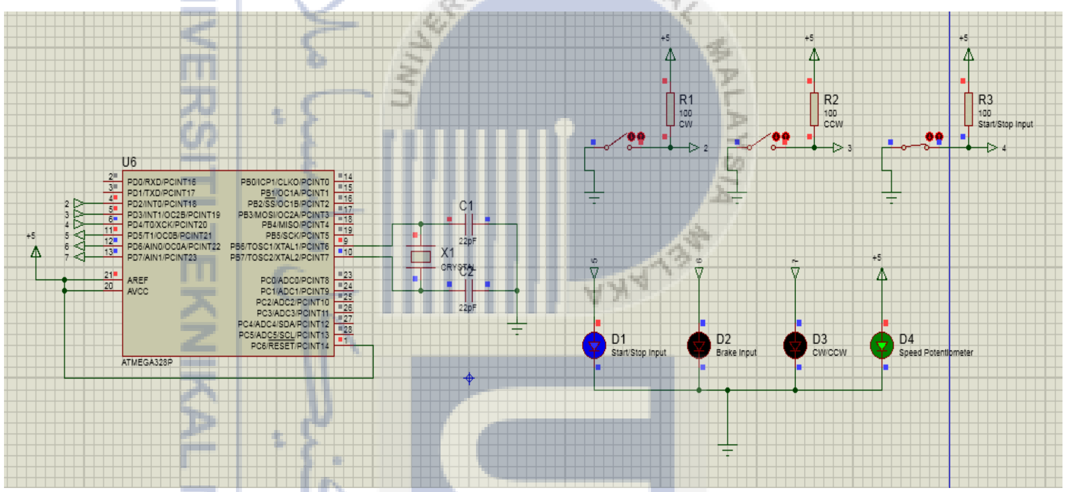


Figure 3.18: Waist Assistive Suit Circuit 2

In the figure above the push button is been pushed thus the LED for START/STOP will be ON. This will start the whole system. If this button is OFF the CW/CCW button will not be function as it should. This will be safety to the user if they push accidently push the CW/CCW button.

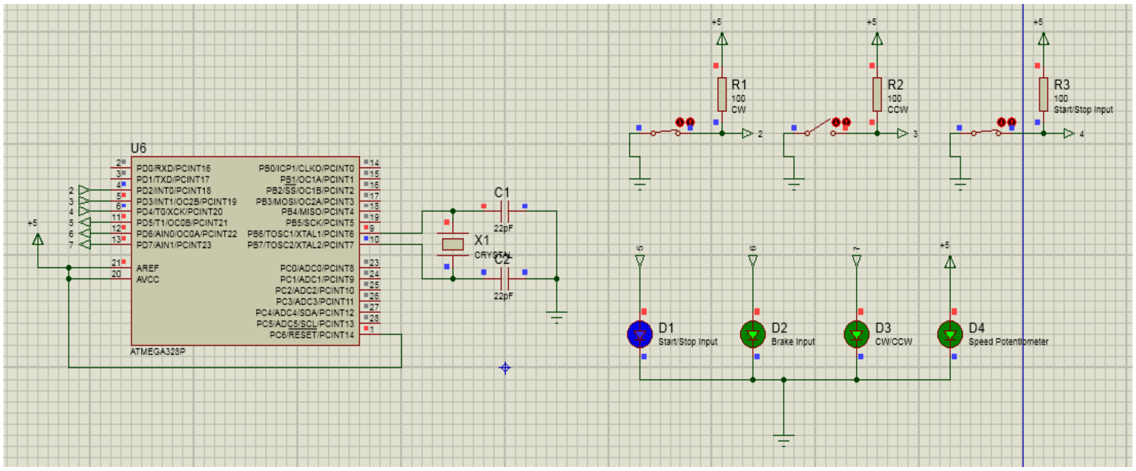


Figure 3.19: Waist Assistive Suit Circuit 3

In the figure above when the CW button is pushed, all the LED will be turn ON, this indicated that the motor is rotate in clockwise motion and when the LED for the BRAKE is ON this will release the brake function that act as the holding torque.

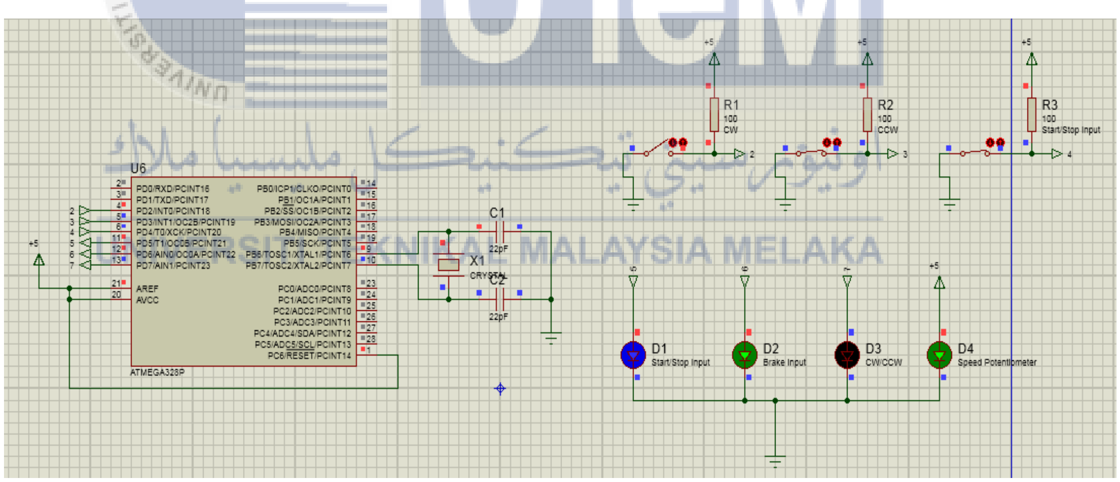


Figure 3.20: Waist Assistive Suit Circuit 4

In the figure above, the CW button is released and the CCW button is pushed. The LED for CCW will turn OFF and this will indicate that the motor is move in counter clockwise motion.

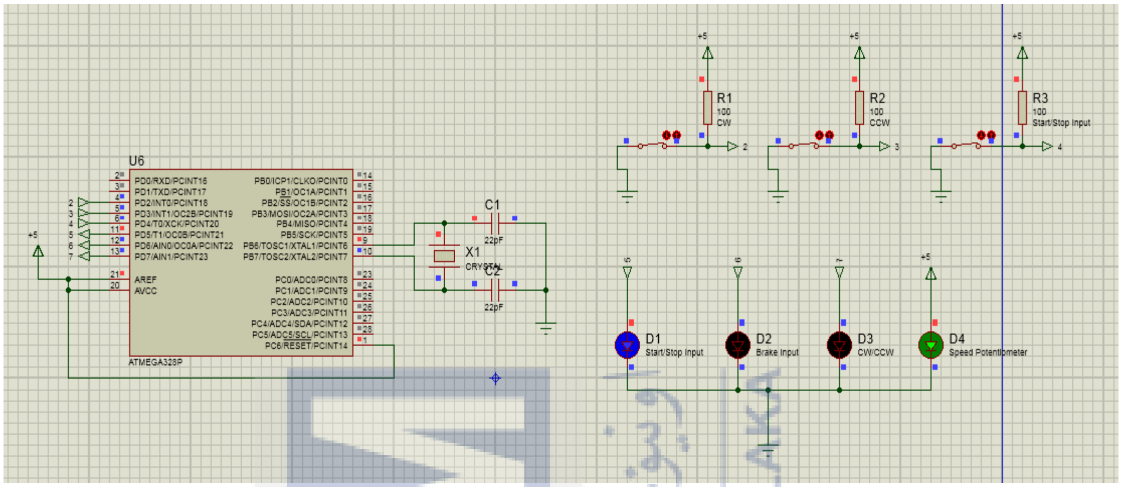


Figure 3.21: Waist Assistive Suit Circuit 5

In the figure above, if the push button for both CW and CCW is pushed the BRAKE function will automatically turn ON because the controller will decide that there are 2 input from the circuit. This is one of the safety of the circuit.

3.6 Simulation and Experiment

3.6.1 Experiment 1: Assistive Torque and Force in the spring Test

In this section, the assistive torque and force will be find using simulation and experiment. In the simulation part, the data and graph will be find using the Solidwork Xpress with the condition to get the same result with the experiment part. In the experiment part the load that will be used varies to 1 kg, 2 kg,3 kg, 4 kg, 5 kg, 6 kg, and 7 kg. The experiment is stop at 7 kg because there are no load left to be used.

Objective

To measure the Assistive Torque and Force in the spring

Equipment

1. Camera
2. Prototype
3. SolidWork
4. Protractor
5. Spring
6. Wire Cable
7. Load
8. Microsoft Excel

Experiment Setup

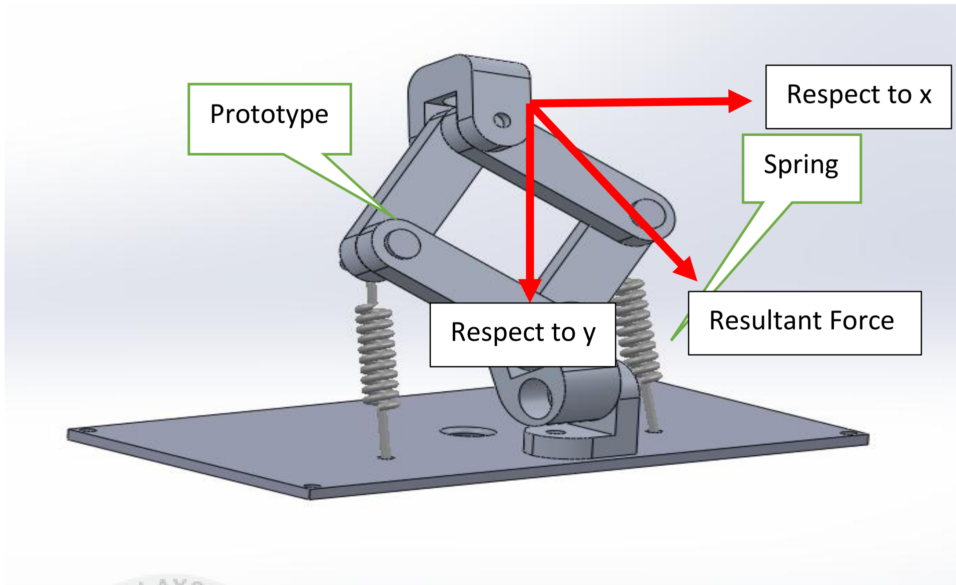


Figure 3.22: Setup for Experiment 1 Setup(Simulation)

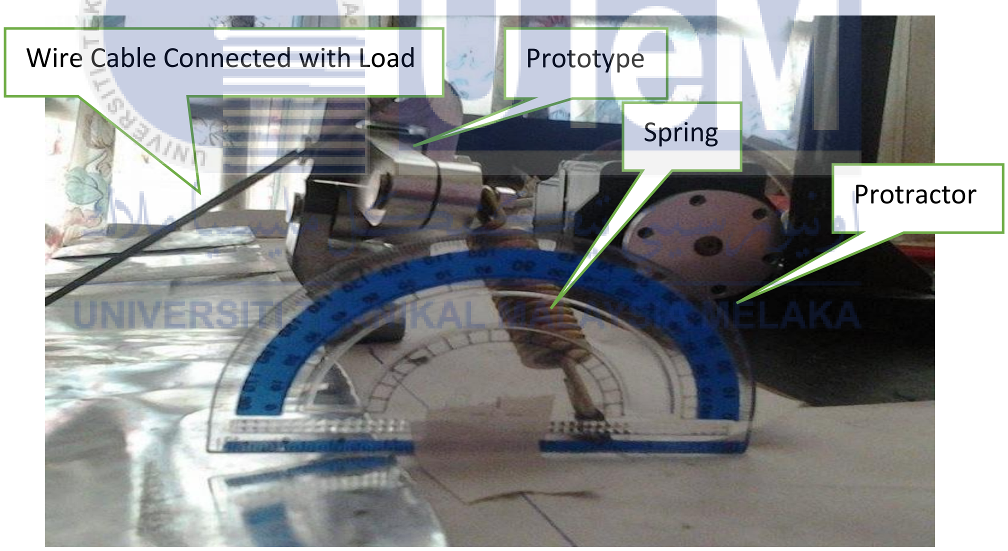


Figure 3.23: Setup for Experiment 1 Setup (Experiment)

Table 3.7: Parameter for Experiment 1

Parameter	**Value**	**Unit**
-Angle of joint -Spring constant, Load -Gravity	-6,16,26,36,46 -3000 -1 , 2 ,3 , 4 , 5 , 6 , 7 -9.81	-° - N/m -kg

Procedure (Simulation)

1. The Simulation in Solidwork are drawn with respect to x and y axis
2. The link are assigned according the weight of the prototype
3. Apply the material according to the material used in the prototype.
4. All the link are assigned either to the angle 6˚, 16˚, 26˚, 36˚, and 46˚.
5. Simulate the Solidwork and and find the assitive force produced by the spring
6. Convert the force into assistive torque
7. Tabulate the data
8. Analyze all the data according to the assistive torque equation

Procedure (Experiment)

1. Setup the prototype with the spring
2. Put the protractor in line with the protoytpe,
3. Place the load to the end of the wire cable
4. Used load that varies from 1 kg to 7 kg.
5. Find the angle correspond to the load place on the wire cable
6. Calculate the force and convert it to assistive torque
7. Tabulate the data
8. Analyze all the data according to the assistive torque equation

3.6.2 Experiment 2: Required Torque and Force in the Hip Test

This section will discuss on the theoritical and simulation result that produced from the calculation of dynamic and mechanism of structure and simulation through Solidworks motion simulation. To calculate the torque at the hip, all the parameter must be found out first either be estimated or weigh. The maximum of angle required are from the back rage motion of human biomechanics [8]. The motion that are related to this experiment is spine flexion. Spine flexion is most important DOF to lifting motion while extend total flexion range and allow natural bending postures. The maximum required torque values during lifting are calculated from all the value that are estimated and weighed. Thus to make the calculation easier the value 1 kg, 2 kg,3 kg, 4 kg, 5 kg, 6 kg, and 7 kg are pick to standardized the increase of the value load. The estimated mass of link are taken from the solid work mass properties, thus it has its own plus minus value but in the situation the value is not that large that can affect the whole calculation.

Objective

- To measure the Required Torque and Force in the Hip using Simulation and Calculation

Equipment

1. Camera
2. Prototype
3. SolidWork
4. Protractor
5. Spring
6. Wire Cable
7. Load
8. Microsoft Excel

Setup

- Simulation Setup

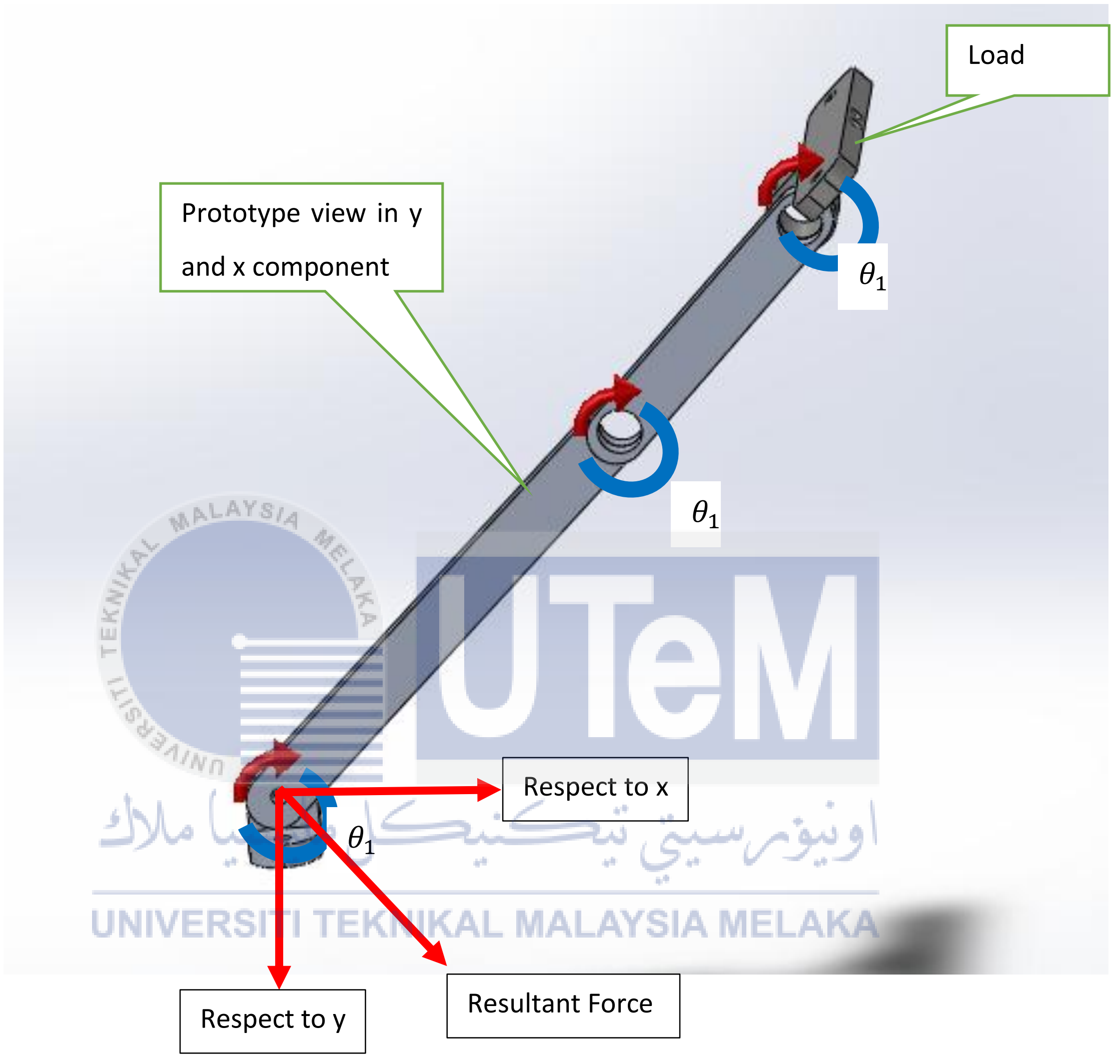


Figure 3.24: Setup for Experiment 2 (Simulation)

Table 3.8: Parameter for Experiment 2

Parameter	Value	Unit
Mass of link 1	0.4	-kg
Mass of link 2	0.6	-kg
Length of link 1	150	-mm
Length of link	250	-mm
Load	1 , 2 ,3 , 4 , 5 , 6 , 7	-kg

Procedure

1. The Simulation in Solidwork are drawn with respect to x and y axis
2. The link are assigned according the weight of the prototype
3. Apply the material according to the material used in the prototype.
4. All the link are assigned either to the angle 6˚, 16˚, 26˚, 36˚, and 46˚.
5. In first experiment assigned all three link as 6˚.
6. Used load that varies from 1 kg to 7 kg.
7. Simulate the Solidwork and tabulate the data
8. Analyze all the data according to the assistive torque equation

3.6.3 Experiment 3: Stress and Strain Test

In this part we will discuss the important of the stress and strain test to the fabrication of the design in this waist assistive suit project Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on. Strain is defined as the amount of deformation an object experiences compared to its original size and shape. For example, if a block 10 cm on a side is deformed so that it becomes 9 cm long, the strain is (10-9)/10 or 0.1 Note that strain is dimensionless.

Objective

- To Analyze the Stress and Strain of the Waist Power Assistive Suit Using Solidwork Simulation

Table 3.9: Parameter for Experiment 3

Parameter	Value	Unit
Stress Strain Load	 10 , 20 ,30 , 40 , 50 , 60 , 70	- N/m^2 -dimensionless -kg

Equipment

1. SolidWork Software
2. Microsoft Excel

Setup

- Simulation Setup

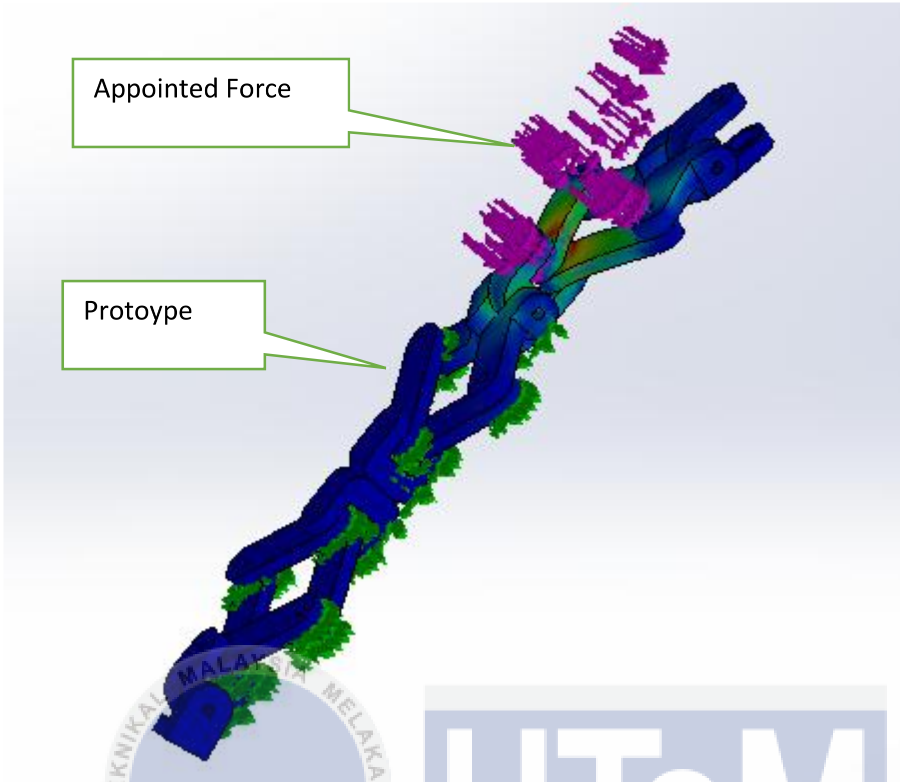


Figure 3.25: Setup for Experiment 3 (Simulation)

Procedure

1. The Simulation in Solidwork are simulate using Solidwork Xpress
2. Select the fixed part on the prototye and the parts that will be applied force
3. Place the force and start the load from 10 kg and rise it by 10 kg each times
4. Find the yield strength break point for the alloy steel material
5. Repeat the process in 3 until the yield strenth is over the alloy steel yield strength
6. Tabulate the data
7. Analyze the table and plot the graph

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will discuss on the result and analysis that are been either simulated, calculated or experimented. The first components is modeling the 3 degree-of freedom of lower back suit mathematically in term of dynamics analysis. In this part we will calculate the motor torque that are required at the help. We will see the relationship between motor torque and the load that human can carry versus the angle with regards to the gravity of earth. The second components is to design the assistive torque that can help to distribute the required torque. We will study on the relationship between the distances (angle) of the spring to the assistive torque that the spring can produced. The last components is to analyze the structure of the in term of stress, strain analysis. We will use the simulation in solid work to see the break point of the material use, in this case alloy steel. From that we can see the relationship between the load uses to the break point of the material use.

4.2 Experiment 1: Assistive Torque and Force in the spring Test

In this section will discussed on assistive torque. The torque that produced by motor and drive system are not enough compare to the calculated torque. Thus to solve this, the assistive torque must be applied. The spring can produce a large number of torque corresponding to the spring constant. Thus the selection of the spring is very important to the design. In this design the value of the extended spring is estimated because there are no specific ways to determine the accuracy of the extended value of the spring. Thus to make the calculation easier the value 10 mm, 20 mm,30 mm, 40 mm, 50 mm, 60 mm, 70mm are pick to standardized the increase of the value x. laod that are used varies from 1 kg,2 kg,3 kg, 4 kg, 5 kg,6 kg,and 7 kg.

$$F = mg = kx \tag{13}$$

In the simulation using Solidwork, we will find the assistive force that can be produced by the spring. This will help to assist the motor to distribute the torque to carry the load.

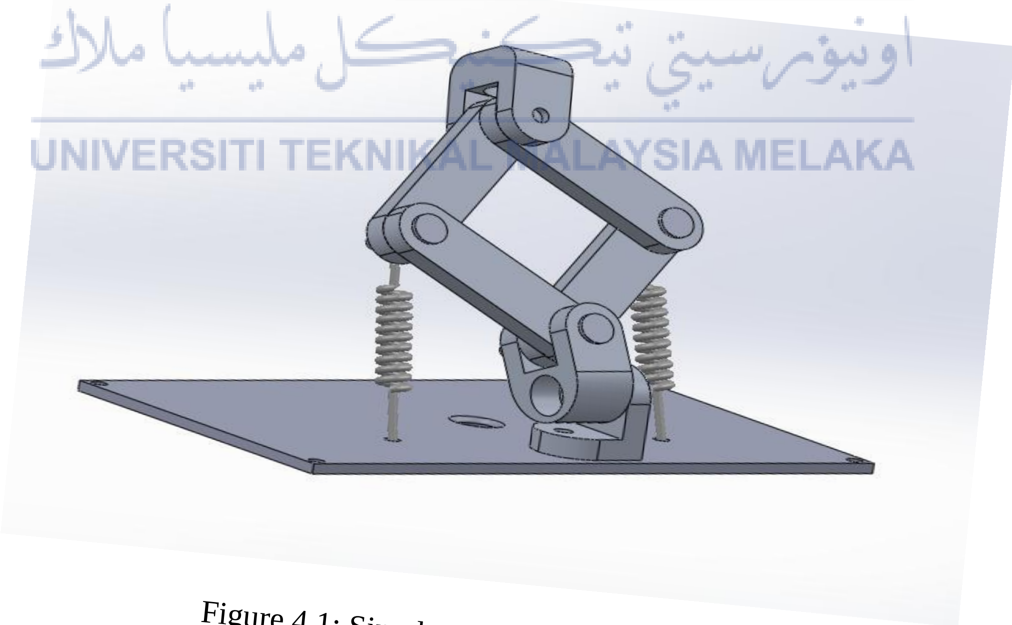
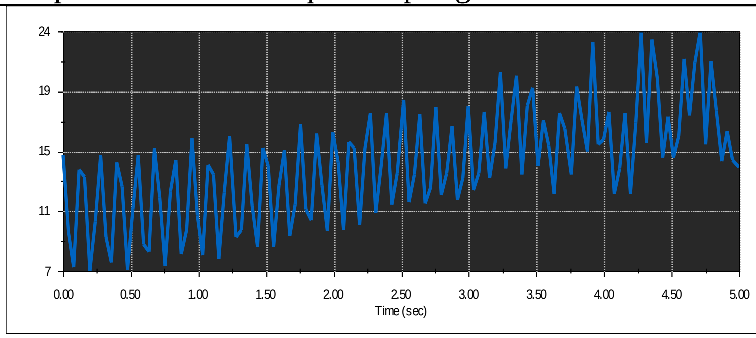
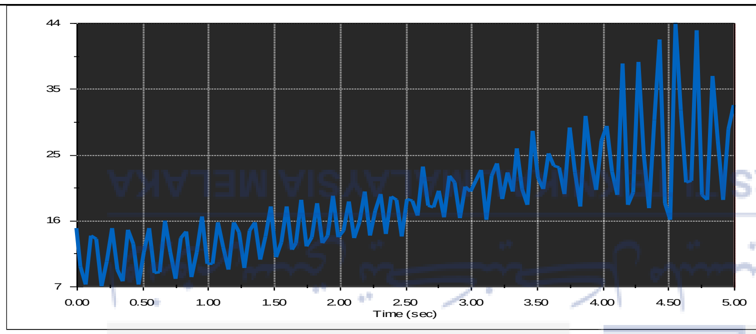
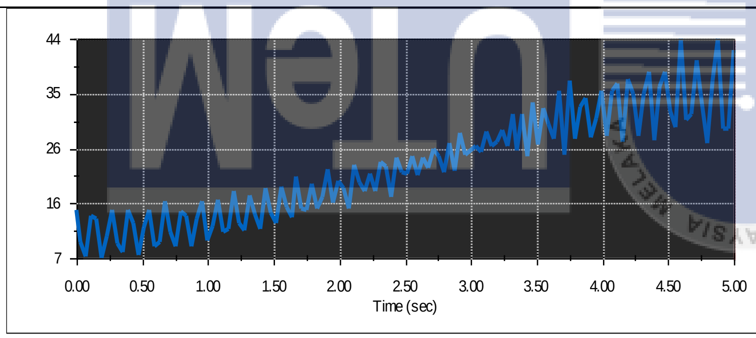
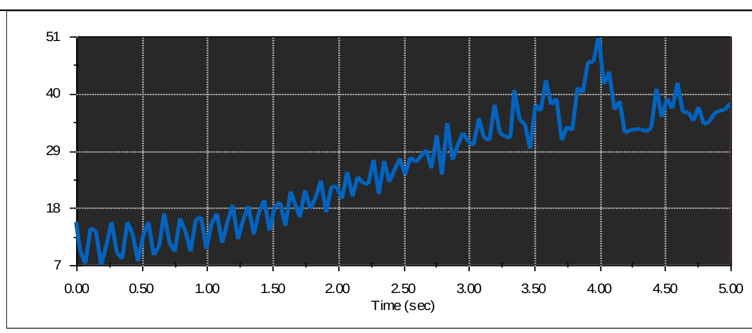


Figure 4.1: Simulation on Assistive Spring

Table 4.1: Graph for Assitive Torque in Spring

NO	Graph for Assitive Torque in Spring	Comment
1		When the spring push down in regardd of 5 mm distance, the force produce by the sping is 24 N. from that the assistive torque from the spring is 0.12 Nm and can carry 2.45 kg load.
2		When the spring push down in regardd of 10 mm distance, the force produce by the sping is 44 N. from that the assistive torque from the spring is 0.44 Nm and can carry 4.49 kg load.
3		When the spring push down in regardd of 15 mm distance, the force produce by the sping is 44 N. from that the assistive torque from the spring is 0.66 Nm and can carry 4.49 kg load.
4		When the spring push down in regardd of 20 mm distance, the force produce by the sping is 51 N. from that the assistive torque from the spring is 1.02 Nm and can carry 5.2 kg load.

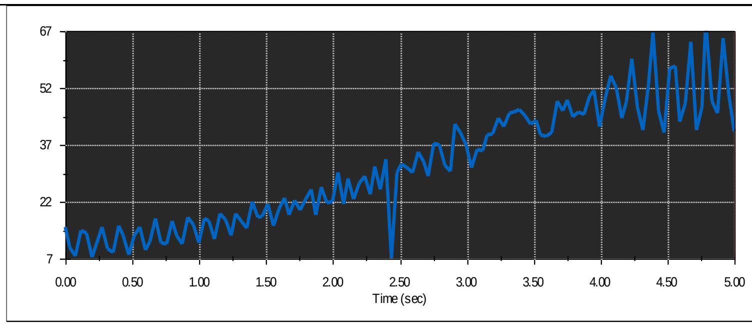
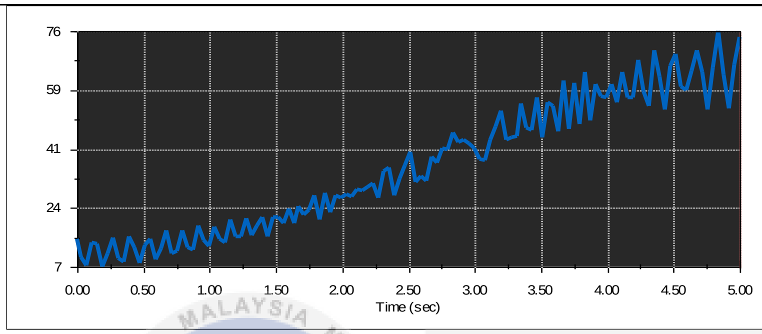
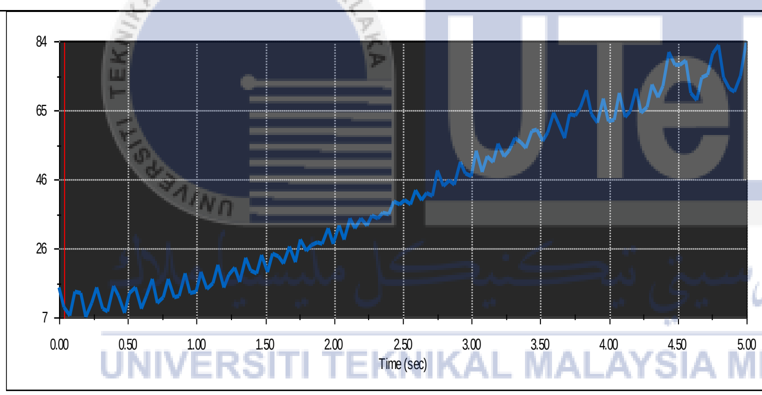
5		When the spring push down in regardd of 25 mm distance, the force produce by the sping is 67 N. from that the assistive torque from the spring is 1.675 Nm and can carry 6.83 kg load.
6		When the spring push down in regardd of 30 mm distance, the force produce by the sping is 76 N. from that the assistive torque from the spring is 2.28 Nm and can carry 7.75 kg load.
7		When the spring push down in regardd of 35 mm distance, the force produce by the sping is 84 N. from that the assistive torque from the spring is 2.94 Nm and can carry 8.56 kg load.

Table 4.2: Assistive Torque and Forces (Simulation)

No	Distance,d (mm)	Force,F (N)	Mass,m(kg)	Torque, τ (Nm)
1	5	24	2.45	0.12
2	10	44	4.49	0.44
3	15	44	4.49	0.66
4	20	51	5.2	1.02
5	25	67	6.83	1.675
6	30	76	7.75	2.28
7	35	84	8.56	2.94

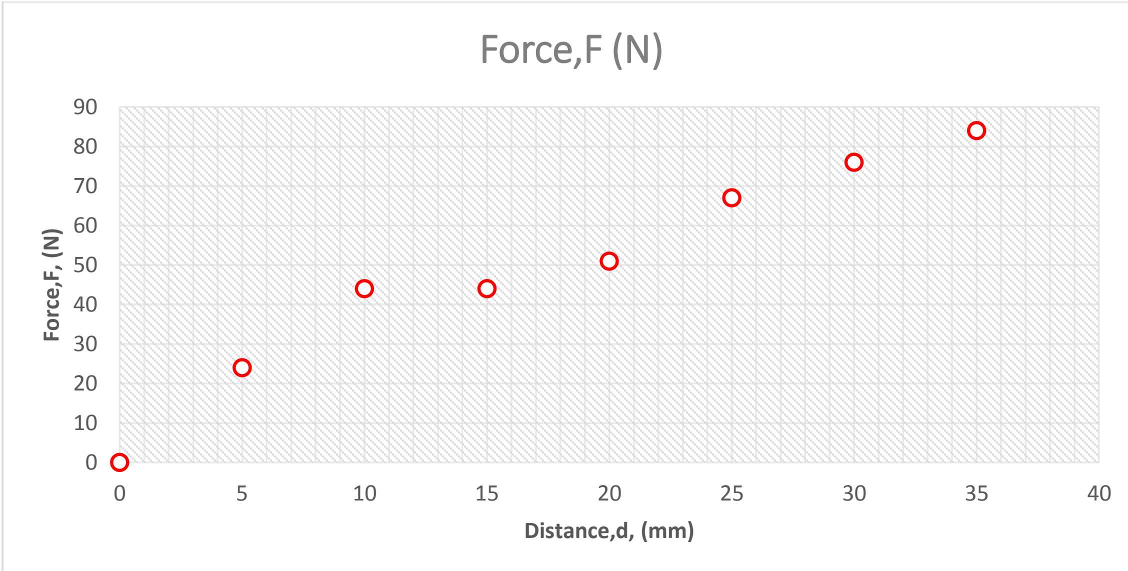


Figure 4.2: Graph for Force vs Distance

In the simulation part, the load that is use in simulation are varies from 1 kg to 7 kg. this corresonding to the load that are use in the experiment part. In the simulation using solidwork, the angle are replace by distance because the only way to get the assistive force created by the spring is by using distance. Thus in the graph the distance,d will against the assistive force created by the spring. By this information, we will know how much torque created by the spring and by this the assistive torque will directly become one of the assitive force to help the movement of the user of waist assistive suit. The assistive force varies from 22 N to 84 N when we pushed the spring to fixed distance in the simulation.

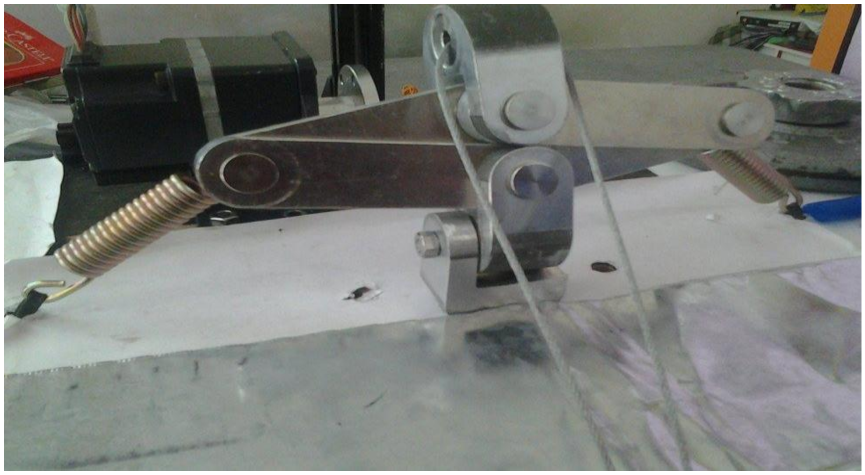


Figure 4.3: Experiment Setup 1

Figure 4.4: Experiment Setup 2

Figure 4.5: Experiment Setup 3

The experiment setup to find the assistive force are using load varies to 1 kg to 7 kg. The load are connected to waist assistive suit using cable. When the load are add, we will be looking at the protractor to find the angle and by that, the corresponding angle we will use $F = mg\sin\theta$ to find the assistive force in the spring.

$$F = mg\sin\theta = kx \tag{14}$$

Table 4.3: Assistive Torque and Force (Experiment)

No	Mass,m,(kg)	Angle,a, (˚)	Force,F (N)
1	1	76	9.5186
2	2	78	19.91
3	3	80	28.98
4	4	82	38.858
5	5	85	48.86
6	6	86	58.7
7	7	89	68.66

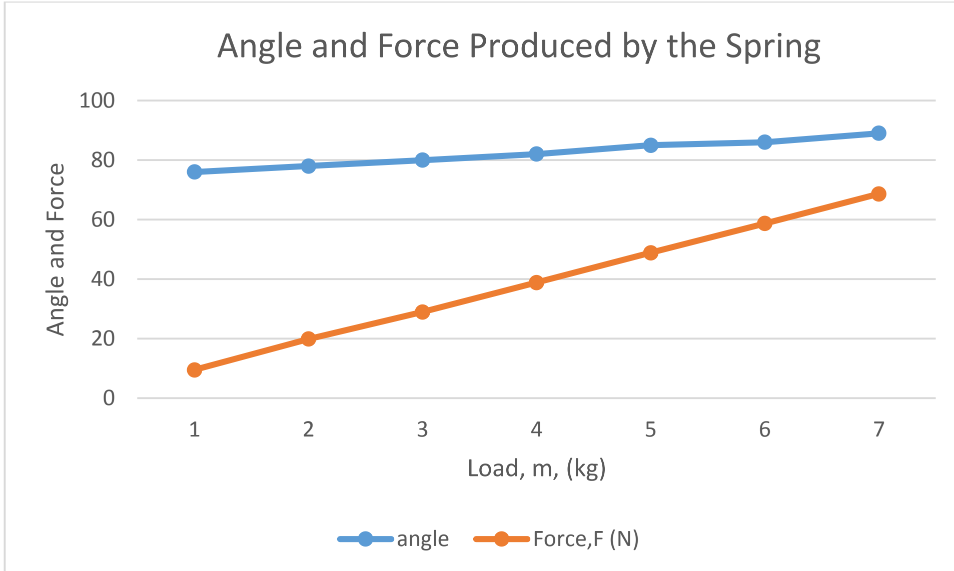


Figure 4.6: Graph for Relation between Angle and Force Produced by the Spring

The table and graph above show the correlation between angles produced when the load applied and the back force produced by the spring. When the angle increase the force is also increase. This can be explained thru the equation of $F = mg \sin\theta$. When the angle increase, the total multiplication will be increase too. When the angle of the waist assistive suit at angle 76 degree, the assistive produced by the spring is 9.5186 N. when the angle increase to 89 degree with the increase of mass, the assistive force produced by the spring increase significantly to 68.66 compare to the force that produced before this.

4.3 Experiment 2: Required Torque and Force in the Hip Test

This section will discuss on the theoritical and simulation result that produced from the calculation of dynamic and mechanism of structure and simulation through Solidworks motion simulation. To calculate the torque at the hip, all the parameter must be found out first either be estimated or weigh. The maximum of angle required are from the back rage motion of human biomechanics [8]. The motion that are related to this experiment is spine flexion. Spine flexion is most important DOF to lifting motion while extend total flexion range and allow natural bending postures. The maximum required torque values during lifting are calculated from all the value that are estimated and weighed. Thus to make the calculation easier the value 1 kg, 2 kg,3 kg, 4 kg, 5 kg, 6 kg, and 7 kg are pick to standardized the increase of the value load.

By using free body diagram (FBD),

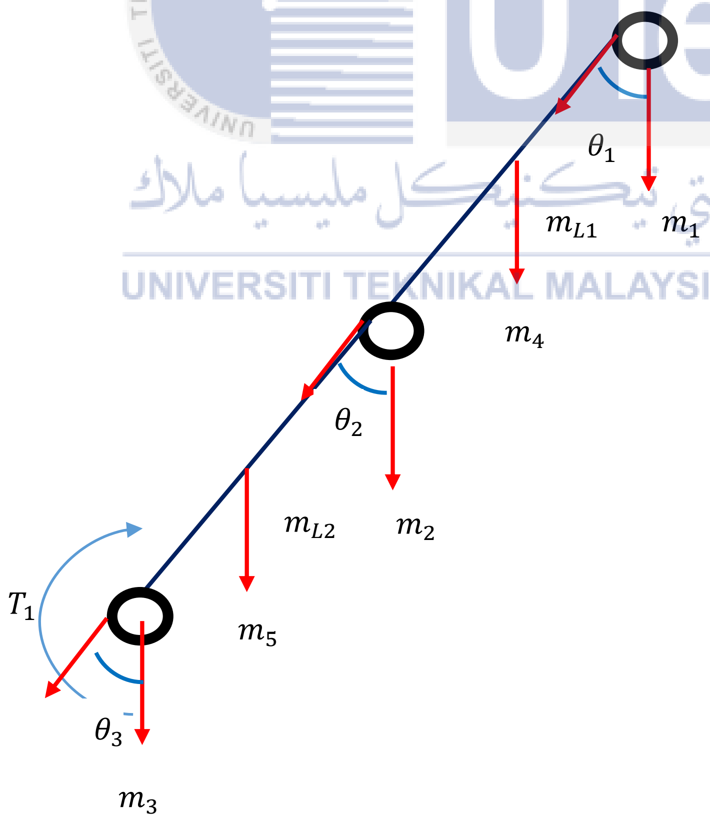


Figure 4.7 : Free Body Diagram

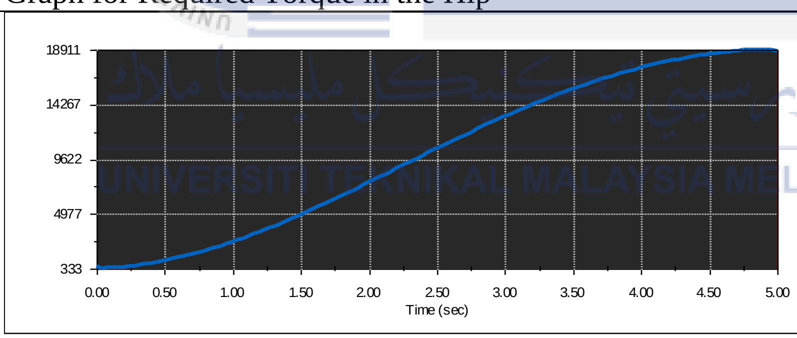
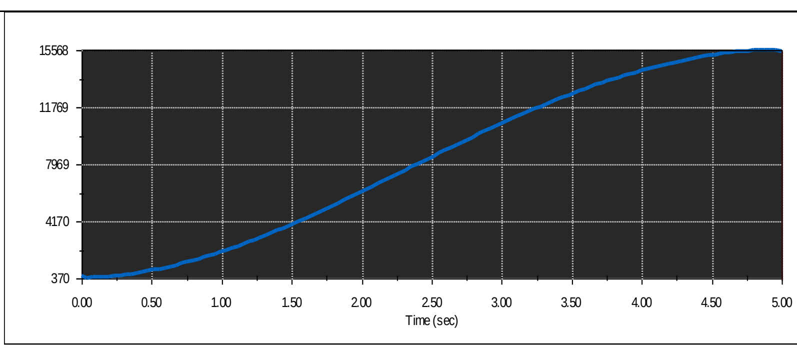
Table 4.4 :Parameter for Experiment 2

Parameter	**Value**	**Unit**
Mass of link 1	0.4	-kg
Mass of link 2	0.6	-kg
Length of link 1	150	-mm
Length of link	250	-mm
Load	1 , 2 ,3 , 4 , 5 , 6 , 7	-kg

$$\tau_1 = \sin\theta \left[(m_5 + m_{L2})g\left(\frac{l_2}{2}\right) + m_2 l_2 g \right] + \sin\theta \left[(m_4 + m_{l1})\left(\frac{l_1}{2} + l_1\right) g\right] + \sin\theta\ [(m_1(l_1 + l_2)g] \quad (6)$$

From the equation and the parameter above, we will find the theoritical required torque via calculation. The value for the calculated required torque will filled the table below acording to their load used.

Table 4.5: Graph for Required Torque in the Hip

NO	Graph for Required Torque in the Hip	Comment
1		In this simulation, the load that are used are 7 kg, and the angle are 46˚ for each joint. The graph shows that the required torque at the hip are 18.911 Nm.
2		In this simulation, the load that are used are 7 kg, and the angle are 36˚ for each joint. The graph shows that the required torque at the hip are 15.568 Nm.

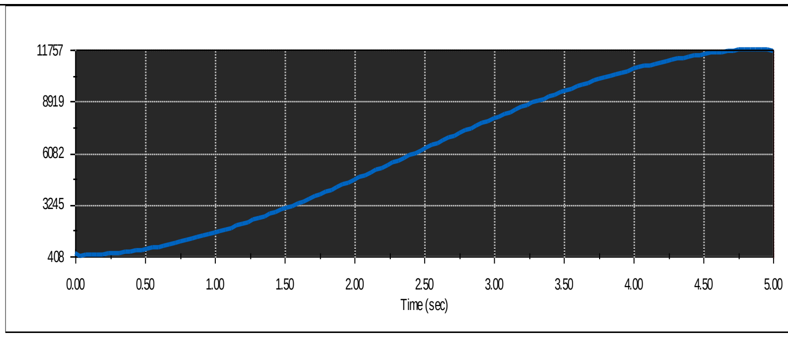
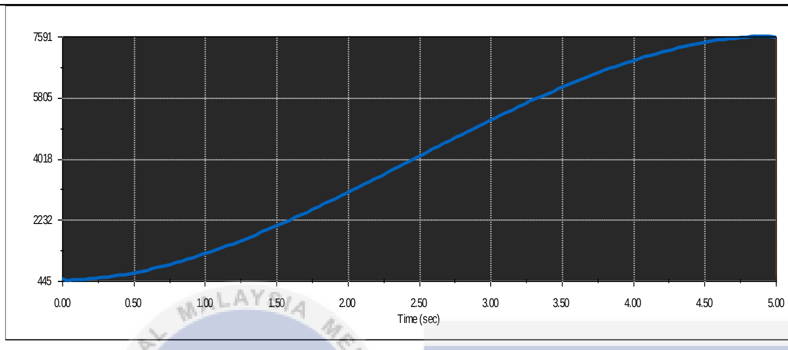
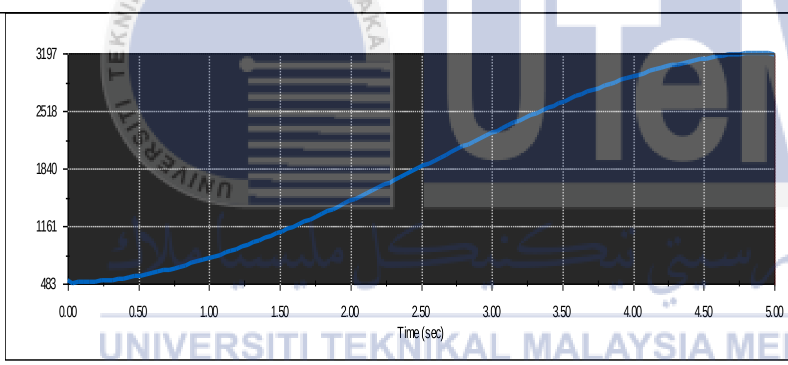
3		In this simulation, the load that are used are 7 kg, and the angle are 26° for each joint. The graph shows that the required torque at the hip are 11.757 Nm.
4		In this simulation, the load that are used are 7 kg, and the angle are 16° for each joint. The graph shows that the required torque at the hip are 7.591 Nm.
5		In this simulation, the load that are used are 7 kg, and the angle are 6° for each joint. The graph shows that the required torque at the hip are 3.197 Nm.

Table 4.6: Calculated Torque vs. Simulated Torque (7 kg)

No	Total angle, (̊)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	3.0809	3.197
2	16,16,16	8.1253	7.591
3	26,26,26	12.9225	11.757
4	36,36,36	17.3324	15.568
5	46,46,46	21.2063	18.911

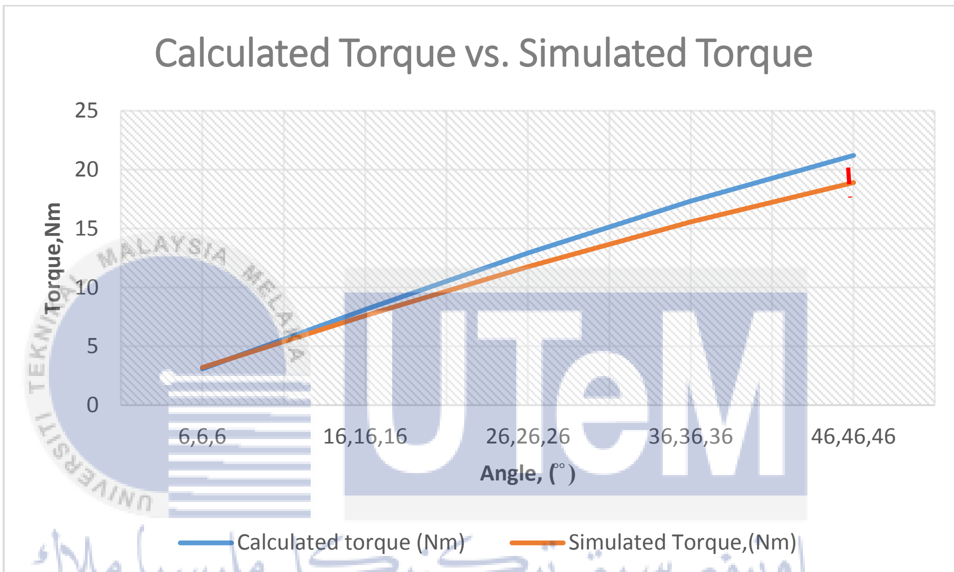


Figure 4.8: Graph of Calculated Torque vs. Simulated Torque Graph (7 kg)

From the table and graph above, the load that are use are 7 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The maximum angle bend that human can bend forward are limited to 4 zone. The maximum angle in the zone 4 are 46 degree. Thus we limit the maximum angle that we can test is to 46 degree and below. The angle increase varies from 3.0209 Nm to 21.2063 Nm in the calculation part while in the simulation part varies from 3.197 Nm to 18.911 Nm.

Table 4.7: Calculated Torque vs. Simulated Torque (6 kg)

No	Total angle, (ͦ)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	2.6708	2.864
2	16,16,16	7.045	6.802
3	26,26,26	11.20253	10.534
4	36,36,36	15.0201	13.949
5	46,46,46	18.3817	16.944

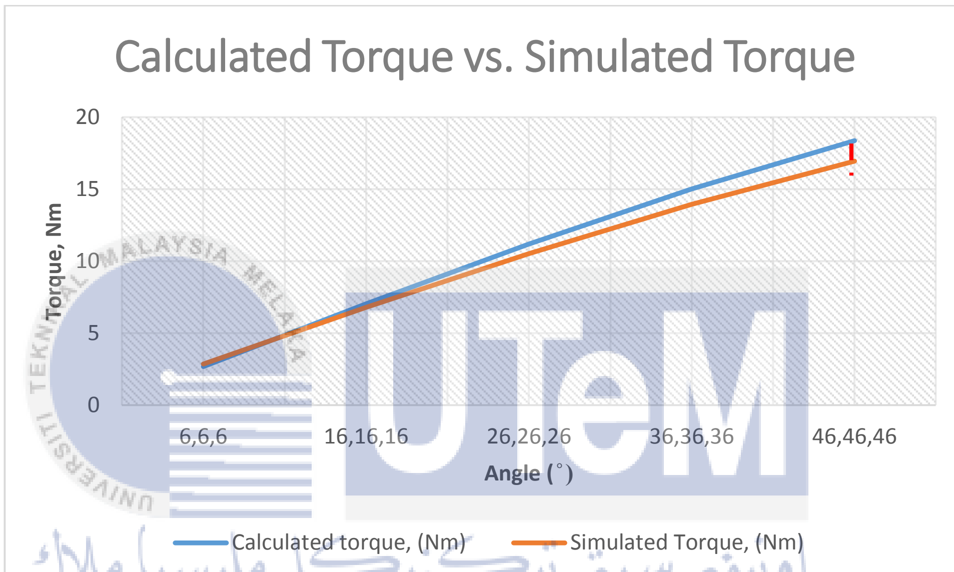


Figure 4.9: Graph of Calculated Torque vs. Simulated Torque Graph (6 kg)

From the table and graph above, the load that are use are 6 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 2.6708 Nm to 18.3817 Nm in the calculation part while in the simulation part varies from 2.864 Nm to 16.944 Nm.

Table 4.8: Calculated Torque vs. Simulated Torque (5 kg)

No	Total angle, (̊)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	2.2599	2.609
2	16,16,16	5.955	6.196
3	26,26,26	9.48153	9.597
4	36,36,36	12.7121	12.708
5	46,46,46	15.5597	15.437

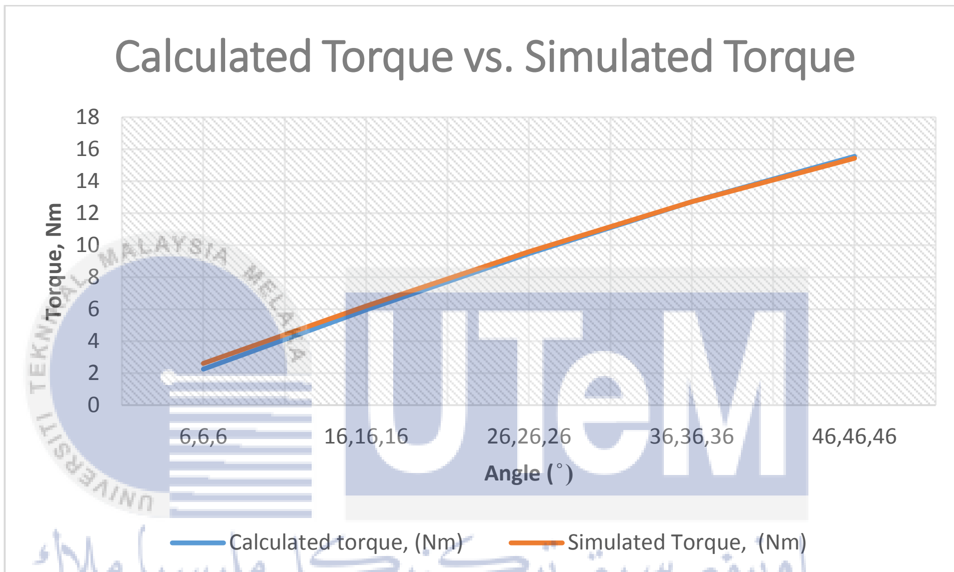


Figure 4.10: Graph of Calculated Torque vs. Simulated Torque Graph (5 kg)

From the table and graph above, the load that are use are 5 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 2.2599 Nm to 15.5597 Nm in the calculation part while in the simulation part varies from 2.609 Nm to 15.437 Nm.

Table 4.9: Calculated Torque vs. Simulated Torque (4 kg)

No	Total angle, (˚)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	1.8509	2.344
2	16,16,16	4.881	5.565
3	26,26,26	7.7253	8.619
4	36,36,36	10.4079	11.413
5	46,46,46	12.7371	13.863

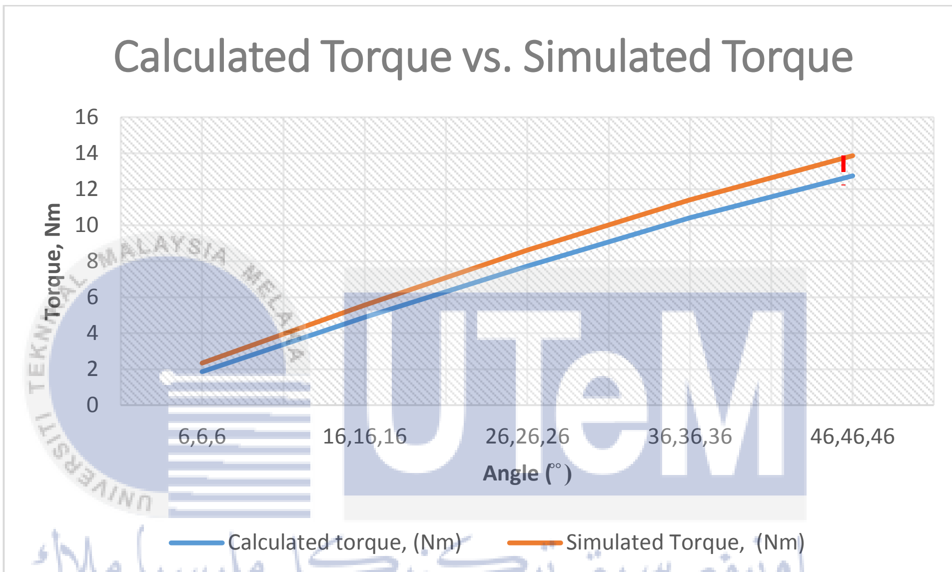


Figure 4.11: Graph of Calculated Torque vs. Simulated Torque Graph (4 kg)

From the table and graph above, the load that are use are 4 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 1.8509 Nm to 12.7371 Nm in the calculation part while in the simulation part varies from 2.344 Nm to 13.863 Nm.

Table 4.10: Calculated Torque vs. Simulated Torque (3 kg)

No	Total angle, (̊)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	1.4394	2.067
2	16,16,16	3.7998	5.565
3	26,26,26	6.04253	8.619
4	36,36,36	8.1024	11.413
5	46,46,46	9.9147	13.863

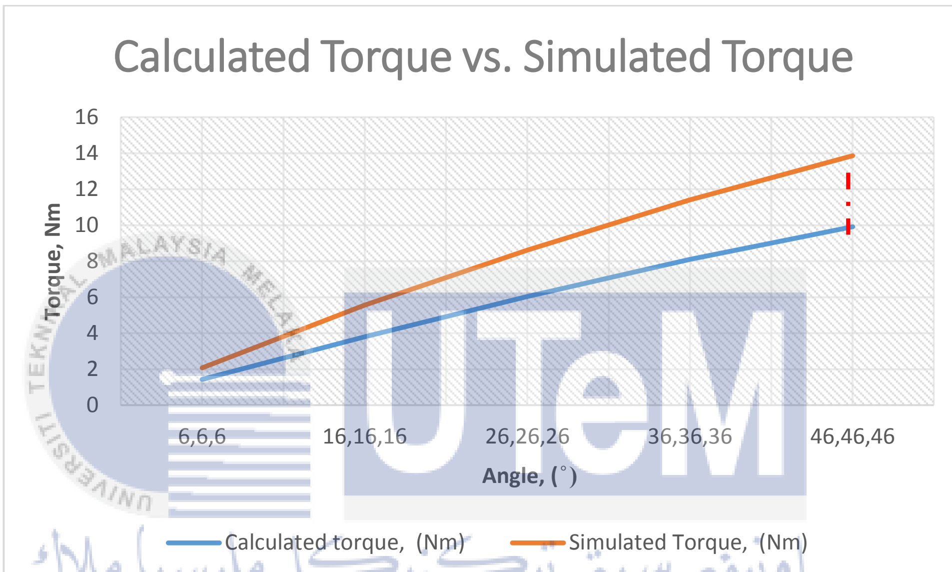


Figure 4.12: Graph of Calculated Torque vs. Simulated Torque Graph (3 kg)

From the table and graph above, the load that are use are 3 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 1.4394 Nm to 9.9147 Nm in the calculation part while in the simulation part varies from 2.067 Nm to 13.863 Nm.

Table 4.11: Calculated Torque vs. Simulated Torque (2 kg)

No	Total angle, (̊)	Calculated torque, τ c, (Nm)	Simulated Torque, τ s, (Nm)
1	6,6,6	1.0297	1.812
2	16,16,16	2.7182	4.302
3	26,26,26	4.32153	6.663
4	36,36,36	5.7951	8.822
5	46,46,46	7.0917	10.717

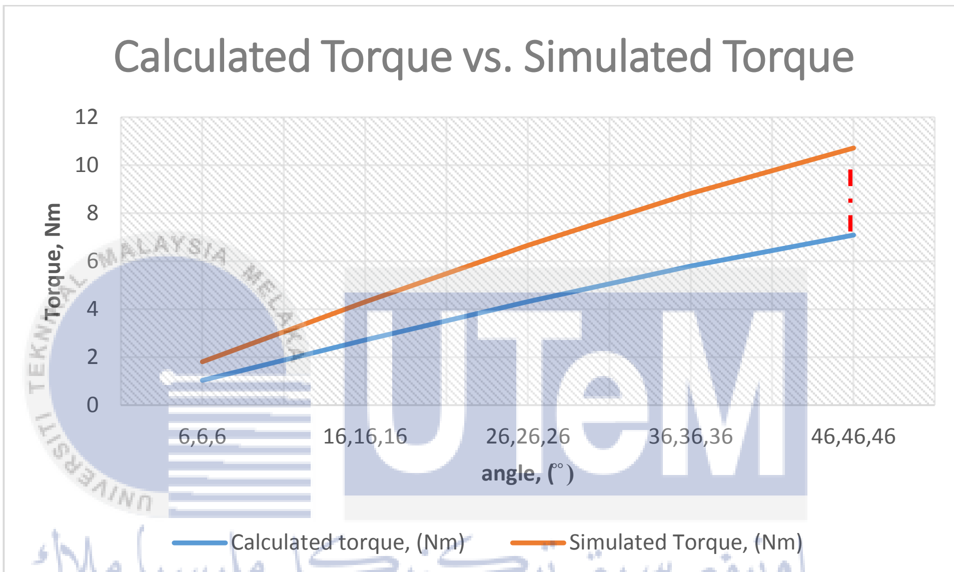


Figure 4.13: Graph of Calculated Torque vs. Simulated Torque Graph (2 kg)

From the table and graph above, the load that are use are 2 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 1.0297 Nm to 7.0917 Nm in the calculation part while in the simulation part varies from 1.812 Nm to 10.717 Nm.

Table 4.12: Calculated Torque vs. Simulated Torque (1 kg)

No	Total angle, (˚)	Calculated torque, (Nm)	Simulated Torque, (Nm)
1	6,6,6	0.6194	1.546
2	16,16,16	1.635	3.670
3	26,26,26	2.0153	5.684
4	36,36,36	3.4881	7.527
5	46,46,46	4.2699	9.143

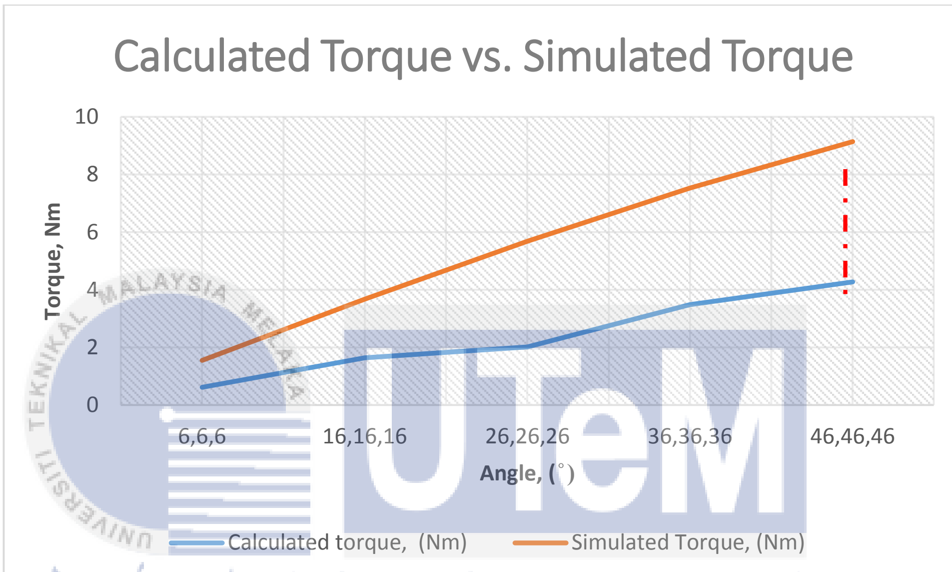


Figure 4.14: Graph of Calculated Torque vs. Simulated Torque Graph (1 kg)

From the table and graph above, the load that are use are 1 kg, and the angle varies from 6, 16, 26, 36, and 46 degree this is to show the relationship between the calculated data and the simulation data. From this data from both data, we can see that the correlation of both data is effect by the increase of the angle in both calculation and simulation. The required torque in the hip are increase with the increase of angle. The angle increase varies from 0.6194 Nm to 4.2699 Nm in the calculation part while in the simulation part varies from 1.548 Nm to 9.143 Nm.

All the link are placed at 6°, 16°, 26°, 36°, 46° in all the 3 joints that are related to forward dynamics to calculate the maximum torque with corresponding to the limit that human can bend [8]. Therefore the motor and drive system should produce more torque than the calculated and simulated. There are many combination of angle that we can use but to make the calculation easy and there are no time to calculate and simulate the waist assistive suit thus the increasing of angle are limited to 10 degree for each increase of the joint.

4.4 Experiment 3: Stress and Strain Test

In this part we will discuss the important of the stress and strain test to the fabrication of the design in this waist assistive suit project Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on.

Table 4.13: Stress Test

Weight of Load (kg)	Position of Exoskeleton in Home Position		
	Minimum (N/m^2)	Maximum (N/m^2)	Average (N/m^2)
10	2.65206e-13	5.0626e+6	2.53e+6
20	1.98285e-12	1.01264e+7	5.06e+6
30	5.30805e-12	1.51914e+7	7.60e+6
40	2.76602e-12	2.02584e+7	1.01e+7
50	1.49823e-13	2.53268e+7	1.27e+7
60	5.49324e-13	3.03964e+7	1.52e+7

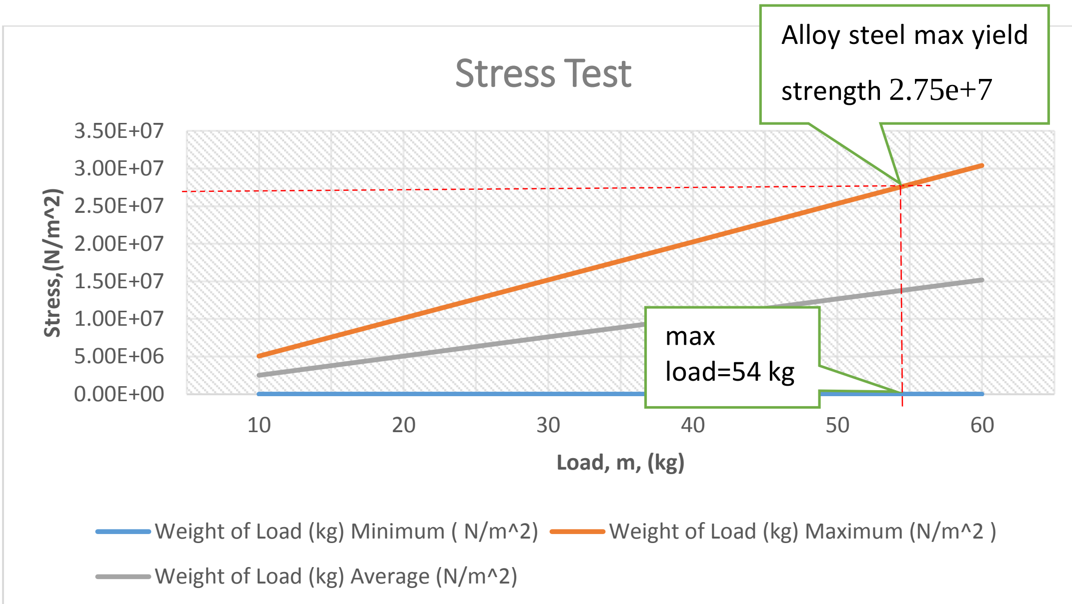


Figure 4.15: Stress Test

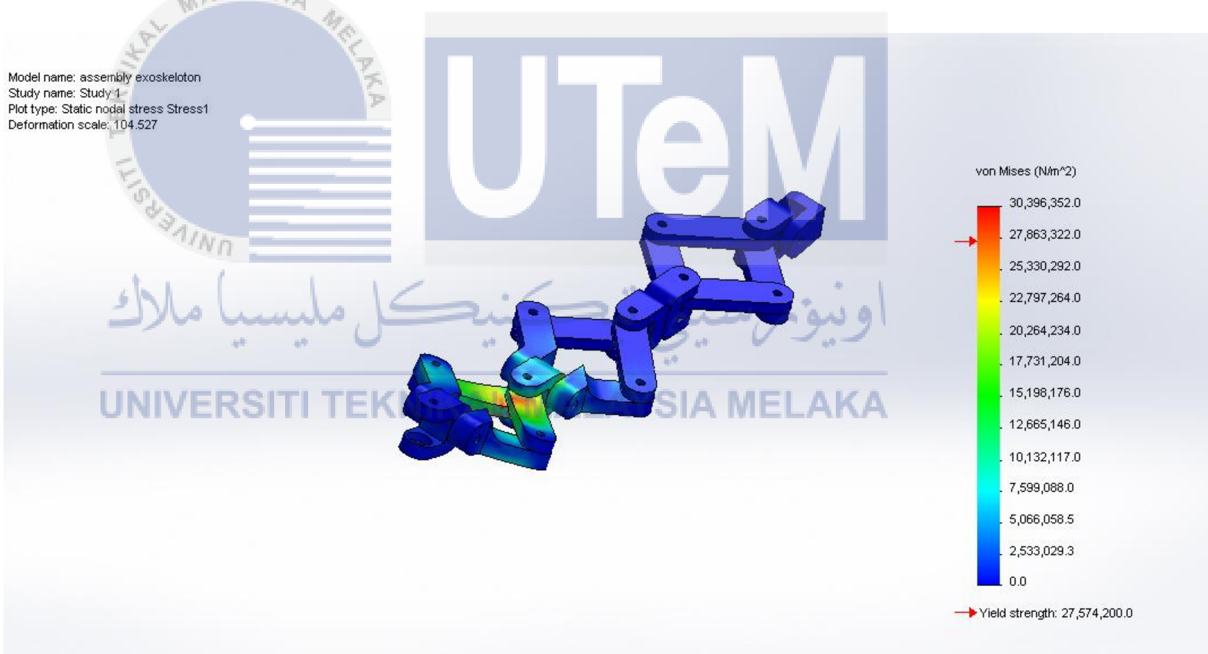


Figure 4.16: Stress Test (Simulation)

In the figure above, it shows that the stress is corresponding to the weight of the load. If the load increase then the stress will increase corresponding to the load. In this experiment the load that will be used is range from 10 kg, 20 kg, 30 kg, 40 kg, 50 kg, and 60 kg. The average if the load of 1 kg is been applied is 2.53e+6 N/m^2 and the average for 7 kg load is 1.52e+7 N/m^2. The maximum yield strength of alloy steel 2.75e+7, thus according to simulation, the maximum yield strength lies between 50 kg to 60 kg. We can concluded that the material will be bend if applied direct force between 50 kg to 60 kg.

Strain is defined as the amount of deformation an object experiences compared to its original size and shape. For example, if a block 10 cm on a side is deformed so that it becomes 9 cm long, the strain is (10-9)/10 or 0.1 Note that strain is dimensionless.

Table 4.14: Strain Test

Weight of Load (kg)	Position of Exoskeleton in Home Position		
	Minimum	Maximum	Average
10	0	5.24067e-5	2.62e-5
20	0	0.000104829	5.24e-5
30	9.90408e-23	0.000157263	7.86e-5
40	0	0.000209708	1.05e-4
50	0	0.000262192	1.31e-4
60	0	0.000314661	1.57e-4

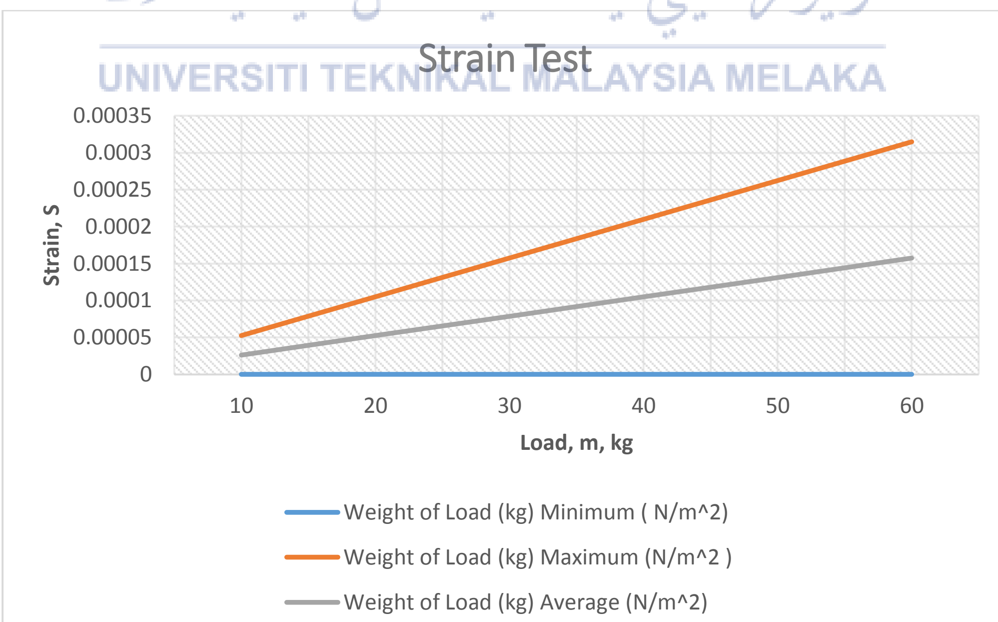


Figure 4.17: Strain Test

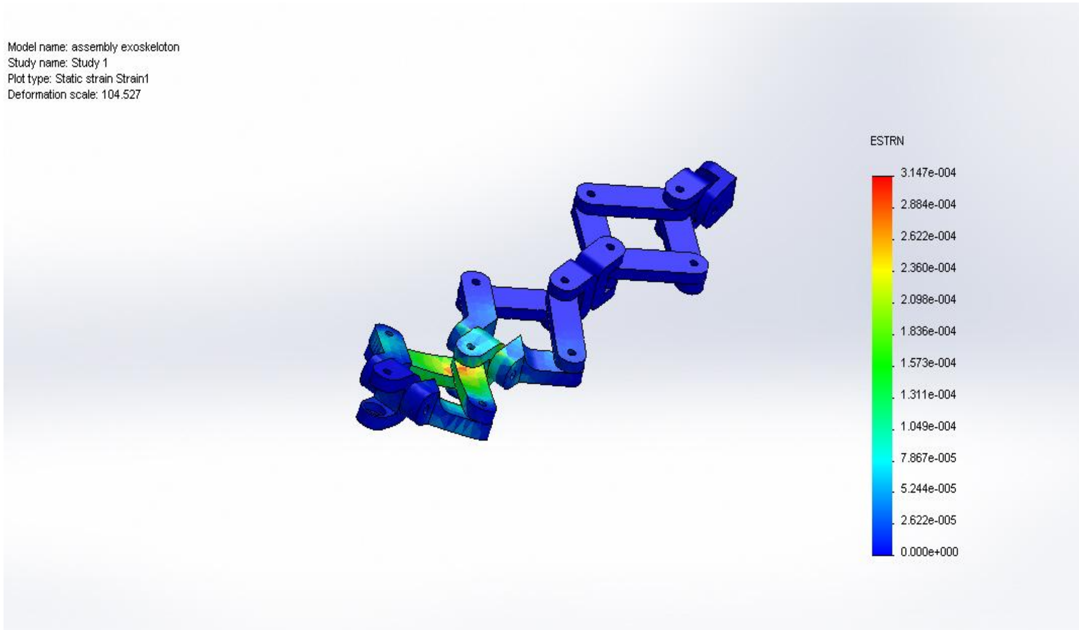


Figure 4.18: Strain Test (Simulation)

In the figure above, that the strain is corresponding to the weight of the load. If the load increase then the strain will increase corresponding to the load. In this experiment the load that will be used is range from 10 kg, 20 kg, 30 kg, 40 kg, 50 kg, and 60 kg. The average if the load of 10 kg is been applied is 2.62e-5 and the average for 60 kg load is 1.57e- 4. The value is so small that this indicate that the deformation of the material is so small that we cannot see with naked eye. The material is strong enough to hold until 60 kg without deformed the shape of the design.

CHAPTER 5

CONCLUSION AND RECOMENDATONS

5.1 CONCLUSION

This chapter represents conclusion of this project. The first components is modeling the 3 degree-of freedom of lower back suit mathematically in term of dynamics analysis. In this part we calculated the motor torque that are required at the help. We see the relationship between motor torque and the load that human can carry versus the angle with regards to the gravity of earth. The second components is to design the assistive torque that can help to distribute the required torque. We studied on the relationship between the distances (angle) of the spring to the assistive torque that the spring can produced. The last components is to analyze the structure of the in term of stress, strain analysis. We used the simulation in solid work to see the break point of the material use, in this case alloy steel. From that we can see the relationship between the load uses to the break point of the material use.

. The objective is accomplished with the testing for each load in the simulation using 1 kg, 2kg, 3 kg, 4kg, 5kg, 6kg, and 7 kg. The movement will be manually control by the user with the restrictions of motion according to the ergonomics design in 3 DOF waist power assistive suits in flexion, lateral flexion and rotation motion. The purpose of studying the spring determine how much can mechanism can produced assistive torque that help onto reduce the cost to buy a higher torque motor. The higher the torque of the motor the expensive and big the size in term of weight of the motor. The second objective is been achieved by the calculation in both experiment where it involved on dynamics analysis. The calculation help to determine the required torque and the assistive torque in the spring.

5.2 RECOMMENDATIONS

For the future, the design should be reduced into simple mechanism to reduce the cost and weight. The motor should be chosen by referring to the maximum weight that the waist assistive suit can handle. This can minimize the cost for developing the waist assistive suit. The material should be using a light weight because a person will be wearing the suit. Thus a light weight material is been proposed on the future research.

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APPENDIX A

PROJECT PLANNING														
List major activities involved in the proposed project. Indicate duration of each activity to the related week(s).														
Activities	**Week**													
										0	**1**	**2**	**3**	**4**
Final Year Project 1														
Selecting The Title For The Project														
Identify The Objectives And Scope														
Research And Literature Review														
Methodology Of Project														
Design Hardware And Circuit														
Experiment														
Final Year Project 1 Presentation														
Progress Report														
Final Year Project 2														
Hardware Development														

Software Development														
Experiment And Collect Data														
Troubleshooting														
Hardware Performance Analysis														
Final Year Project 2 Presentation														
Final Report														

APPENDIX B

```
int val_1 = 0;

int val_2 = 0;

int start = 0;

void setup() {

  // put your setup code here, to run once:

  pinMode(5, OUTPUT); // start/stop input

  pinMode(6, OUTPUT); // Brake input

  pinMode(7, OUTPUT); // CW/CCW

  pinMode(2, INPUT);

  pinMode(3, INPUT);

  pinMode(4, INPUT);

}

void loop() {

  // put your main code here, to run repeatedly:

  val_1 = digitalRead(2); // CW

  val_2 = digitalRead(3); // CCW

  start = digitalRead(4);

 if(start == 0){

     digitalWrite(5,HIGH); // start
```

```
  // CW
  if(val_1 == 0 && val_2 == 1){
    digitalWrite(6,HIGH);
    digitalWrite(7,HIGH); // CW
  }

  // CCW
  else if(val_2 == 0 && val_1 == 1){
    digitalWrite(6,HIGH);
    digitalWrite(7,LOW); // CCW
  }
  else{
   digitalWrite(6,LOW);
  }
 }
 else{
  digitalWrite(5,LOW); // stop
 }
}
```