EXPERIMENTAL OF FREE-LOAD HYDRO-PNEUMATIC PROPULSION SYSTEM

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A project report submitted
in fulfillment of the requirements for the degree of
Bachelor Mechanical Engineering (with Honours)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I hereby declare that this project entitled "Experimental of Free Load Hydro-Pneumatic Propulsion System" is the result of my own work except as cited in reference.

Signature :……………………………

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Date : 28 JUNE 2019

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honour).

Signature	:……………………
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Date	: 28 JUNE 2019

DEDICATION

To my beloved family for the endless support that they had gave, especially to my beloved father and mother, Muhammad Yusoff bin Ibrahim and Azlina binti Aziz.

ABSTRACT

The hydro-pneumatic hybrid system is one of the new hybrid systems, where it is a combination of the Internal Combustion Engine (ICE) and hydraulic system. This system promises an advantage in term of environment, fuel efficiency, and more efficient compared to a conventional car. However, the problem of this system is there too little data regarding its driveline behavior and there are no data for the maximum RPM of the system. This research is focused on experimental free load hydro-pneumatic propulsion system. The hydro-pneumatic propulsion system has been designed and the simulation was run by using Automation Studio software. The fabrication also involves in this research were to fabricate the test rig. This research aims to find free load RPM, flow, pressure losses and to calculate the free load efficiency of the system. The experimental method was chosen in this research in order to obtain the value of RPM, flow, pressure losses, and system efficiency. The experiment was conducted with a pressure of 100, 120, 140, 160, 180 and 200 bar. The analysis of the flow, pressure difference, power, torque, system efficiency and motor efficiency to the system pressure have been analyzed. Based on the experiment result, the highest value of RPM is achieved at maximum setting pressure which is 236.477 while the flow rate is proportional to the system pressure. The efficiency of the system is decreased with increasing the pressure. This is due to the high-pressure losses in the system. It can be concluded that the value of RPM, flow and power are depending on the input pressure.

ABSTRAK

Sistem hibrid hidro-pneumatik adalah salah satu sistem hibrid yang baru, di mana ia adalah gabungan Sistem Pembakaran Dalaman (ICE) dan sistem hidraulik. Sistem ini menjanjikan kelebihan dari segi persekitaran, kecekapan bahan api, dan lebih cekap dibandingkan dengan kereta konvensional. Walau bagaimanapun, masalah sistem ini ada terlalu sedikit data dan tidak ada data maksimum untuk putaran per minit (RPM). Kajian ini menumpukan pada eksperimen sistem penggerak hidro-pneumatik yang tidak mepunyai beban. Sistem penggerak hidro-pneumatik telah direka dan simulasi dijalankan dengan menggunakan perisian Automation Studio. Fabrikasi juga terlibat dalam kajian ini, di mana untuk menghasilkan rig ujian. Tujuan penyelidikan ini adalah untuk mencari nilai maksimum putaran per minit, aliran, kehilangan tekanan dan untuk mengira kecekapan sistem. Kaedah eksperimen dipilih dalam kajian ini untuk mendapatkan nilai putaran per minit, aliran, kehilangan tekanan dan kecekapan sistem. Eksperimen ini dijalankan dengan tekanan pada 100, 120, 140, 160, 180 dan 200 bar. Analisis aliran, perbezaan tekanan, kuasa, tork, kecekapan sistem dan kecekapan motor kepada tekanan sistem telah dianalisis. Berdasarkan hasil eksperimen, nilai putaran per minit tertinggi dicapai pada tekanan maksimum iaitu 236.477 manakala kadar aliran adalah berkadar terus dengan tekanan sistem. Kecekapan sistem berkurang apabila tekanan sistem dinaikkan. Ini disebabkan oleh kehilangan tekanan tinggi di dalam sistem. Secara kesimpulannya, nilai putaran per minit, aliran dan kuasa bergantung pada tekanan sistem.

ACKNOWLEDGEMENT

Bissmillahirrahmanirrahim,

Alhamdulillah. Praise to Allah SWT, who has given me the opportunity and His blessing, guidance to complete this final year project.

Firstly, I would like to express my deepest thanks to my supervisor En. Faizil Bin Wasbari from Universiti Teknikal Malaysia Melaka (UTeM) for his supervision, guidance, endless support and encouragement towards the completion of this final year project.

I also would like to thanks to my examiner, Dr. Yusmady Bin Mohamed Arifin and En. Shamsul Bahari Bin Azraai for their advice, suggestion and some tips to complete this project. Besides that, a special thanks to En. Ikhmal Hisham Bin Ibrahim, Fluid Power lab assistance, for the advice, helps and valuable information which helps me in completing the test rig and the experiment. Not to forget, thanks to all my friend that always help, and giving their idea in order to complete this project.

Lastly, deepest thanks to my mother Azlina Binti Aziz, my father Muhammad Yusoff Bin Ibrahim and other family members for always be with me and full of support for the report completion, from the beginning to the end.

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LIST OF ABBREVIATIONS

ICE	Internal Combustion Engine
HEV	Hybrid Electric Vehicle
HHV	Hybrid Hydraulic Vehicle
FCV	Flow Control Valve
PCV	Pressure Control Valve
DCV	Directional Control Valve
RPM	Revolution per minute
SOP	Standard Operating Procedure

LIST OF SYMBOLS

p	Pressure (bar)
Q_{avg}	Average flow rate
Δp	Pressure difference
$Pout$	Power output at hydraulic motor
N	Speed in RPM
T	Torque
Pin, sys	Input power at the system
p_{sys}	System pressure
η_{sys}	System efficiency
η_{motor}	Motor efficiency
Pin	Power Input

CHAPTER 1

INTRODUCTION

1.1 Background

The hybrid technology system is the system that combined two or more technologies to achieve an efficient system. In this era of technology and globalization, the hybrid system is now growing in popularity in the automotive field due to its advantages in term of the environment, fuel-efficiency and more efficient compared to a conventional car (N.d., 2016). In a field of automotive, hybrid means the vehicle that use two or more different power sources that are work together to move the vehicle or create power. Hybrid hydraulic technology is famous among the heavy vehicle such as buses and a garbage truck, and this technology is still in research and development for applying at the passenger car (Wasbari, Anas and Abu Bakar, 2016).

The hydro-pneumatic hybrid system is a new hybrid system that been introduced. It is a combination of the internal combustion engine (ICE) and hydraulic system for the propulsion and pneumatic system for the energy source. The hydro-pneumatic driveline consists of five sub-systems which are propulsion, regenerative system, storage, transmission, and control system (Wasbari, Anas and Abu Bakar, 2016). Propulsion is a mechanism to move a vehicle. Regenerative system or know as the regenerative braking system is a system that captures the energy loss during the braking or decelerates that are in the form of kinetic energy and change the energy to compression energy. The compression energy is then be stored in a hydraulic-pneumatic accumulator in the form of the potential energy. When the energy required by a car to accelerate, the stored energy will be a channel to the hydraulic motor to rotate the wheel.

Hydro-pneumatic hybrid offers a few advantages and disadvantages over the other hybrid vehicle. Hydro-pneumatic hybrid requires less energy conversion compare to an electric hybrid vehicle. An electric hybrid will convert kinetic energy to electrical energy and then to chemical energy to store in the battery. For the hydro-pneumatic hybrid, it converted kinetic energy to fluid pressure energy and stored in the storage system. Due to less energy conversion by hydro-pneumatic hybrid, this leads to higher efficiency compared to electric vehicle (Kumar, 2012). Besides its advantage, the hydro-pneumatic hybrid also has its disadvantages which is in parallel hydro-pneumatic hybrid it does not allow the engine to turn off when the vehicle does not result in motion, unlike a hybrid electric car. The vehicle will always burn gas (Valente and Ferreira, 2012).

This research is focusing on the hydro-pneumatic driveline. The free load running experiment is important to find the net power supplied to the by the energy storage. The system efficiency will be calculated.

1.2 Problem statement

The hydro-pneumatic hybrid system is a new system that is still in the research and development stage for a passenger car. This system can contribute higher efficiency compare to another hybrid vehicle. Due to this is a new system, there are a few data regarding it driveline is still not studied. This paper focuses on finding free load RPM, flow, pressure and pressure losses. Next, the efficiency of the free load system will be calculated.

1.3 Objective

(i) To find the free load RPM, flow, pressure and pressure losses.

(ii) To calculate the efficiency of free load system.

1.4 Scope

The energy that gains from brakes will store in the accumulator. The concern in this project is to run an experiment to find the net power supplied by the energy storage. The simulation has been conducted by using Automation Studio software. After connecting the system to shaft and differential, the power will drop so it can be calculated. The data then will be used to calculate the system efficiency. This project will only involve design and experimentation.

1.5 Hypothesis

This research is expected to get the net power supplied by the energy storage. To obtain the net power supply, the free load experiment will be carried out. Other than that, system efficiency also will be calculated. Once the system is connected to the shaft and differential, the power will be drop so it can be calculated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, a review of the hybrid system and hydraulic hybrid vehicle will be discussed. Next, a review of the hydro-pneumatic system is being discussed. This chapter also includes types of propulsion which describe the different types of propulsion and its advantage and disadvantage. Other than that, the hydraulic motor propulsion system is also included in this chapter where it discusses more detail about the hydraulic motor propulsion system. On section 2.7, type of hydraulic motor and their advantages and disadvantages are discussed. This chapter also included a hydraulic motor control system. On section 2.9, discussed hydraulic motor for dual function.

2.2 Hybrid system

The hybrid system can be defined as a combination of a different approach. In a term of automotive, hybrid means that the vehicle that uses two different forms of power such as electric motor and internal combustion engine (ICE) for propulsion. The hybrid system has been introducing due to environmental concerns demand improvement in fuel economy and lowering emission for a passenger vehicle (Hawkins, 2012). Hybrid electric vehicle (HEV) have proven to be the best choice due to the usage of the smaller battery pack and its similarities to the conventional vehicle (Bitsche and Gutmann, 2004). HEV is also the most efficient fuel consumption compared to another hybrid vehicle (N.d., 2013a). However, with a new system that is called “Hybrid Air” PSA claim that this system will be far most cost-effective than the petrol-electric drivetrain (Holloway, 2014). Based on the experiment that been carried out, for the 11km drive, the fuel consumption for the HEV is 0.37 liter while for the hybrid-hydraulic vehicle (HHV) Hybrid Air are about 0.32 liter (Boretti and Zanforlin, 2014). This show that the HHV is more efficient fuel consumption compared to HEV.

2.3 Hydraulic hybrid vehicle

Hydraulic hybrid vehicle is also known as HHV is a new hybrid system that is still in the research process. It consists of an internal combustion engine (ICE) and energy storage device. This system is the same as hybrid electric vehicle (HEV), but it will store the kinetic energy that was originally momentum as potential energy in the form of pressure. Hydraulic hybrid mainly consists of two accumulators that are high pressure and low-pressure accumulator. The high-pressure accumulator is operating between 135 and 485 bar while low-pressure accumulator is operating between 3.5 and 13.5 bar (Boretti and Zanforlin, 2014). When the vehicle decelerates, the hydraulic pump will pump the fluid that is from the low-pressure accumulator to high-pressure accumulator. When the vehicle accelerates, the pressure will be released from the accumulator which will spin the drive shaft and accelerates the vehicle. The engine will remain idle while the pressure is released and when the accumulator is empty, or desired speed is achieved, the engine will start operating to maintain a constant velocity or to accelerate beyond the limit of accumulator capable (Kumar, 2012). Figure 2.1 shows that the configuration of the accumulators in the vehicle. The red represents the high-pressure accumulator while the green represents low-pressure accumulator.

There is a lot of advantage and disadvantage of the hydraulic hybrid vehicle. The main advantage and disadvantage are:

- Environmentally friendly

  One of the biggest advantages of the HHV over ICE is it runs clearer and has better gas mileage. It is because the hybrid car runs two engines and cut fuel consumption and converse energy.

- Regenerative braking system

  Each time the brake is applied, the energy loss during braking will then be stored in storage devices and will be used to accelerates.

- Less dependence on fossil fuels

  The hybrid car requires less fuel consumption which means less emission and less dependent on fossil fuel. It also helps in reducing the price of gasoline in the market.

- Built from light material

  Mostly, all hybrid vehicle made of light material which means it requires less energy to run.

- Less power

  The gasoline engine which is the primary engine is much smaller compared to a single gasoline car engine. The combination of the gasoline engine in the hybrid and the hybrid system provides less power. This car is suitable for city driving and not for speed and acceleration.

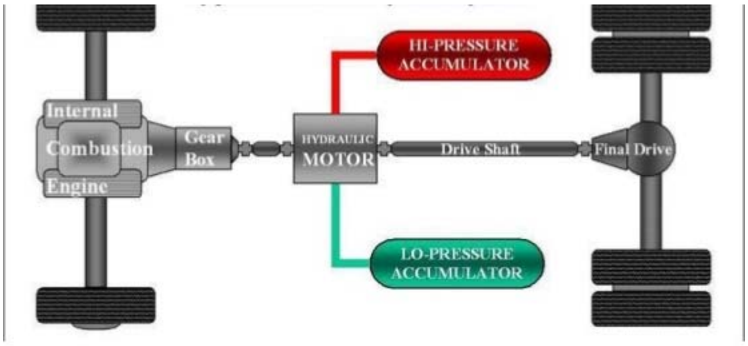


Figure 2.1: Configuration of the accumulator

2.4 Hydro-pneumatic system

Hydro-pneumatic can be defined as a system that operates using both fluid and air or other gases (Radu, 2013). The hydro-pneumatic system has been used for many applications such as car suspension system, hydropneumatic tanks, and other applications.

The hydro-pneumatic suspension has been introducing by Citroen employee Paul Mages (Radu, 2012). Basically, cars use spring to act as a shock absorber, to protect the passengers from the jolts when the car undergoes imperfection of the road. The spring and shock absorber system has replaced by a sphere that contains nitrogen gas and hydraulic fluid. Both of it is separated by a flexible membrane. Figure 2.2 below shows an example of hydro-pneumatic suspension (sphere). Every wheel was attached to a control arm, and the movement of the arm will push the hydraulic fluid. Generally, the car that equipped with this hydro-pneumatic system has five or six spheres, which is one for each corner as shown in Figure 2.3 below. The main advantage of these systems, it improves and provides the ride quality and comfortability of the vehicle.

Figure 2.2: Hydro-pneumatic suspension (sphere)

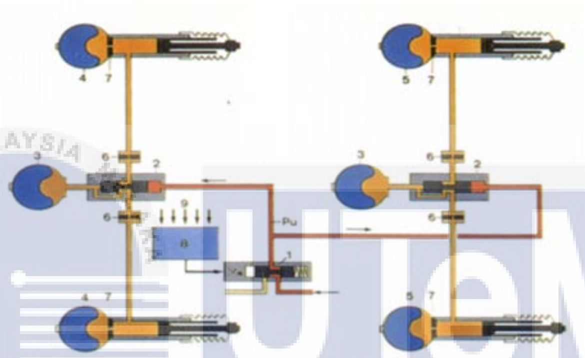


Figure 2.3: Schematic diagram hydro-pneumatic suspension

Hydro-pneumatic tanks is a storage tank that is designed to store water and air under pressure. It does not have a bladder, where the air and water are direct contacts. The purpose of hydro-pneumatic tanks is to provide pressurized water quickly and do not require the use of a pump often. In a well water application, the water will be provided when the pressure range is reached. It is to reduce the pump from running constantly. By having hydro-pneumatic tanks system, the system can be more effective; this is because when the small amount of water is needed, hydro-pneumatic tanks can supply it without the need to start up or use the pump. The main advantage of this system is it prevents the constant use of the pump even if a small amount of water is needed for the system. Next, this system also could reduce the water hammer. Figure 2.4 shows an example of the hydro-pneumatic water tanks.

Basically, the hydro-pneumatic system is the type of system that is consist of hydraulic and air. Hydraulic being used in order to compress the bladder inside the accumulator that contain nitrogen gas. The compressed air will then be used to pressurize the hydraulic fluid through the system.

Figure 2.4: Hydro-pneumatic water tank

2.5 Type of propulsion

Propulsion can be defined as creating a force that will lead to a movement. Propulsion comes from a word propeller which means to push away. The modern meaning of the propulsion is the act of moving forward. The propulsion system consists of a mechanical power source where it converts the mechanical power into a propulsive force. This concept of force is explained in Newton's third law of motion where the force of the first object is in the opposite direction of the force in the second object. There are several types of propulsion system that is an internal combustion engine, electric motor, and hydraulic motor.

2.5.1 Internal combustion engine (ICE)

Internal combustion engine (ICE) is a type of propulsion system that is widely used for power generating devices. It can be divided into two groups which is continuous combustion engines and intermittent-combustion engine (Proctor, 2018). The continuous-combustion engine is the type of engine that has a steady flow of fuel and oxidizer into the engine. For example, are a jet engine. The intermittent-combustion engine is the type of engine that produces a periodic ignition of air and fuel. This is referred to as a reciprocating engine. The reciprocating engine is widely used in automotive industries.

Spark ignition gasoline engine and compression ignition diesel engine are an example of a reciprocating engine. These two engines are widely used in a vehicle. Most of these are four strokes cycle engine, which means it needs four piston strokes to complete a cycle. Both two types are different in the way how they supply and ignite the fuel (N.d., 2013b). For the spark ignition gasoline engine, during the intake process, the fuel and air are mixed and then inducted in the cylinder. When the piston compresses the fuel-air mixture, the spark from the spark plug ignites it and cause combustion. During the power stroke phase, the expansion of the combustion gas will push the piston to move downward. During the last phase, which is exhaust stroke, the piston will move upward and releasing the combustion product through the exhaust valve. The system cycle is shown in Figure 2.5. While for the compression ignition diesel engine during the first phase of this cycle which are called intake process, only the air is inducted into the engine and then will be compressed at phase two. At the combustion phase, the diesel engine sprays the fuel into the hot compressed air and will cause it to ignite. This process will cause the piston to move downward. For the last phase, the piston will then move upward and releasing the combustion product through the exhaust valve. The cycle for this system shown in Figure 2.6.

The internal combustion engine has its advantage and disadvantage (Technical, 2018). The advantage of ICE is that it requires less starting time. Next, the lubricant consumption is less compared to the external combustion engine. Besides that, ICE serves high efficiency compared to the external combustion engine. ICE also requires less maintenance and safer to operate. The disadvantages of ICE are the fuel used very costly, like gasoline or diesel.

Furthermore, in the case of reciprocating internal combustion noise is generated due to the detonation of fuel. This system is also not suitable for large-scale power generation. Lastly, the engine emissions are generally high compared to the external combustion engine.

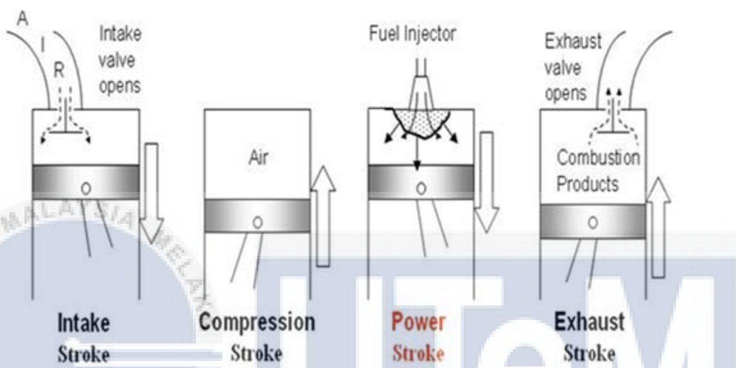


Figure 2.5: Spark ignition gasoline engine

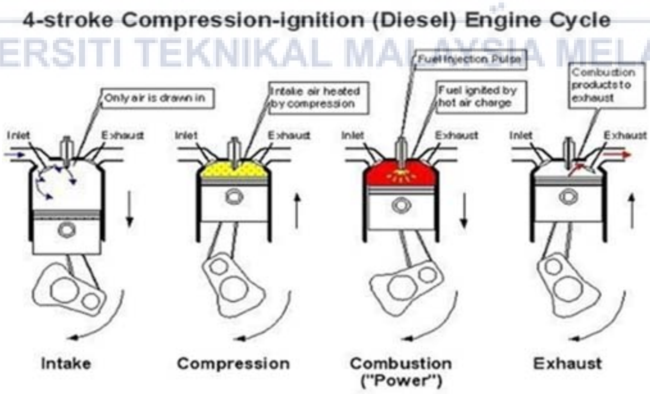


Figure 2.6: Compression ignition diesel engine

2.5.2 Electric motor

The electric motor is the device that is used to convert electrical energy into mechanical energy. One type of electric motor that is commonly used is the DC motor. Direct current motor or more familiar with DC motor. The principal of the DC motor is when a current carrying conductor is placed between the magnetic field, it will lead to torque and move. This behavior is known as motoring action. The direction of the rotation depends on the direction of the current. If the direction of current reversed, the rotation would be reversed as well. Mechanical force is produced when the magnetic field interacts with the electric field. By using Flaming's left rule, the direction rotation of a motor can be determined.

Figure 2.7 below shows an example of the working principle of the DC motor. As shown in the figure below, when the input voltage is supply, the electric current which is flows, and the presence of the magnetic field, produce the torque. Due to this torque, the DC motor armature will rotate. The DC motor has a shaft that comes out from the center of the armature, and the shaft is attached to the mechanical load.

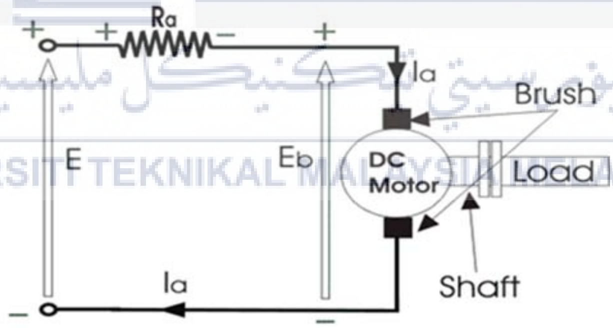


Figure 2.7: Working principle of DC motor

2.5.3 Hydraulic motor

The hydraulic motor is the devices that are commonly used to convert hydraulic or fluid energy into mechanical power. The hydraulic motor usually works with a hydraulic pump, which converts fluid power into mechanical power. There are several types of hydraulic motor that are commonly used nowadays. The hydraulic motor consists of variable displacement or fixed displacement and operates either unidirectionally or bidirectionally. For the fixed-displacement motor, it provides constant torque while for the variable-displacement motor provide variable speed and torque (Gannon, 2013).

2.6 The hydraulic motor propulsion system

The hydraulic motor propulsion system can be defined as on how the system works to move the hydraulic motor. In the hydraulic system, the main source is fluid pressure the circuit or drive system for hydraulic motor basically the same as the cylinder circuit (N.d., 2018). The basic component that is involved is a pump, pressure relief valve, directional control valve, connectors, and line. The example of the circuit for the cylinder and motor are shown below in Figure 2.8 and Figure 2.9 respectively. In a basic cylinder circuit as well as a hydraulic motor circuit, it uses a four-way directional control valve where it can exert force in both directions. The function of the control valve is to return the neutral flow to the reservoir. For the first position, where the control valve is in a neutral position, there is no fluid can flow past to the upstream of the directional control valve. This fluid will then back to the reservoir. When the control valve is shifted into one direction, the fluid will be directed to the piston side and cause it to extend. The fluid from the rod side will pass through the valve and back to the reservoir. When the valve is shifted to another direction, the fluid will flow directly through the rod side of the cylinder and cause it to retract. The existing oil at the piston side will be compress and back to the reservoir. For the rotary hydraulic motor circuit, the working principle is the same. The amount of torque is based on the pressure and motor size whereas for the speed it depends on the flow and motor size.

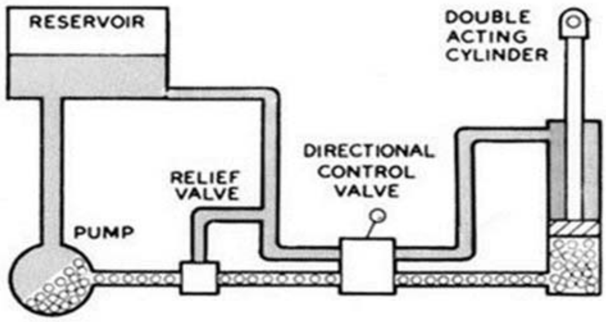


Figure 2.8: Hydraulic cylinder circuit (N.d., 2018)

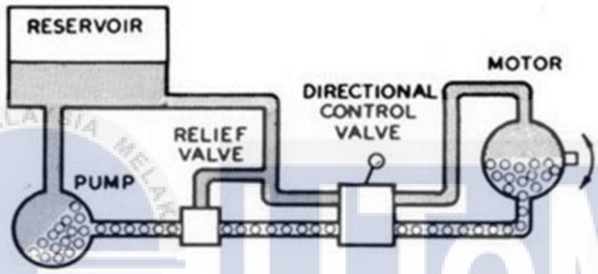


Figure 2.9: Hydraulic motor circuit (N.d., 2018)

2.7 Type of hydraulic motor

The hydraulic motor consists of many types, and all of it has its design and specification. It may be different in the ability of the pressure surface to withstand the force, volumetric and mechanical efficiency, and a mechanical connection between the surface area and an output shaft. Based on research, positive displacement types of motor are being used for the high-pressure purpose. Positive displacement motor consists of several types and in this research three types of motor are being selected for consideration which is gear, vane and piston motor.

2.7.1 Gear motor

External gear motor consists of two symmetrical gears that are enclosed in one housing. Both of this gear has the same tooth form and are driven by pressure fluid. One gear will be connected to the shaft, and the other gear is an idler. Both of this gear mesh together, which mean if one gear rotates the other gear will also rotate. When the fluid enters at the inlet port, the fluid forces the gear to rotate and follow the least resistance around the periphery of the housing. The fluid will exit at the outlet port at the low pressure. The fluid leakage and volumetric efficiency are controlled by having a close tolerance between the gears and housing. The purpose of the wear plate on the sides of the gears helps the gears from moving axially and help control leakage. Close tolerance and shaft support allow external gear motor to run to pressures beyond 3,000 PSI / 200 BAR, making them well suited for use in hydraulics. Small external gears motor usually operates in a range 1750 or 3450 rpm while for the larger models operate at a speed of 640 rpm (N.d., 2017). The overall efficiency of the external gear motor is about 85% (Casey, 2011). Figure 2.10 shows an example of the external gear pump and the component inside the motor.

Table 2.1: Advantage and disadvantage of external gear motor (N.d., 2017)

No	Advantage	Disadvantage
1	High-speed operation	Four bushings in the liquid area
2	High pressure	No solid allowed
3	No overhung bearing loads	Fixed end clearance
4	Relatively quiet operation	
5	Design accommodates a wide variety of materials	

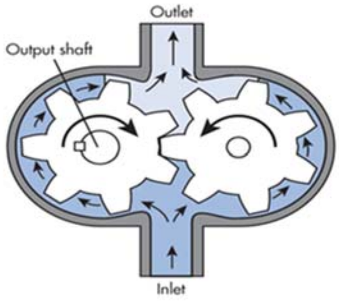


Figure 2.10: External gear pump

Internal gear motor which is direct drive gerotor motor consists of shaft, inner and outer gear. The inner gear is smaller than an outer gear, and the number of teeth for inner gear is less than outer gear. Due to a smaller number of teeth, the pocket is formed between inner gear and the outer gear. The center of the internal gear is coinciding with the center of the output shaft. When the pressure fluid is introduced, both gears will be rotated. The fluid will trap at the pocket that is formed. When the internal gear rotates, the fluid will then travel from one to another pocket. When the fluid reach at the outlet port, the internal gear will rotate and create a pressurized and push the fluid to goes out. The overall motor efficiency for the internal gear motor is about 90% (Casey, 2011). The internal gear motor can be operating at 200bar. Figure 2.11 shows an example of the direct-drive gerator motor.

Table 2.2: Advantage and disadvantage of Internal gear motor

No	Advantage	Disadvantage
1	Excellent for high-viscosity liquids	Usually requires moderate speed
2	Easy to maintain	Medium pressure limitation
3	Only two moving parts	One bearing runs in the product pumped
4	Non-pulsating discharge	Overhung load on the shaft bearing
5	Operates well in either direction	

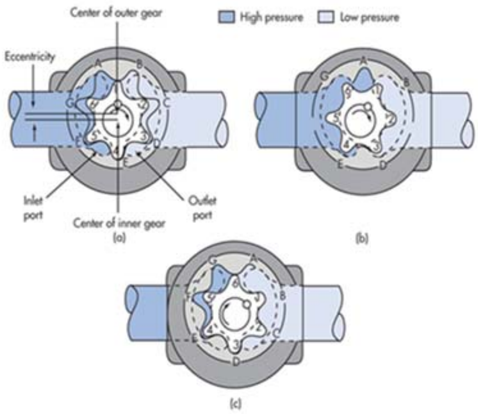


Figure 2.11: Direct drive gerator motor (N.d., 2014)

2.7.2 Vane motor

Hydraulic vane motor is the type of hydraulic motor which its operation is based rotor that contains a radial slot for the vane and rotates by a shaft. Hydraulic vane motor can be divided into two which is balanced and unbalanced vane motor.

Unbalanced vane motor consists of the vane that is mounted to the rotor. The vane is on and off-center drive shaft. As the shaft rotates, the variable length vane slides in and out to maintain contact with the motor housing. The tension in vane is maintained by either spring or hydraulic pressure. As the vane rotate, they create a chamber of varying sizes within the motor. Fluid enters at the largest chamber. As the vane rotate and retract, the chamber gets smaller, forcing the fluid to exit through the discharge port. Vane motor provides good efficiency, but not as high as a piston motor (N.d., 2014). The service life for the vane motor is shorter compared to a piston motor. Figure 2.12 shows the example of unbalanced vane motor.

Table 2.3: Advantage and disadvantage of the unbalanced vane motor (N.d., 2015)

No	Advantage	Disadvantage
1	Develop a good vacuum	Complex housing and many parts
2	Can run dry for a short period	Not suitable for high pressure
3	Handles thin liquid at relatively high pressure	Not suitable for high viscosity
4	Can have one seal or stuffing box	

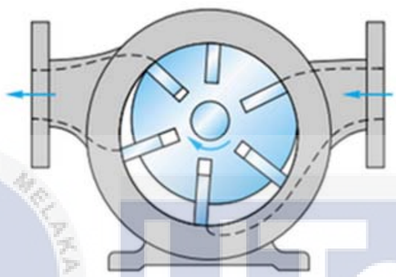


Figure 2.12: Unbalanced vane motor (N.d., 2014)

Balanced vane motor has an elliptical cam ring with two inlets and two outlet ports. The inlet and outlet ports are distributing symmetrically on the pump body. The pressure exerted by the pressurized oil create equal but opposite forces in a rotor. Zero net force on the shaft and bearing increase motor lifespan. Figure 2.13 shows an example of a balanced vane motor.

Table 2.4: Advantage and disadvantage of balanced vane motor (N.d., 2015)

No	Advantage	Disadvantage
1	It has a bigger flow	Complex housing and many parts
2	It has bigger pressure	Not suitable for high pressure
3	Its life is bigger	Not suitable for high viscosity
4	Constant volume displacement	

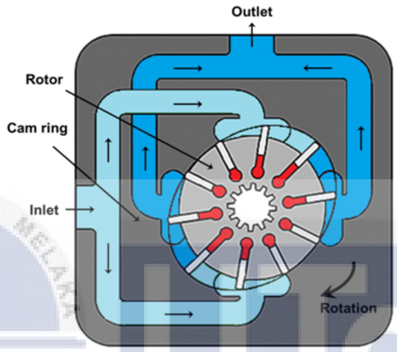


Figure 2.13: Balanced vane motor

2.7.3 Piston motor

Hydraulic piston motor can be divided into two which is the radial-piston motor and axial-piston motor. The radial-piston motor consists of the cylinder barrel that is attached to the driven shaft. The barrel contains a few pistons. The piston is arranged to surround the cylinder block with the eccentric central cam mounted on the drive shaft. As the shaft rotates, the cam moves toward the pistons forcing them down into the cylinder block and discharging the fluid. As the cam move away, spring help retracted the piston and caused the intake stroke. Check valve ensure that the fluid only enter inlet ports and only exit at the outlet ports. Radial-piston motor are very efficient and provide high torque at a low shaft speed (N.d., 2014). Furthermore, the radial-piston motor is excellent in low-speed operation with high efficiency. Figure 2.14 shows the example of the radial-piston motor.

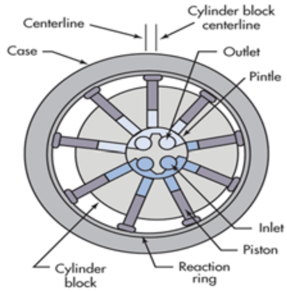


Figure 2.14: Radial-piston motor (N.d., 2014)

Axial-piston motor working principle is the same as a radial-piston motor. It uses the reciprocating piston motion principle to rotate the shaft, but the difference is, the motion in axial. It consists of the swashplate that the function to translate the motion of the rotate shaft into the reciprocating motion of the pistons. Swashplate piston motor has a rotating shaft that is connected to a cylinder block containing pistons. The pistons will be press against the stationary swashplate that sits at the angle to the cylinder block. As the shaft rotates, the piston moves against the swash plate, causing them to reciprocate within the piston block. The piston creates a vacuum that forces fluid in during half revolution and discharges it during at the other half of its revolution. At the intake stroke, the spring ensures the piston pulls back and maintain contact with the swash plate, causing the fluid to fill the empty cavities. On the discharge stroke, the angle of the swash plate forces the pistons back inside the piston block and discharge the fluid. The axial-piston motor has the same efficiency characteristic as a radial-piston motor. Axial-piston motor is good in high-speed capabilities and has a long operating life. Figure 2.15 shows the type of the axial-piston motor.

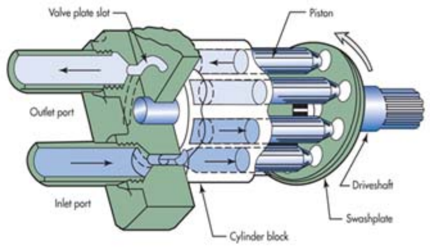


Figure 2.15: Axial-piston motor

2.8 Hydraulic control system

Hydraulic system controls the transmitting energy. This system consists of several important components being used. Each of the components has its roles and effect on the hydraulic system. As shown in Figure 2.16 below, is an example of the basic hydraulic system. It consists of several components such as pressure gauge, directional control valve, pressure relief valve, and others.

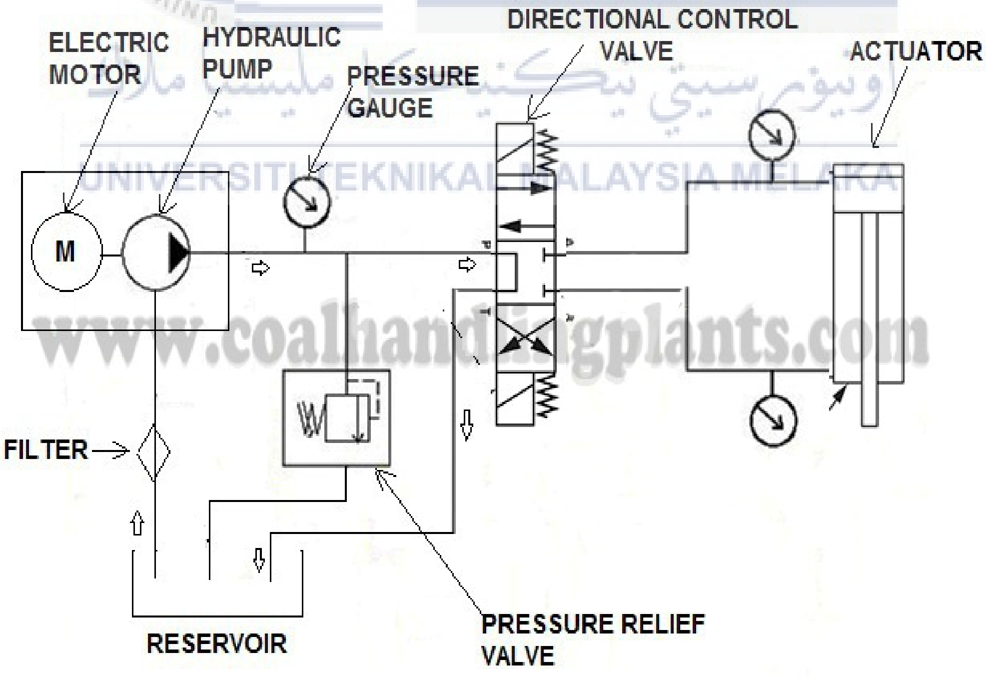


Figure 2.16: Basic hydraulic system (Mahato, 2018)

The basic component and its function that is basically involved in a hydraulic system are (Mahato, 2018):

- Reservoir / Tank

  In the hydraulic system reservoir or tank are used to hold the hydraulic oil or fluid.

- Hydraulic pump

  The purpose of the hydraulic pump is to pressurize the fluid and force the fluid through the system. There are three types of hydraulic pump, as shown in Table 7 below.

Table 2.5: Types of hydraulic pump

Type of pump	Characteristic	Example
Fixed Displacement pump	• Has set flow rates, which every stroke of the motor moves the same amount of fluid. • Perfect for single jobs that to be repeated indefinitely over a long period.	Gear pump, Gerotor pump, Screw pump
Variable Displacement pump	• Flow rate and outlet pressure can be changed as the operates. • More expense and need more attention.	Bent axis pump, Axial piston pump, Rotary Vane pump, Radial piston pump
Hand/ Manual Hydraulic pump	• Operated by hand and foot.	Lightweight Hydraulic Hand pump, Steel

		hydraulic hand pump

Figure 2.17 below shows the symbol of pump that is commonly used in the hydraulic system circuit diagram.

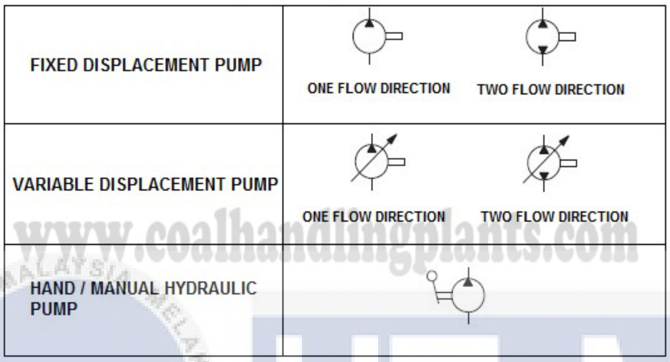


Figure 2.17: Symbol of the pump (Mahato, 2018)

- Hydraulic motor

The hydraulic motor is a mechanical, hydraulic actuator that converts the hydraulic energy into torque and angular displacement. Figure 2.18 below shows the type and symbols of the hydraulic motor that is used in hydraulic system circuit.

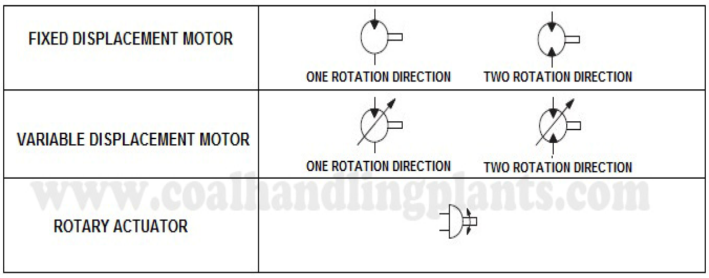


Figure 2.18: Types and symbols of hydraulic motor

- Hydraulic cylinder

The hydraulic cylinder is another type of mechanical, hydraulic actuator that is used to convert hydraulic energy into linear displacement. The hydraulic cylinder consists of a cylindrical barrel, a piston rod, and piston. There is two types of hydraulic cylinder, which is a single-acting cylinder and double-acting cylinder. Figure 2.19 shows the symbols for the hydraulic cylinder in the hydraulic system.

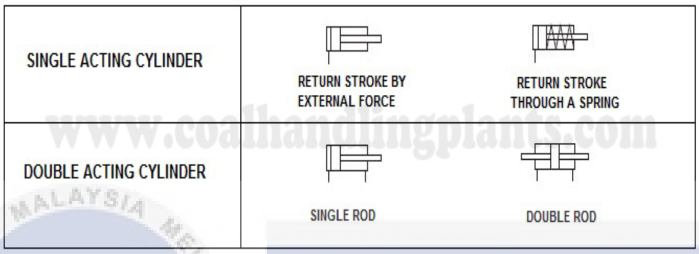
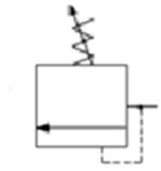
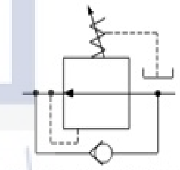
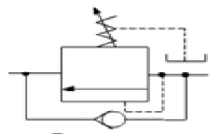
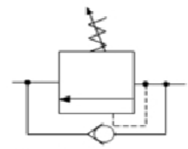


Figure 2.19: Symbols for the hydraulic cylinder

- Pressure control valve

The pressure control valve is the hydraulic component that it purposes to limit the system pressure in order to protect the system component. There are four types of pressure control valve, as shown in the table below

Table 2.6: Types of hydraulic pump

Type of pressure control valve	Characteristic	Symbol in the hydraulic circuit
Pressure Relief Valve	• Protect hydraulic system when the pressure in system increase beyond the specified design pressure. • Normally it closed and open once the pressure exceeds the limit and send the hydraulic fluid back to the tank. • Normally placed near the hydraulic pump.	
Pressure reducing valve	• Design to limit and maintain the output pressure. • Normally its open and closed when the pressure at the outlet are exceed the design limit. • Located near the hydraulic actuator.	
Sequence valve	• Used to make sure that a certain pressure level is achieved in one branch before the activated second branch.	
Counterbalance valve	• It is designed in order to create backpressure at the return line of the actuator to prevent losing control over the load.	

- Flow control valve

  The flow control valve is used to adjusting or control the flow rate of the fluid in the pipeline. The valve contains a port whose area can be varied. There are two types of flow control valve that is a variable throttling valve and a compensated flow regulator valve. Figure 2.20 below shows the symbol for the flow control valve.

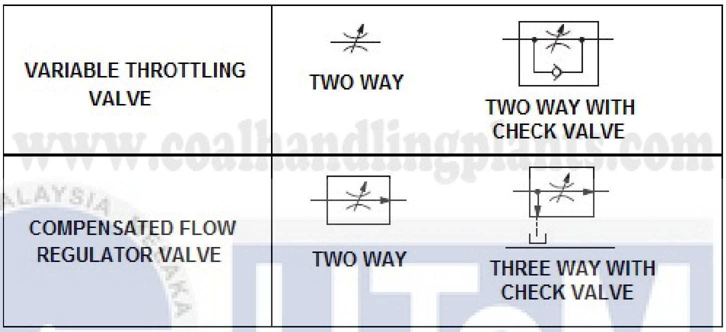


Figure 2.20: Symbol for flow control valve

- Directional control valve

  The directional control valve can be divided into two, which is a check valve and spool type directional control valve. Check valve are used to allow free flow in only one direction. The spool-type directional control valve is used to control the direction of the fluid flow. Figure 2.21 shows the type and symbol of the directional control valve.

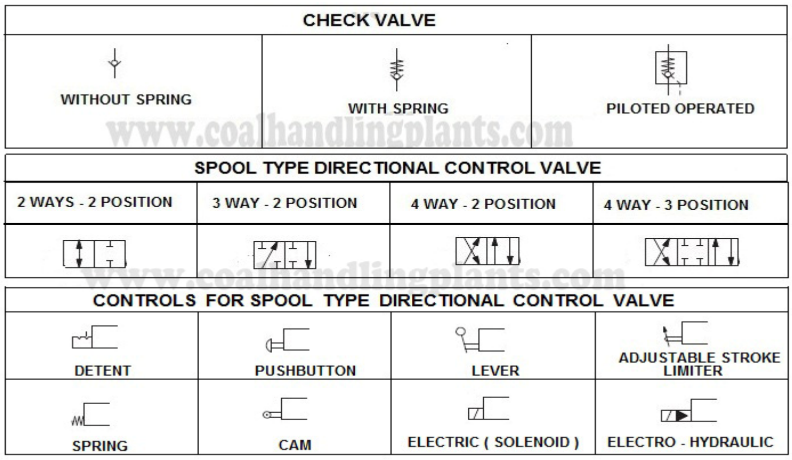


Figure 2.21: Type and symbol of the directional control valve

2.9 Hydraulic motor for dual function

In a hydraulic hybrid system, hydraulic motor and hydraulic pump are the main devices. Both of this device have their own function and characteristic. The hydraulic motor is used in order to convert fluid energy into mechanical energy, whereas the hydraulic pump is used to deliver the hydraulic fluid to the hydraulic motor. Sometimes, the hydraulic motor can act as a hydraulic pump. In the application of any machinery that needs continuous power, a hydraulic gear motor is more suitable than the pump (lee, 2017). This application mostly for a simple mechanism. Continuous power can also be created by a series hydraulic pump, but it can cause mechanical failure due to the made up of the component. The hydraulic motor is more suitable for any application for long distance.

CHAPTER 3

METHODOLOGY

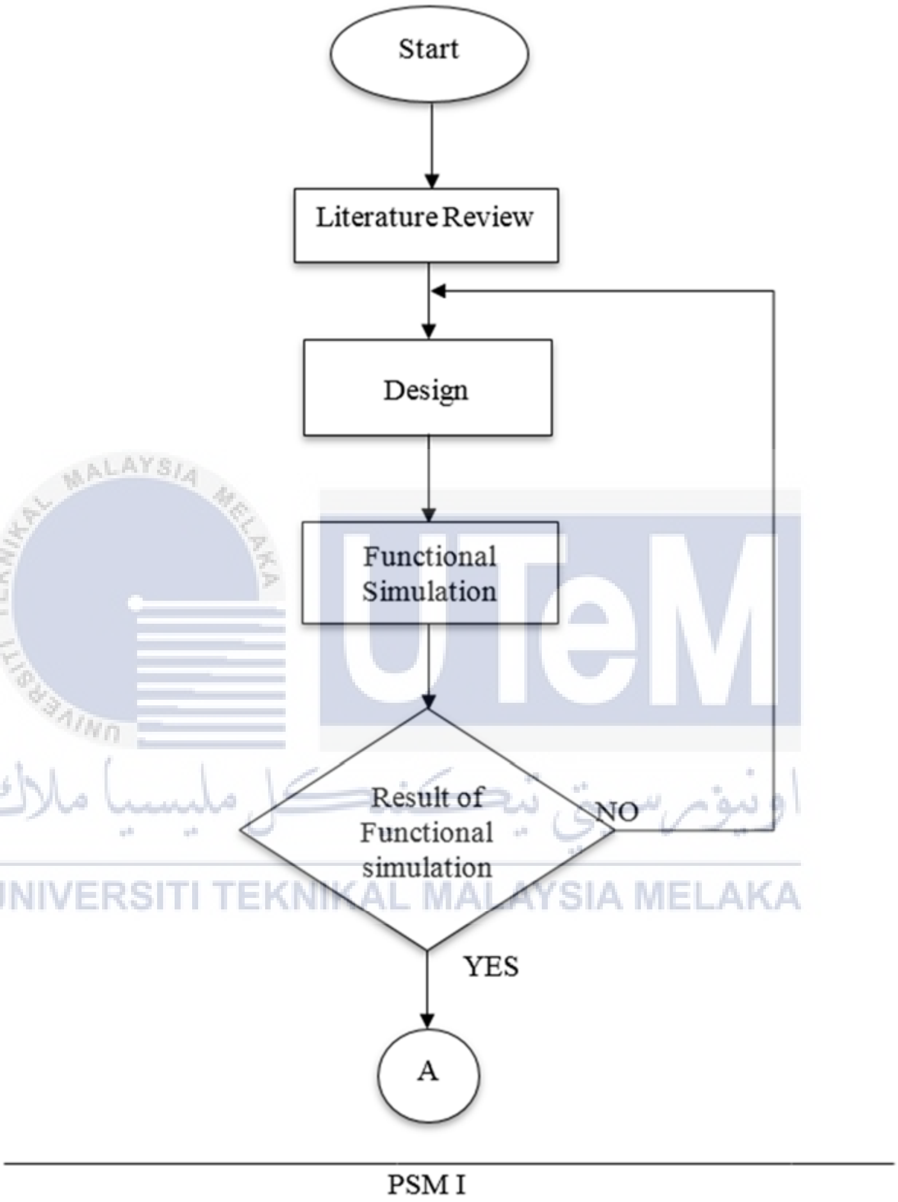
3.1 Introduction

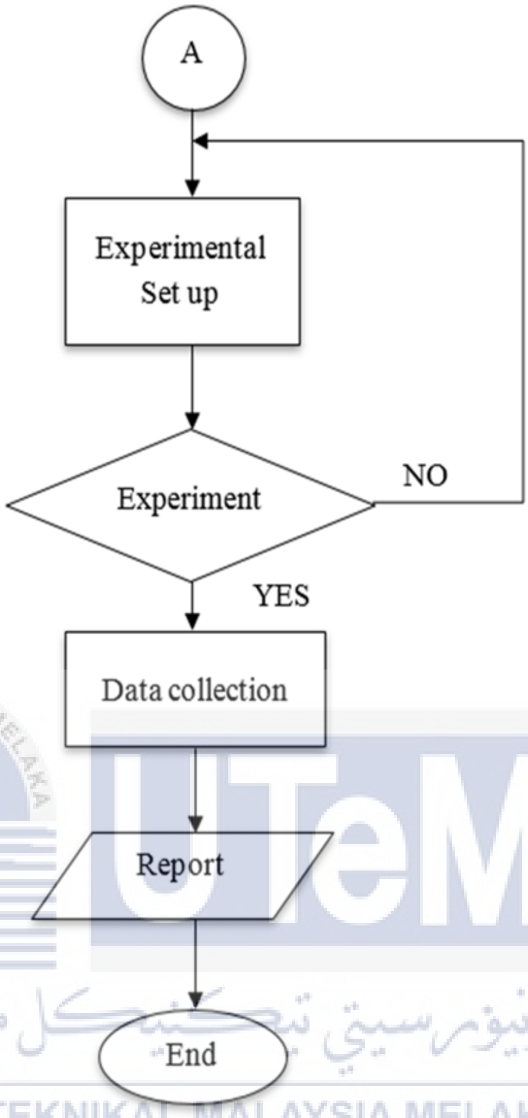
Methodology is defined as the specific procedure in order to obtain information and knowledge. This chapter will be covered all the process that will be involve in this project.

The flow of the project on how the project will be carried out start with section 3.2 that is a flow chart. Section 3.3 discussed literature review. A literature review is to gain information and knowledge that are related to this project. This is to ensure that the project is runs successfully. Next, section 3.4 discuss the design of the hydraulic system. Then, section 3.5 discusses a simulation that been carried out by using Automation Studio. In section 3.6, the experimental set-up will be discussed. In this section, the final design and component that are involved will be selected and discussed. Experiment procedure and all the equation that are involved will be discussed in section 3.7. Section 3.8 and 3.9 are briefly explained about the data collection and final report. Lastly, in section 3.10 are Gantt chart for the whole process for PSM 1 and PSM 2.

3.2 Flow chart

The flow chart below shows the overall process that is involved in this project.





II

PSM

Figure 3.1: Flow chart

3.3 Literature review

A literature review is important in order to gather some knowledge and information about the overview of the hybrid system, hydro-pneumatic system, and type of motor that is used in the hydraulic system. Therefore, when doing the simulation, the information that has gained from the literature review will make the project run smoothly and lead to obtain the expected result. The method of doing a literature review is by finding the journal and article from the internet. The best result can be obtained if all the information and knowledge about the system to be developed are well study and understand.

3.4 Design

3.4.1 Introduction

Design is a process of plan and drawing that are used to show an idea and a picture of the system or product. Design is important because, in this phase, the idea of the system will be described in the form of a picture and an explanation of the system. In this section, the design of the system is introduced by the pictorial diagram. Next, the schematic diagram will show the system that is designed by using Automation Studio. At the end of the section, the system is designed by using Solid Work software.

3.4.2 Pictorial diagram

The pictorial diagram is the simplest diagram that shows a picture or sketch of the component of the system. This type of diagram shows various component without considering their physical position. It is generally to shows the sequence in which that component is being connected.

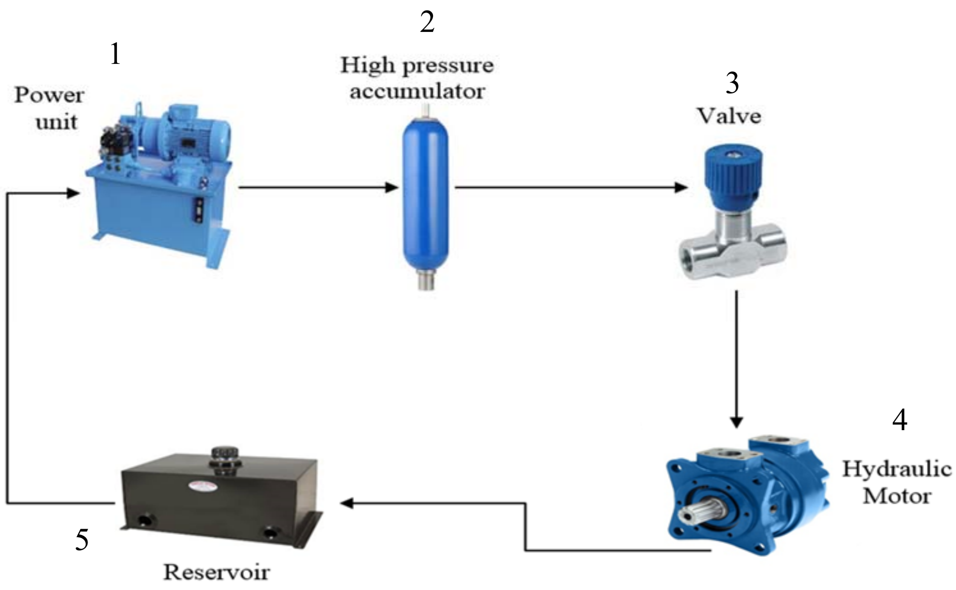


Figure 3.2: Pictorial Diagram

The power unit (1) will drive the hydraulic fluid into the high-pressure accumulator (2). From the accumulator, the hydraulic fluid will flow to the hydraulic motor (4) through the valve (3) and change from hydraulic energy to mechanical energy, which will rotate the shaft. The valve (3) is used to control the speed of the hydraulic motor. The hydraulic fluid that enters the motor will then exit to the reservoir/ low pressure accumulator (5). The flow of the system is shown above in Figure 3.2.

3.4.3 Schematic diagram

A schematic diagram is a diagram that shows all the component, part or the element of a system whether by using abstract, graphic symbols rather than a realistic picture. The schematic diagram for the hydro-pneumatic propulsion system shows and explain the flow of the system and how the system will be operated. The design of the schematic diagram by using Automation studio software.

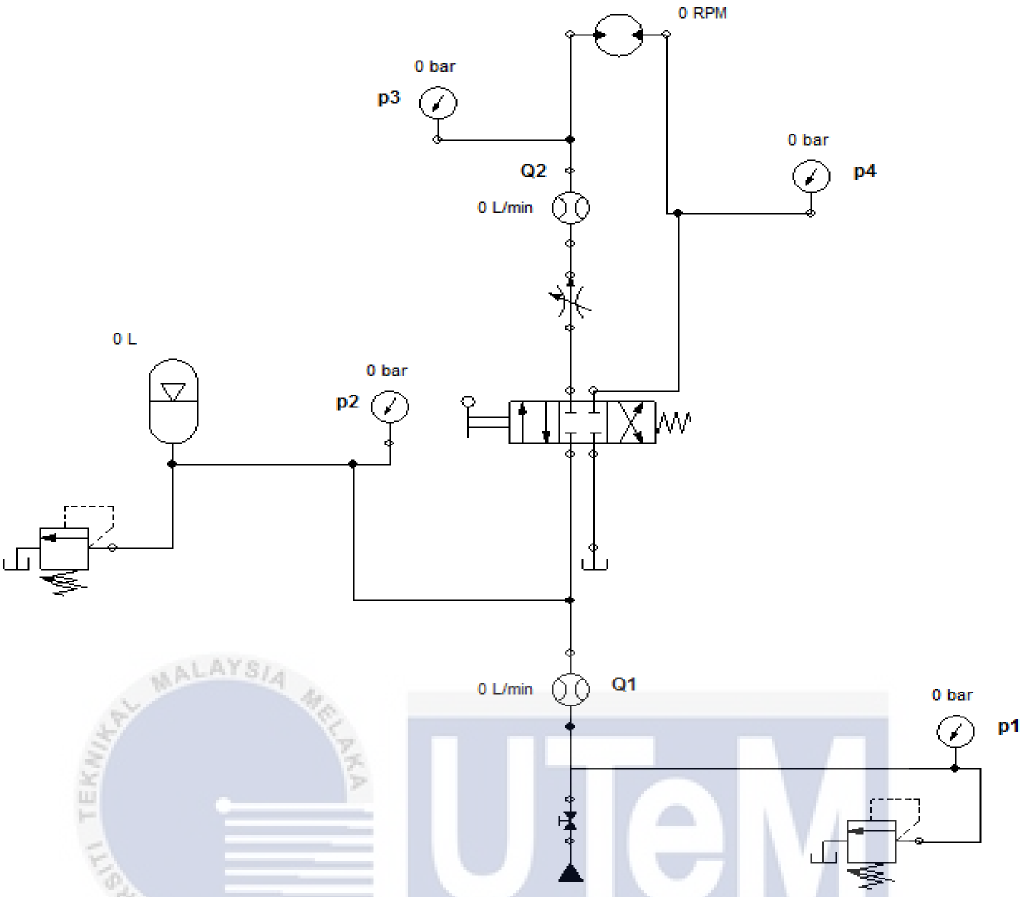


Figure 3.3: Hydraulic system schematic diagram

As shown in Figure 3.3 above is the hydraulic propulsion system by Automation studio software. The system consists of a bi-directional hydraulic motor, high-pressure accumulator, 4/3 ways directional control valve, pressure relief valve, pressure gauge, flow meter, and flow control valve.

3.4.4 Test Rig

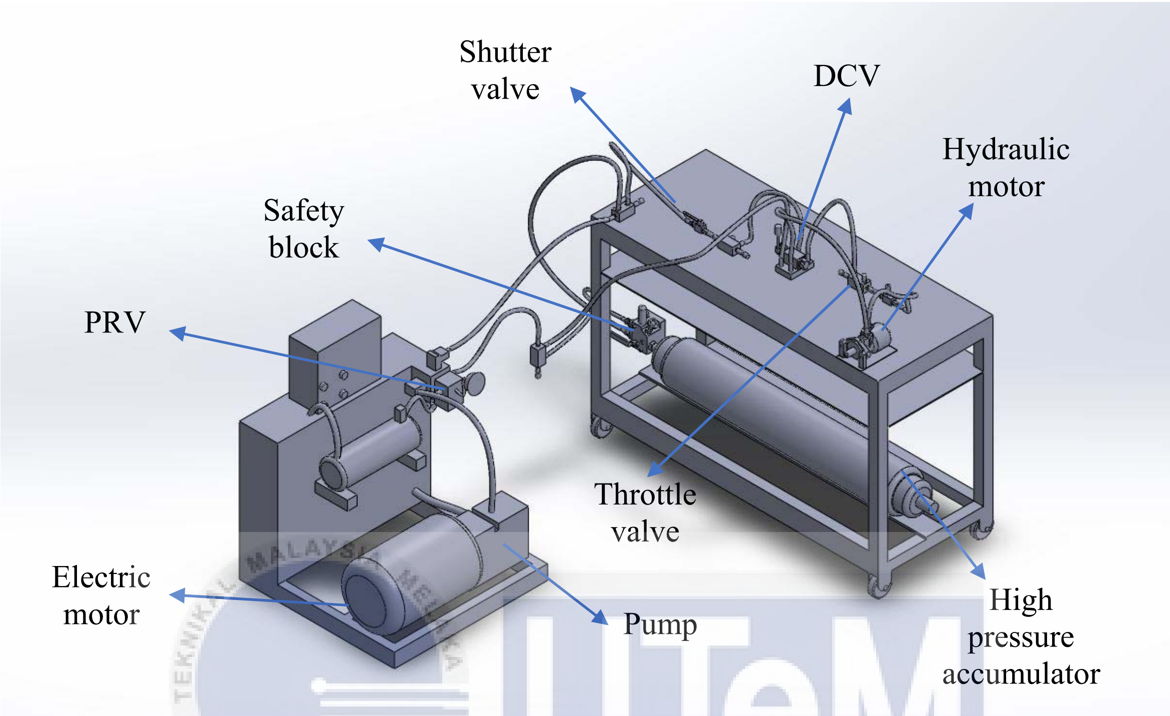


Figure 3.4: Isometric view

Figure 3.4 shows the isometric view of the system design. The test rig consists of two parts, which are the power unit and an experimental part. On the power unit side, it consists of a motor, pump, shutter valve, and pressure relief valve (PRV). While in the experimental part, it consists of the high-pressure accumulator, safety block, throttle valve, hydraulic motor, and directional control valve (DCV).

3.5 Simulation

The simulation of the system is done by using Automation Studio software. Automation Studio is a software that is being used for design, documentation, simulations, and others. This software includes pneumatic, hydraulic, and electrical operative devices.

3.5.1 Schematic diagram

In the first condition, the shutter valve is turn on and the 4/3 ways directional control valve set to be at the neutral position. At this position, the fluid will only flow to the accumulator. The initial pre-charge for the high-pressure accumulator is set at 80bar. When the 30litres accumulator is fully filled, the shutter valve will be closed, and the directional control valve will shift to one side. At this position, the fluid will flow upstream and passes the flow control valve and rotate the hydraulic motor. The reading of pressure and flow rate are determined at a certain point as shown in Figure 3.5 below.

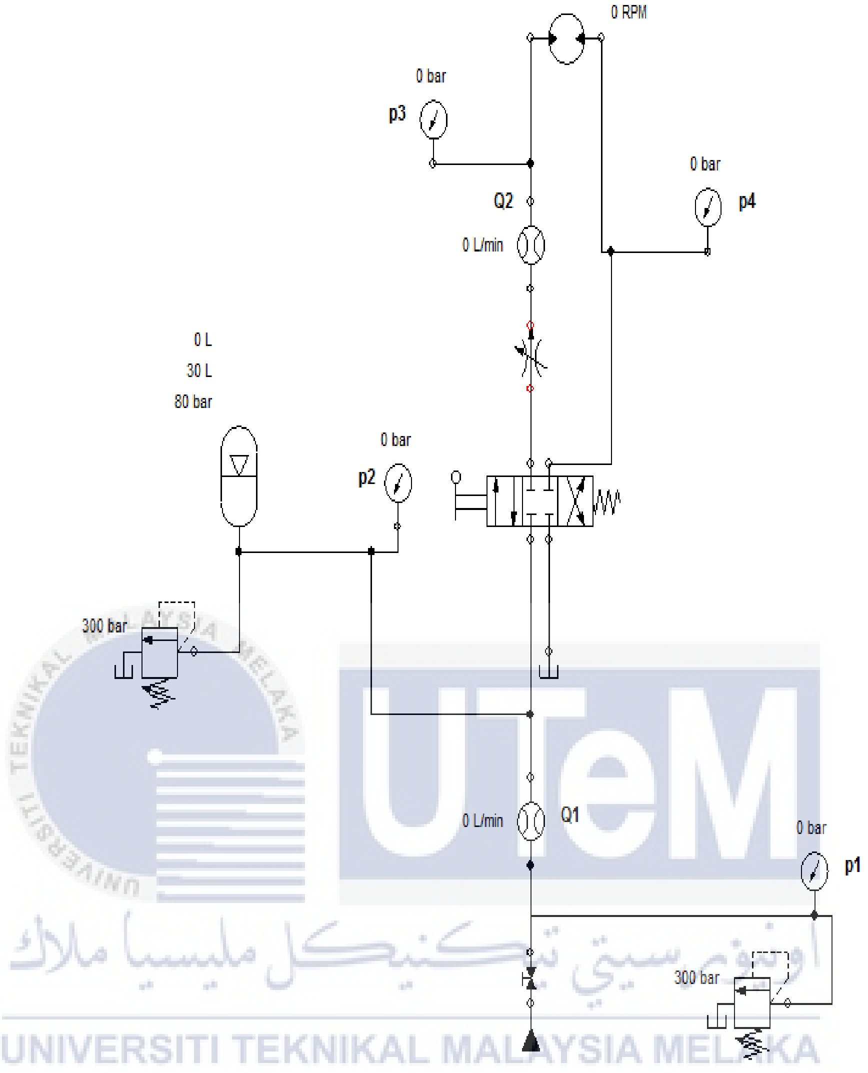


Figure 3.5: Hydraulic circuit configuration

3.5.2 Functional simulation

As shown in Figure 3.6 below, at the initial condition, the fluid will only flow up to a high-pressure accumulator. This process is to fill the high-pressure accumulator. The shutter valve will be open, and the directional control valve is set at the neutral position.

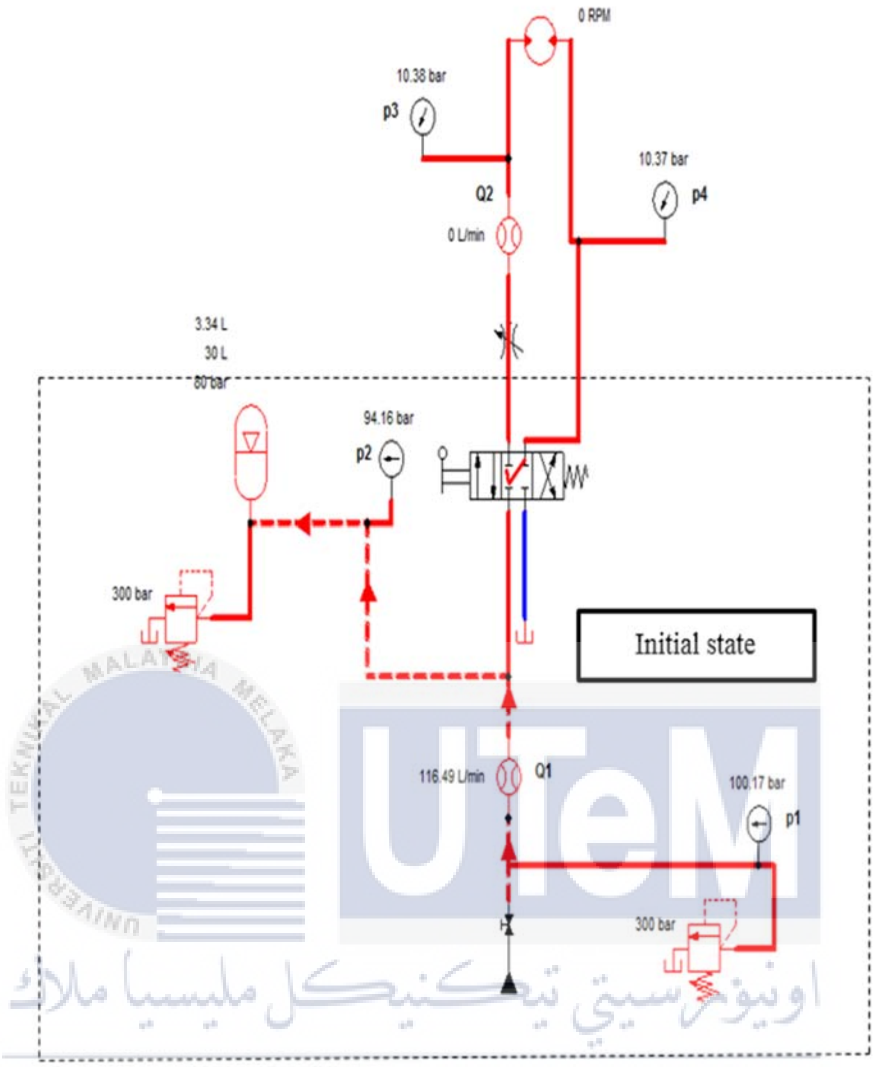


Figure 3.6: Initial state of the system

When the accumulator is filled, as shown in Figure 3.7 below, the shutter valve will be close, and the directional control valve will be shifted to one side. The fluid will flow up to the hydraulic motor and change to mechanical energy.

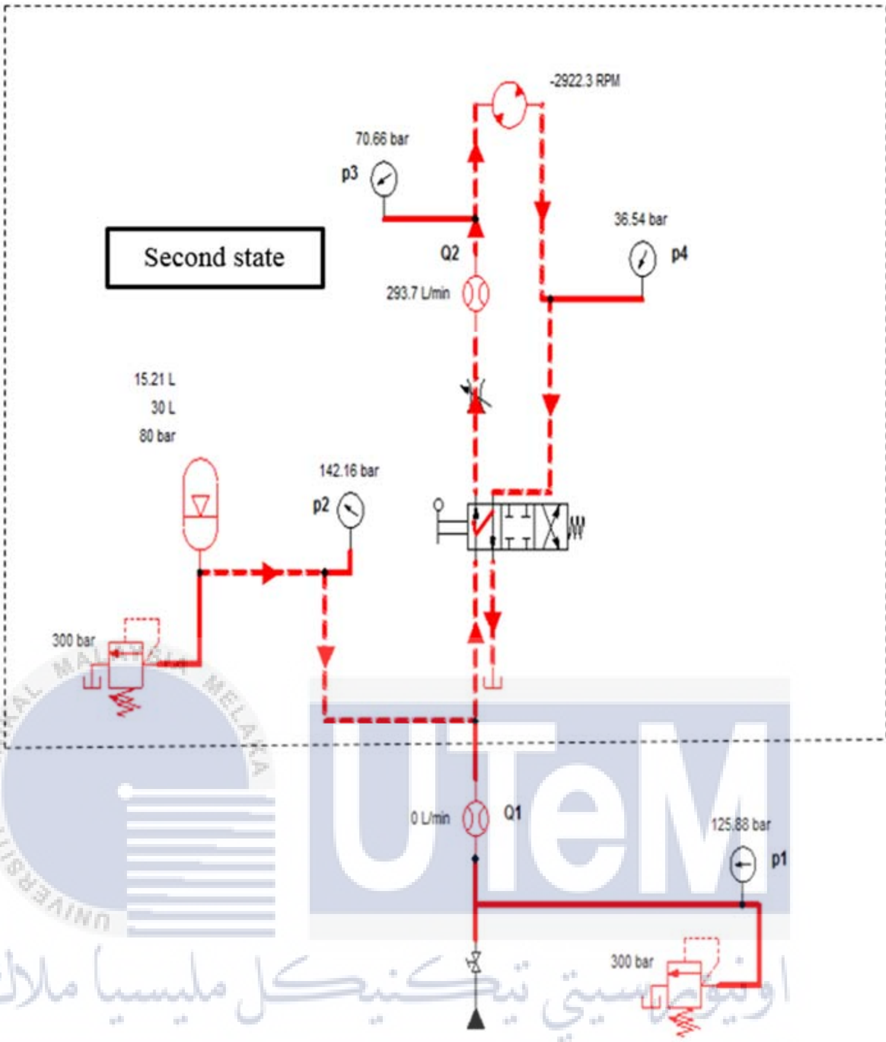


Figure 3.7: Second state of the system

3.6 Experimental set-up

3.6.1 Introduction

The experimental setup is the preliminary phase before experimenting. In this section, all the component, instrument, and apparatus that will be used during the experiment will be determined. The final design will also be selected, and all the component and instrument specification will be identified. The experimental setup is important to ensure that the experiment will run smoothly.

3.6.2 Component and instrumentation

The component and instrument specification that is used in this system is stated in the table below:

Table 3.1: Component and Instrument specification

No.	Equipment	Specification	
1	Pressure relief valve	Size	Port PT: 3/4”
		Pressure	70-250 kg/cm^2
		Maximum flow	180 l/min
2	Flow control valve	Operating Pressure	345 bars
		Temperature range	-15°C - 80°C
		Flow rate	364 l/min
3	Hose	Nominal size	5/16”, 8mm
		Temperature range	-40°C - 100°C
		Operating pressure	215 bars
4	Directional control valve 4/3 ways	Maximum flow	60 l/min
		Temperature range	-30°C - 80°C
		Operating pressure	Port A, B, P: 315 bars Port T: 160 bars
		Viscosity range	2.8 – 500 mm^2/s
5	Accumulator	Operating pressure	330 bars
		Maximum flow	900 l/min
		Temperature range	-15°C - 80°C
		Charging gas	Nitrogen gas
		Size	35 liters

3.7 Experiment

3.7.1 Introduction

The experiment is a method of research for testing a different hypothesis. During the experiment, the independent variable that been decided can be changed, and the effect of the changes will be examined and analyzed. In this section, the procedure of the experiment and the equation are discussed.

3.7.2 Procedure of experiment

In this experiment, the accumulator pressure will first start at the 100 bar. The pressure control valve (PCV) will also set to 100bar. The pressure as the independent variable will be change to 120, 140, 160, 180, and 200 bar. At first condition, the flow control valve (FCV) that located at the hydraulic motor will be open half. When the system operates, the shutter valve will be open to letting the hydraulic fluid to fill the high-pressure accumulator. At this condition, by using 4/3 ways directional control valve (DCV), the hydraulic fluid will not travel up to the hydraulic motor due to DCV at the neutral position. When the accumulator is filled, the shutter valve will be closed, and the directional control valve will be shifted to another side to let the fluid enter the hydraulic motor. The reading of flow rate, torque, and rpm will be taken at the output shaft of the motor. The graph of torque, flow rate, power, pressure losses, system efficiency and motor efficiency against pressure will be plotted and analyzed.

3.7.3 Measuring instrument

The main instrument that is involved in the experiment is a pressure gauge, pressure sensor, dynamometer, flow meter, and data logger. The pressure sensor will be installed at the hydraulic motor, while pressure gauge will be installed at the accumulator. Figure 3.8 below shows the pressure gauge that will be used. The data logger that is used in this experiment is Hydrotechnik MultiSystem 5060 Plus, as shown in Figure 3.9 below. This instrument is used to measure some data, such as pressure and temperature. Next, the flow meter will be placed at the power unit, and before entering the hydraulic motor. Lastly, the dynamometer is used to measure some variable such as torque and power delivered by a hydraulic motor.

Figure 3.8: Pressure gauge

Figure 3.9: Data logger

3.7.4 Model/ Equation

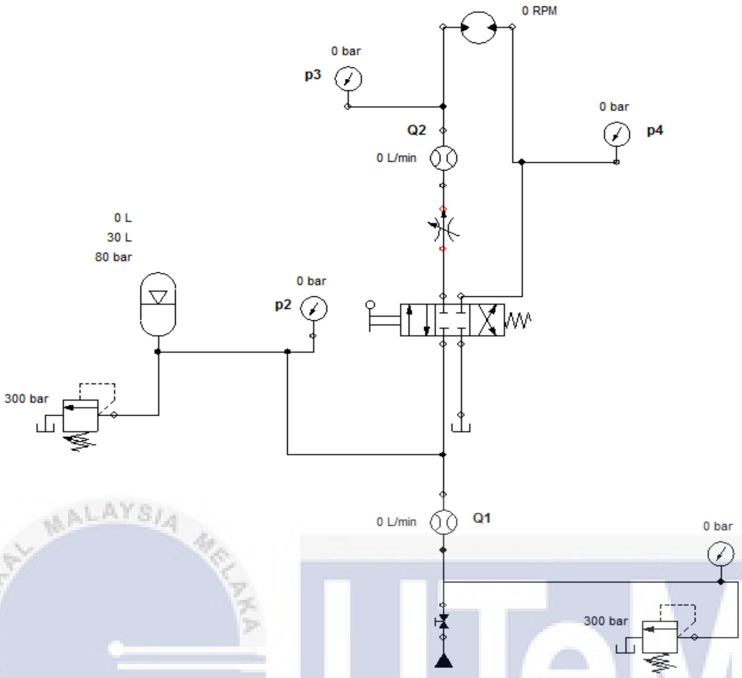


Figure 3.10: Hydraulic system model

Figure 3.10 above shows the schematic diagram that used to simulate the propulsion of the system. The power output by motor and torque can be calculated by using equation 3.1 and 3.4.

The power output by the hydraulic motor can be express as equation (3.1),

$$P_M = \Delta pQ \tag{3.1}$$

Where P_M is power output by hydraulic motor, Δp is the pressure difference at the inlet and outlet of hydraulic motor and Q is the flowrate.

The power of high-pressure accumulator can be express as equation (3.2),

$$P_{HP} = pQ \tag{3.2}$$

Where P_HP is power delivered by high-pressure accumulator, p is the pressure at the outlet accumulator, and Q is the flow rate.

For this experiment, it is to be assumed that there are no losses for delivery from the high-pressure accumulator to the hydraulic motor. The equation can be express as equation (3.3).

$$P_{HP} = P_M \tag{3.3}$$

Where P_{HP} is power by high pressure accumulator are same as power by hydraulic motor, P_M.

Torque, T at the hydraulic motor shaft can be determined by expand the equation (3.3). The equation can express as equation (3.4).

$$\mathrm{Q} \times \mathrm{P} = \frac{2\pi NT}{60}$$

$$\Delta p\mathrm{Q} = \frac{2\pi NT}{60}$$

$$\mathrm{T} = \frac{60\Delta pQ}{2\pi N} \tag{3.4}$$

3.8 Data collection

At the end of the experiment, the data that are obtained will be studied and analyze the effect of the pressure on the system and the hydraulic motor power. Next, the losses in the system will also be analyzed. The graph of power, torque, rpm, and efficiency will be plotted and analyzed.

3.9 Report

Lastly, report writing is the last phase of this project. This report will cover everything from the beginning until the end of the experiment. In this report will include the method of designing the system and the final design of the system. Lastly, in chapter 6 will be discussed about the result that is obtained from the experiment.

3.10 Gantt chart

Gantt chart is one of the popular ways that is used to planning and show the activities. On the left side of the table, it contains the activities that are going to do, and along the top of the table is the time taken to complete the activities. Gantt chart is important because based on this Gantt chart, it is like a timetable which will manage all the activities. Due to that, all work or task can be completed within the prescribed time. **APPENDIX A** shows the Gantt chart for PSM 1 and PSM 2, respectively.

CHAPTER 4

FABRICATION

4.1 Test Rig

The test rig is designed using solid work software. As shown in Figure 4.1 and Figure 4.2 below, the orthographic and isometric view of the complete test rig. It can be divided into two sections, which a first section is a power unit where it consists of the electrical motor, pump, reservoir, and pressure relief valve. The other section is the rig where all the component that is involved in this experiment will be placed. All the orientation and type of component has been decided through simulation.

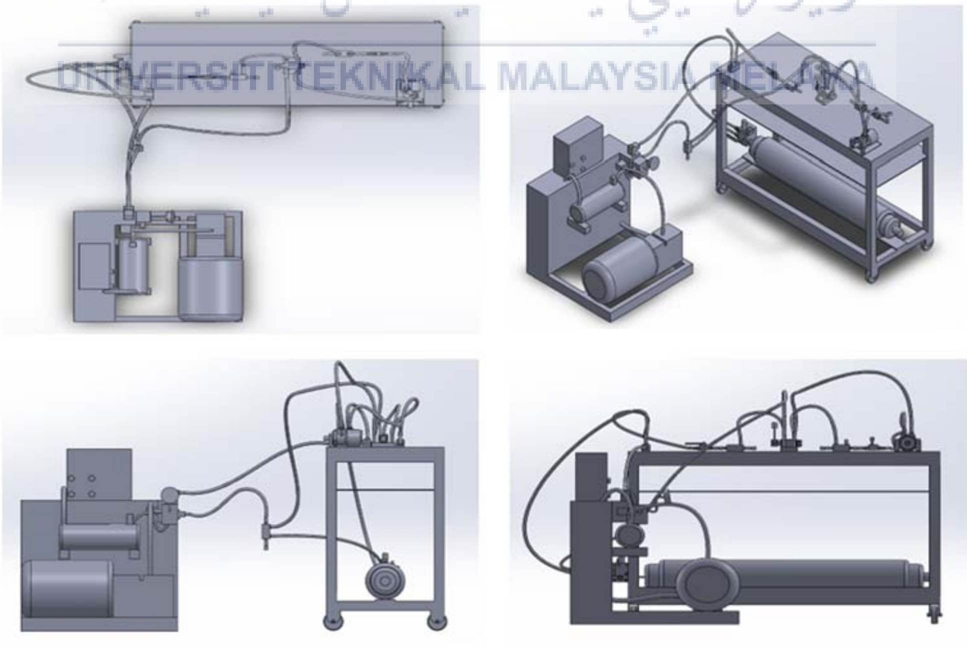


Figure 4.1: Orthographic view

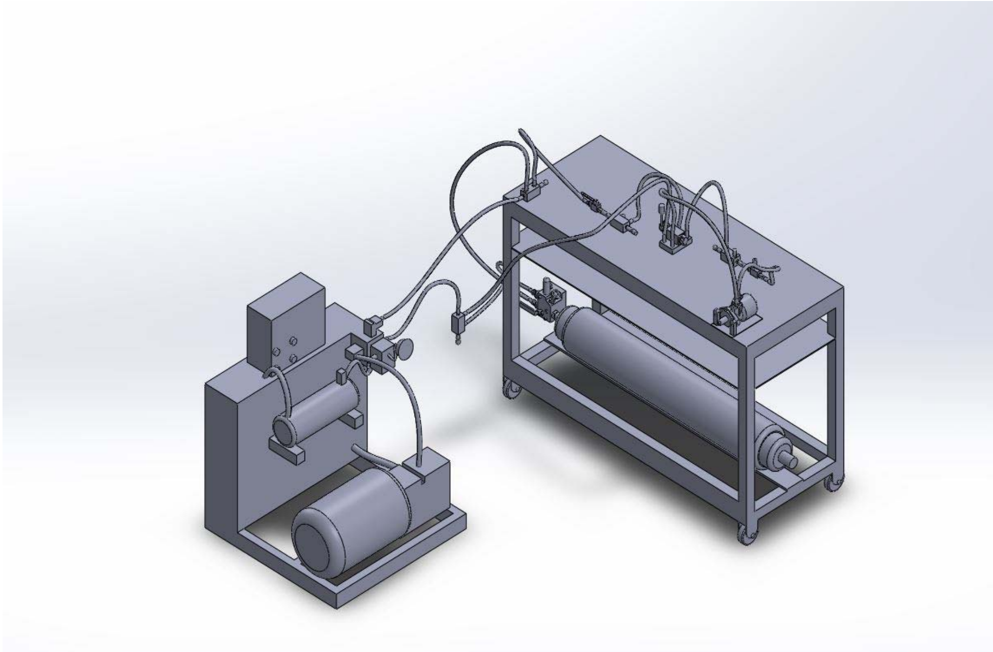
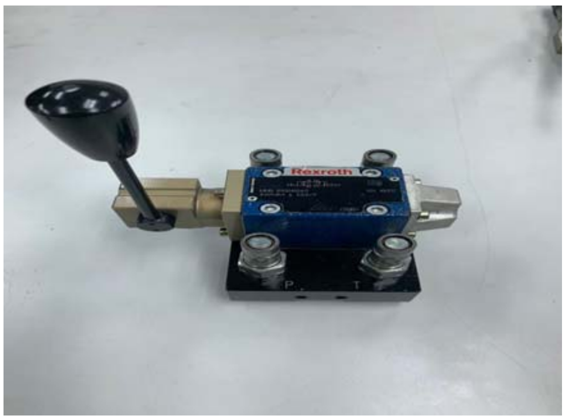


Figure 4.2: Isometric view

4.2 Component

The table below shows all the component and its function that are involved in this experiment.

Table 4.1: Name and function of the component involved

No	Name and function	Component
1	Directional control valve (DCV) 4/3 ways directional control valve • Stop or block fluid flow • Allow fluid flow • Change the direction of fluid flow	

2	Pressure relief valve (PRV) • Used in a hydraulic system to limit the system pressure to a specific set level. • The once set level reached, PRV will respond and feeds the excess flow back to the reservoir.	
3	Shutter Valve • Use to allow or block the flow in the system.	
4	Throttle valve • To control the speed of the hydraulic motor	
5	Connector • Use to connect to component and hose. • Act as a branch.	

4.3 Fabrication Process

The fabrication process that involves in this project such as welding, cutting, and assembling. The main rig for this project has been fabricating but the finishing process and minor touch-up are still not complete. The finishing process involves grinding, polishin, and finally coating. The purpose of the grinding process is to remove the excessive metal at the cutting area. Next, the polishing process is to remove the rust on the surface of the metal. The last step of the finishing process is by coating, as shown in Figure 4.3 below. This process is done in order to avoid the metal from rust and make the rig looks cleaner and safer to use. The minor touch up for the rig also has completely done, for example, adjust the rig tire by welding and others. Figure 4.4 below shows the complete test rig.

Figure 4.3: Coating process

Figure 4.4: Final product

4.4 Product Assembly

The figure below shows the complete test rig that has been assembling with its power unit and all component that is involved in this experiment. All the component has been arranged according to the design that has been made as shown in Figure 4.5 below. The arrangement of the component is also quite important in order to prevent the pipe from straining and to minimize the usage of the connector. This is because the connector can cause losses to the system. Figure 4.6 below shows the complete assembly of the test rig and the power unit.

Figure 4.5: Orientation of the component

Figure 4.6: Full assembly

CHAPTER 5

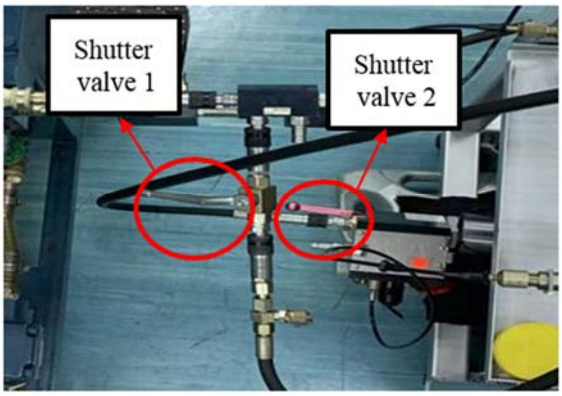
TESTING

5.1 Standard Operating Procedure

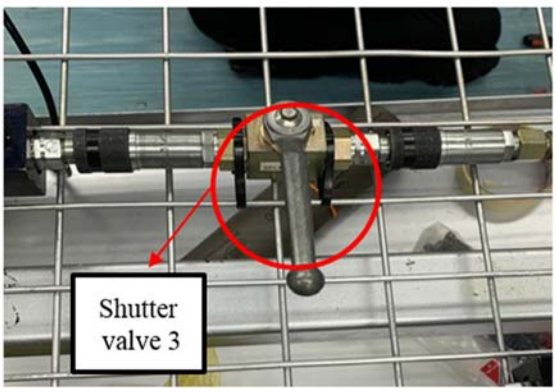
Standard operating procedure (SOP) is a set of step-by-step instructions that been written to help carry out complex routine operations. SOP aims to achieve efficiency and uniformity of performance. Furthermore, SOP is also important in order to prevent process error and act as a control or countermeasure for identified risk that can create a defect.

In this experiment, it consists of six steps in order to get the result. All the step that involved in this experiment are as shown below:

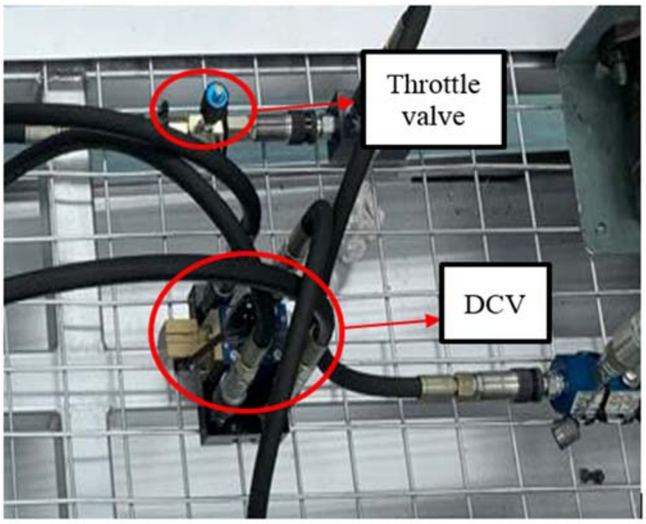
1) Before starting the experiment, make sure the shutter valve 1,2 and 3 are in the closed position, as shown in Figure 5.1(a) and 5.1(b) below. The position of the directional control valve (DCV) must be at the right room and ensure that the throttle valve is fully open, as shown in Figure 5.1(c).



(a)



(b)



(c)

Figure 5.1: (a) Shutter valve 1 and Shutter valve 2. (b) Shutter valve 3. (c) Throttle valve and DCV

2) With all the shutter valve in the closed position, start up the power unit and set the pressure by referring to the pressure gauge at the power unit as shown in Figure 2 below.

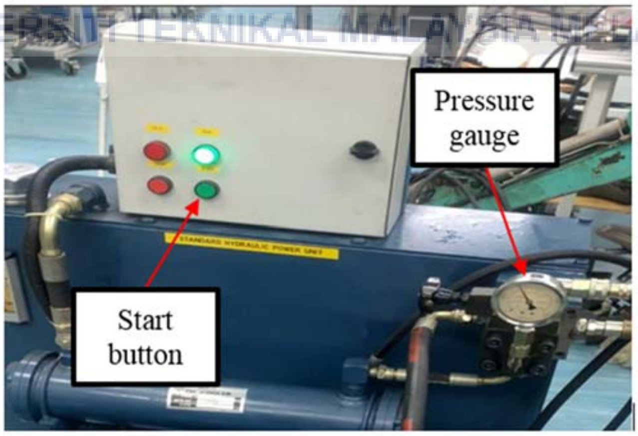


Figure 5.2: Start button and pressure gauge

3) Open the shutter valve 1 and shutter valve 2, as shown in Figure 5.3(a) and 5.3(b) below. The shutter valve 3 remains in the closed position. Refer to the pressure

gauge at the accumulator to monitor the pressure in the accumulator, as shown in Figure 5.3(c) below. The pressure in the accumulator will keep increase until it is equal to system pressure that have been set earlier.

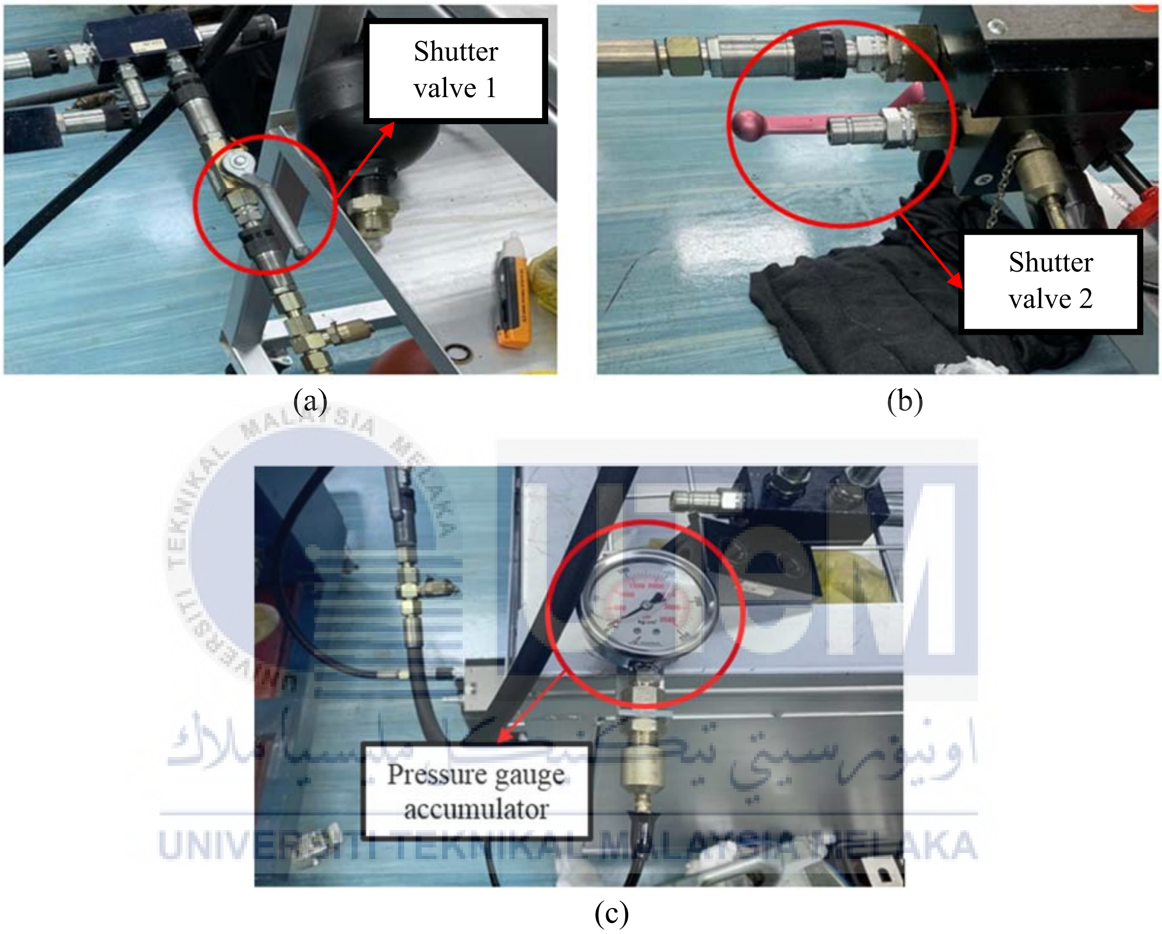


Figure 5.3: (a) Shutter valve 1 at open position. (b) Shutter valve 2 at open position. (c) Pressure gauge for accumulator

4) When the accumulator is fully filled, close the shutter valve 2 and shutter valve 1. Then turn off the power unit.
5) Open shutter valve 3 first, when it is ready to take the reading, open shutter valve 2 as shown in Figure 5.4 below. Before open shutter valve, press start button on the data logger to record the data.

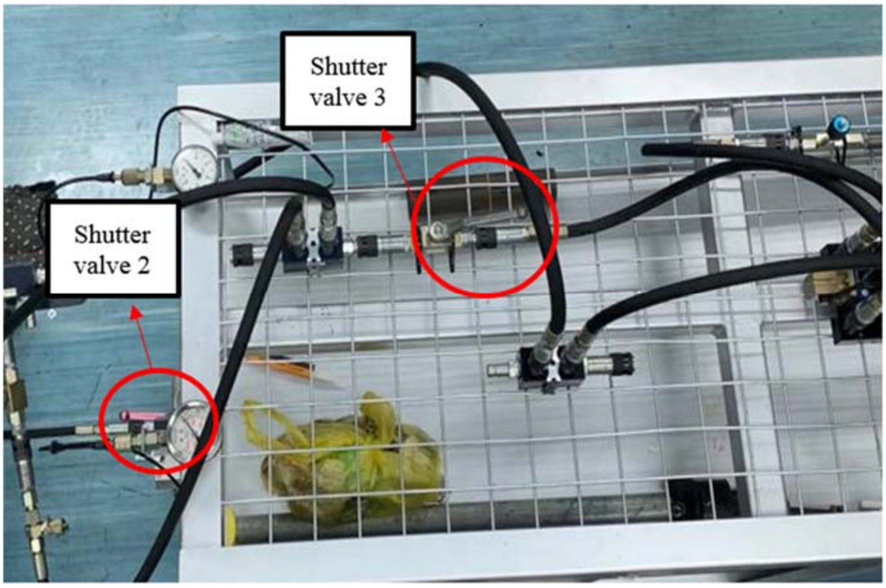


Figure 5.4: Shutter valve 2 and shutter valve 3 in open position

6) Step 1 to 5 is then repeated for the next pressure 120, 140, 160, 180 and 200 bar.

CHAPTER 6

RESULT AND ANALYSIS

6.1 Introduction

During this research, experiment has been conducted to observe and study the effect of the pressure on the flow rate, pressure difference, power, torque, system efficiency, and motor efficiency. The value of the flow rate and pressure difference is obtained directly from the experiment. The value of power, torque, system efficiency, and motor efficiency are manually calculated. The data that obtain from the experiment is selected and calculated. The average value is then taken for the analysis.

6.2 Power, torque and efficiency calculation

6.2.1 Power Calculation

The value of power output at the hydraulic motor is calculated by using equation (6.1) below:

$$Pout = \Delta p \times Q_{avg} \tag{6.1}$$

Where:

Δp: The difference pressure in and pressure out at hydraulic motor (Pa)

Q_{avg}: Average Flowrate (m3/s)

6.2.2 Torque Calculation

Since the value of Power output has been determined, the value of torque can be determined by rearranging the equation (6.2) yielded equation (6.3) as below:

$$Pout = \frac{2\pi NT}{60} \tag{6.2}$$

$$T = \frac{60\ Pout}{2\pi N} \tag{6.3}$$

Where:

$Pout$: Power output at the hydraulic motor (Watt)

N : Revolution per minute (RPM)

6.2.3 System Efficiency Calculation

Since the Power output at the hydraulic motor has determined by using equation (6.1). Hence, to determine the efficiency of the system, the power input must be determined first. The equation to find power input are as equation (6.4) below:

$$Pin, sys = p_{sys} \times Q_{avg} \tag{6.4}$$

Where:

p_{sys}: System pressure (Pa)

Q_{avg} : Average flowrate (m^3/s)

The efficiency of the system can be obtained by using equation (6.5) below:

$$\eta_{sys} = \frac{Pout}{Pin, sys} \times 100\% \tag{6.5}$$

6.2.4 Motor efficiency calculation

As the power output has been determining earlier by using equation (6.1). The motor efficiency can be calculated by obtained the value of power at the hydraulic motor first. The equation of determining power in at hydraulic motor is as shown below in equation (6.6)

$$Pin = p_{in} \times Q_{avg} \tag{6.6}$$

Where:

p_{in} : Pressure in at the hydraulic motor (Pa)

Q_{avg} : Average Flowrate (m^3/s)

The efficiency of the motor is then calculated by using equation (6.7) below:

$$\eta_{motor} = \frac{Pout}{Pin} \times 100\% \tag{6.7}$$

6.3 Flow rate versus pressure system

Figure 6.1 below shows the effect of flow rate on the system pressure. Based on the profile that obtained, the flow rate is linearly proportional to the system pressure. The maximum flow rate is obtained at maximum setting pressure 20000 kPa (200 bar) which is 0.00024 m3/s. The minimum flow rate is 0.00018 m3/s which is at the set pressure of 12000 kPa (120 bar) and 14000 kPa (140 bar). As the system pressure is increasing, the value of flow rate increasing as well. The profile drops between the pressure of 10000 kPa (100 bar) and 12000 kPa (120 bar) are not significant. This is due to the real-time pulse. The profile of the graph is then back to increase as the pressure are increased. The relationship between flow rate and pressure can be illustrated by the equation y = 1E-05x + 0.0002.

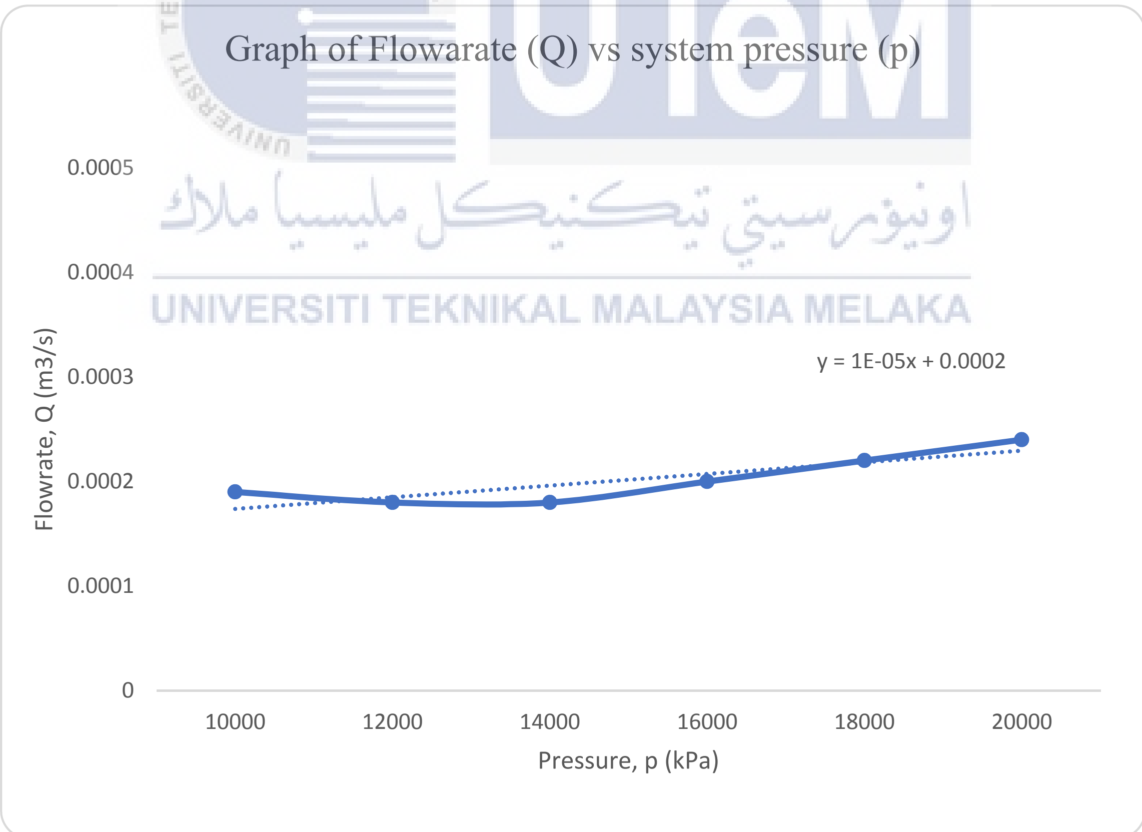


Figure 6.1: Graph of Flowrate vs system pressure

6.4 Pressure Difference versus pressure system

Figure 6.2 below shows the effect of the system pressure to the Δp. Based on the graph above, Δp is linearly proportional to the system pressure. The maximum value of Δp is 1372.78 kPa, which is at maximum system pressure 20000 kPa. At the minimum setting pressure 10000 kPa, the Δp is 817.32 kPa and indicates as the minimum Δp. The value of Δp is affecting the power output that produces by hydraulic motor. As the value of Δp is increasing, the power that produces by the motor will also increase. This is because high losses (pin – pout) in hydraulic motor means that more energy has been converted to work resulted in high-power. The relationship between pressure difference and pressure can be illustrated by the equation y = 112.73x + 742.62.

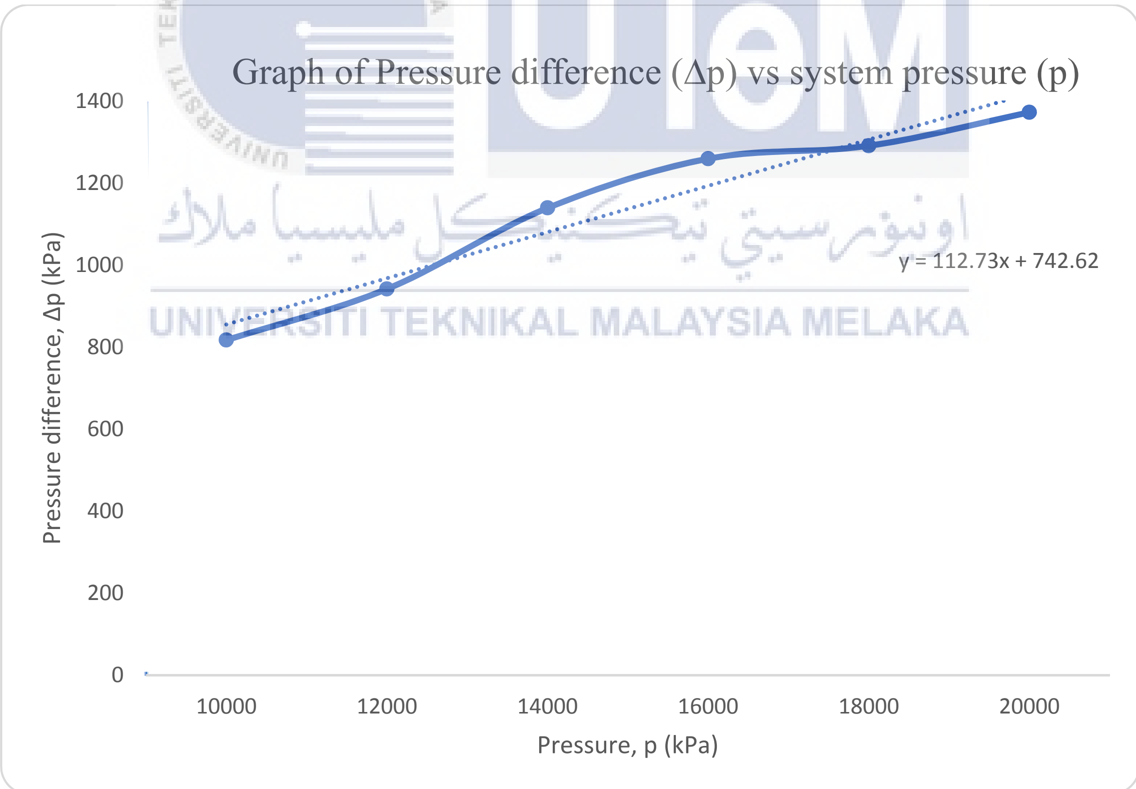


Figure 6.2:Graph of Pressure difference vs system pressure

6.5 Power Analysis

Figure 6.3 below shows the effect of system pressure to the power output at the hydraulic motor. Based on the profile that obtained, the power generated by the hydraulic motor is linearly proportional to the system pressure. As the pressure is increasing, the power also will increase. The highest power generated is 325.65 Watt, which is at 20000 kPa (200 bar) while the lowest power generated is at 10000 kPa (100 bar) which is 159.05 Watt. Based on the graph that is obtain, as the higher pressure that store in the accumulator will produce more power. It is believed that, if the higher pressure is given, the graph profile will keep increasing. The relationship between power and pressure can be illustrated by the equation $y = 34.994x + 111.84$.

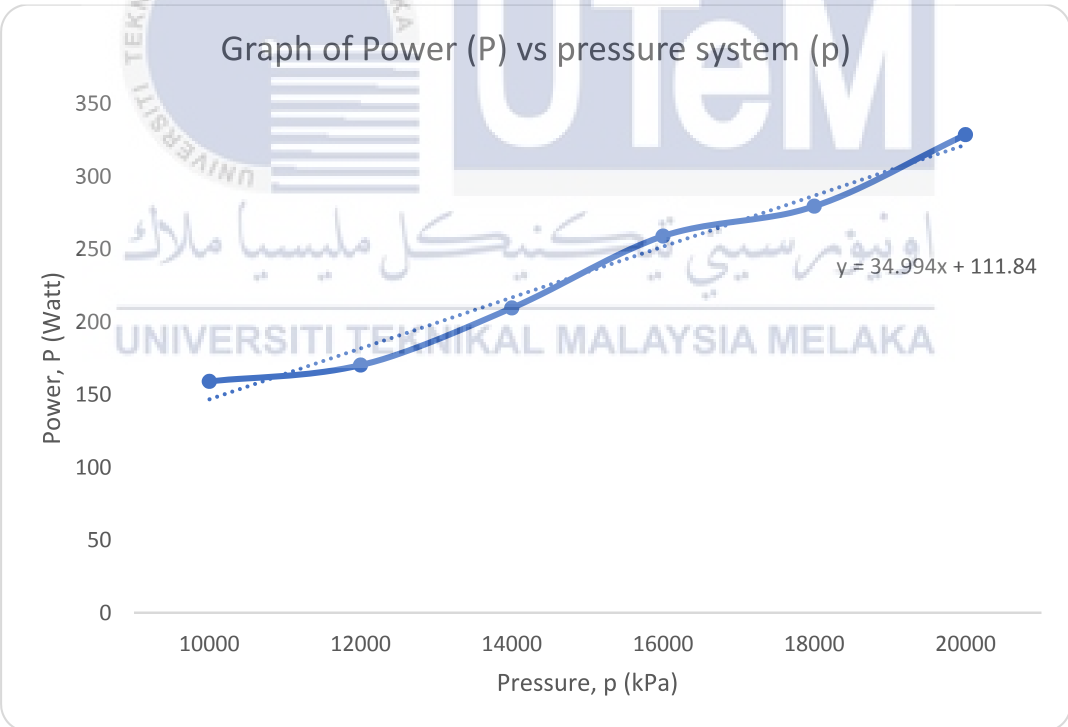


Figure 6.3 Graph of Power vs system pressure

6.6 Torque versus pressure system

The effect of torque to the system pressure as shown in Figure 6.4 below. Based on the result that obtained, it is clearly showed that the torque is linearly proportional to the system pressure. The maximum value of torque is achieved at the pressure 200 bar which is 13.2503 Nm, while for the minimum value of torque is 10.6685 Nm which is at pressure 100 bar. Based on the profile, the torque value at the pressure of 120 bar higher compared to torque at pressure 140 bar. This has caused the profile of the graph to drop at the pressure of 120 bar to 140 bar. This drop is not significant because the drop is too small. This is because of real-time pulse. Where at the certain time, the value of pressure is fluctuated and affecting the value of torque. The value of torque is calculated based on selected point and the average torque value will be analyse. In the selected point, there are certain point where the torque value is higher than it should be. Due to that, it has contributed to the higher average torque value. The relationship between torque and pressure can be illustrated by the equation y = 0.5233x + 9.8505.

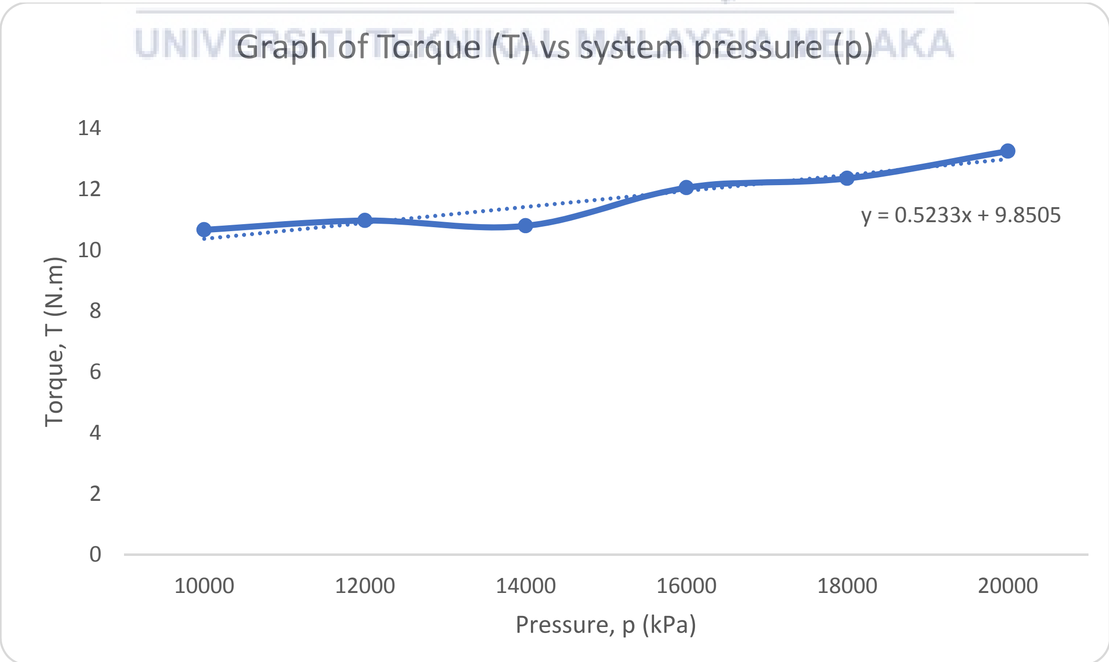


Figure 6.4:Graph of torque vs system pressure

6.7 System Efficiency

Figure 6.5 below shows the effect of system pressure to the system efficiency. The maximum efficiency is 8.37% which is obtained at the pressure of 10000 kPa (100 bar), while at the maximum setting pressure 20000 kPa (200 bar), the efficiency is 6.84% and act as the lowest value of the system efficiency. Based on the profile obtained in Figure 6.5 above, as the system pressure increase, the system efficiency will decrease. This is due to the high-pressure losses at the hose and the hose connector. The diameter of the hose used in this experiment was too small. As the hose diameter is too small, it will increase the speed of the fluid. Based on Bernoulli's Principle, as the speed of the fluid is increased, it will decrease the pressure of the fluid (Stryker, 1997). This is one of the reasons that cause pressure losses. While running the experiment at the pressure of 100 bar and 120 bar, there are no leaking occurs at the hose connector because it still can withstand the given pressure, but the pressure losses due to hose diameter already occur. When the pressure of the system is increased, it is observed that there are a leaking occurs at the hose connector. Due to that situation, when at the high pressure, there are two losses occur, which is losses due to the hose diameter and hose connector.

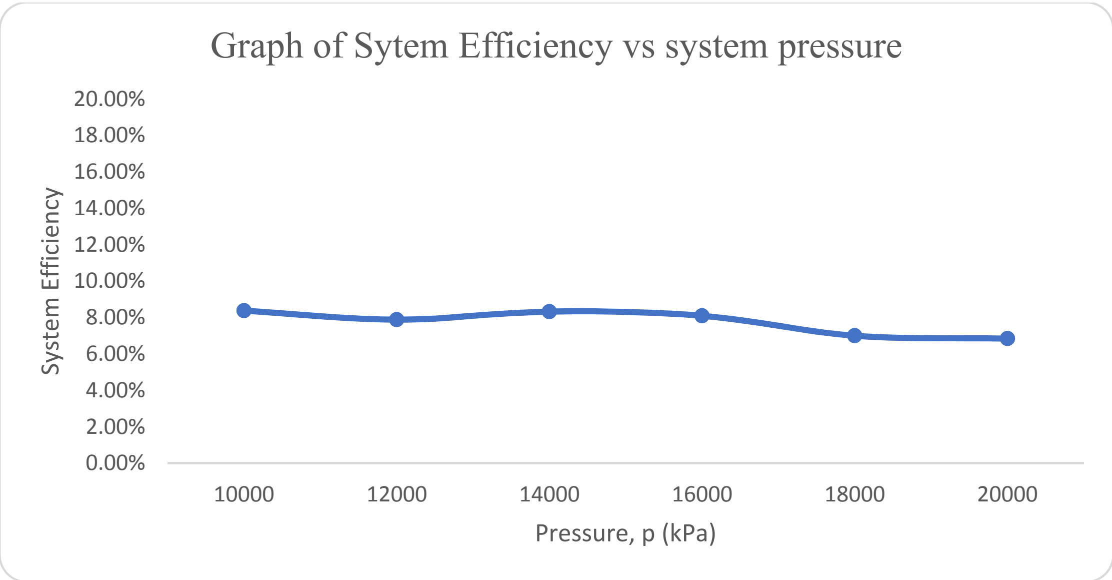


Figure 6.5:Graph of System efficiency vs system pressure

6.8 Motor efficiency

Figure 6.6 below shows the effect of system pressure tomotor efficiency. The highest efficiency that achieved in this experiment is 50.56%, which is at 12000 kPa (120) bar, whereas the lowest efficiency is 45.18% at pressure 20000 kPa (200 bar). The optimum performance of the hydraulic motor can be achieved at the pressure setting of 12000 kPa (120 bar). Based on the profile of the graph above, it shows that the profile is decreased as increasing the pressure. As shown in Figure 6.3 above for Power versus system pressure, the highest power is achieved at the pressure of 20000 kPa (200 bar). It can conclude that, as the power output increases it will decrease the efficiency of the motor. For all, the range of the motor efficiency is between 45% to 51%. This is because, at the hydraulic motor, there are a leaking occur at the connector and contribute to lower efficiency. Furthermore, another factor that contributes to lower efficiency is about the lifetime of the hydraulic motor.

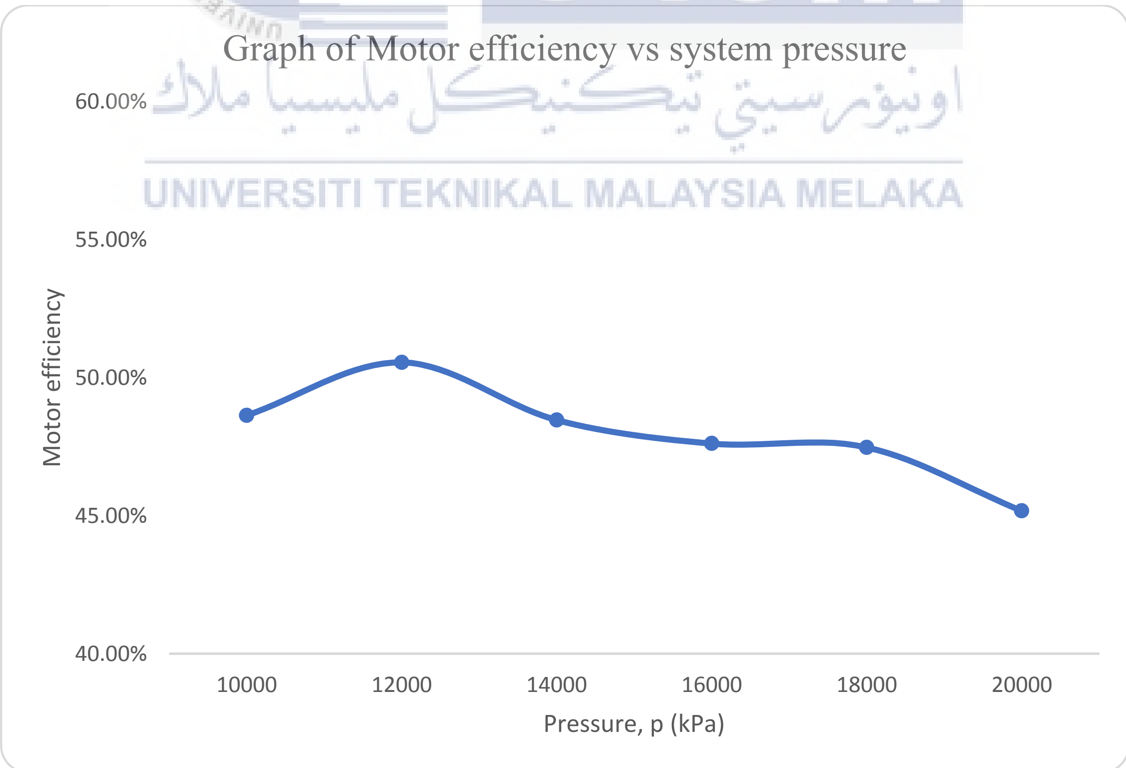


Figure 6.6: Graph of Motor efficiency vs system pressure

CONCLUSION AND RECOMMENDATION

Conclusion

In this chapter, it is briefly discussed about the conclusion and objective achievement. Furthermore, the recommendations on how to improve the performance of the system will also discuss.

Objective 1: *To find free load RPM, flow rate, pressure and pressure losses.*

In this research, the experiment has been done. Based on the experiment that been carried out, the maximum free load RPM and maximum flow rate have been identified. The maximum average RPM and flow rate that obtained is 236.477 and 0.00021 m3/s respectively. Both maximum values are obtained at the maximum set pressure which is 200 bar. So, it is show that, as the higher pressure is supply to the system, the higher the value of the RPM and flowrate. The pressure losses in this system are high. Based on the study and observation that been made, the high losses in the system is due to the hose. This is because, the size of the hose is too small and not suitable for high-pressure usage. Furthermore, the type of hose connector also one of the reasons that contribute to high-pressure losses in the system. This is because the type of the connector at the hose cannot withstand with pressure more than 140 bar. It will start to leak and cause the losses.

Objective 2: *To calculate the free load efficiency of the system.*

Once the power output at the hydraulic motor and the power input at the system has been determined, the system efficiency can be calculated. The efficiency of the system, as shown in Figure 6.5 above, is decreasing as the pressure is increased. This is due to the losses facing the system. As the pressure is increased, the losses of pressure at the hose connector also increase, resulting in high-pressure losses and affecting the system efficiency.

As the analysis that can be made from the result, the value of flow rate, power, pressure losses, and torque is linearly proportional to the system pressure. There is a correlation between pressure losses at the hydraulic motor, power output, and torque. As the pressure losses are increased, the power and torque also will be increased. For the efficiency of the hydraulic motor, as by increasing the power, the efficiency will drop.

Recommendation

There are a few suggestions that can be done to improv e the result of this case study on the hydro-pneumatic propulsion system. Some recommendation is stated below that can improve this study in the future.

The major problem that needs to be fixed first is about hose and its connector. After being study and observed, it is believed that the size of the hose diameter is too small for this system. As have been discussed in Chapter 6 for Figure 6.5 as a speed of the fluid increase, the pressure of the fluid will be decreased. In order to eliminate this scenario from repeating, it is recommended that to use a bigger diameter of the hose. Next, the type of hose connector that uses also need to change. This is because the connector cannot withstand high pressure, and due to that, it will start to leak, resulting in pressure losses.

Next, in the future, it is suggested to conduct the simulation. The design circuit in the simulation must follow all the component specification that is used in the experiment. So, the data that are obtained from the experiment can be compared. By doing this, it will be a better way to prove the data that are obtained. Furthermore, by doing simulation, it will be much easier to validate or determine whether the component that is used is suitable or not.

Finally, is by increasing the system pressure. This is to achieve high performance of the system. As the power, torque, flow rate and RPM linearly proportional to the system pressure, so that, the higher performance could be achieved. However, as to increase the system pressure, this may involve high cost. This is because, mostly all the component and equipment using for previous research, just can be reached until 250 maximum bar pressure. As to increase the system pressure, all the equipment and component must be change to the higher one.

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APPENDICES

APPENDIX A: Gantt chart

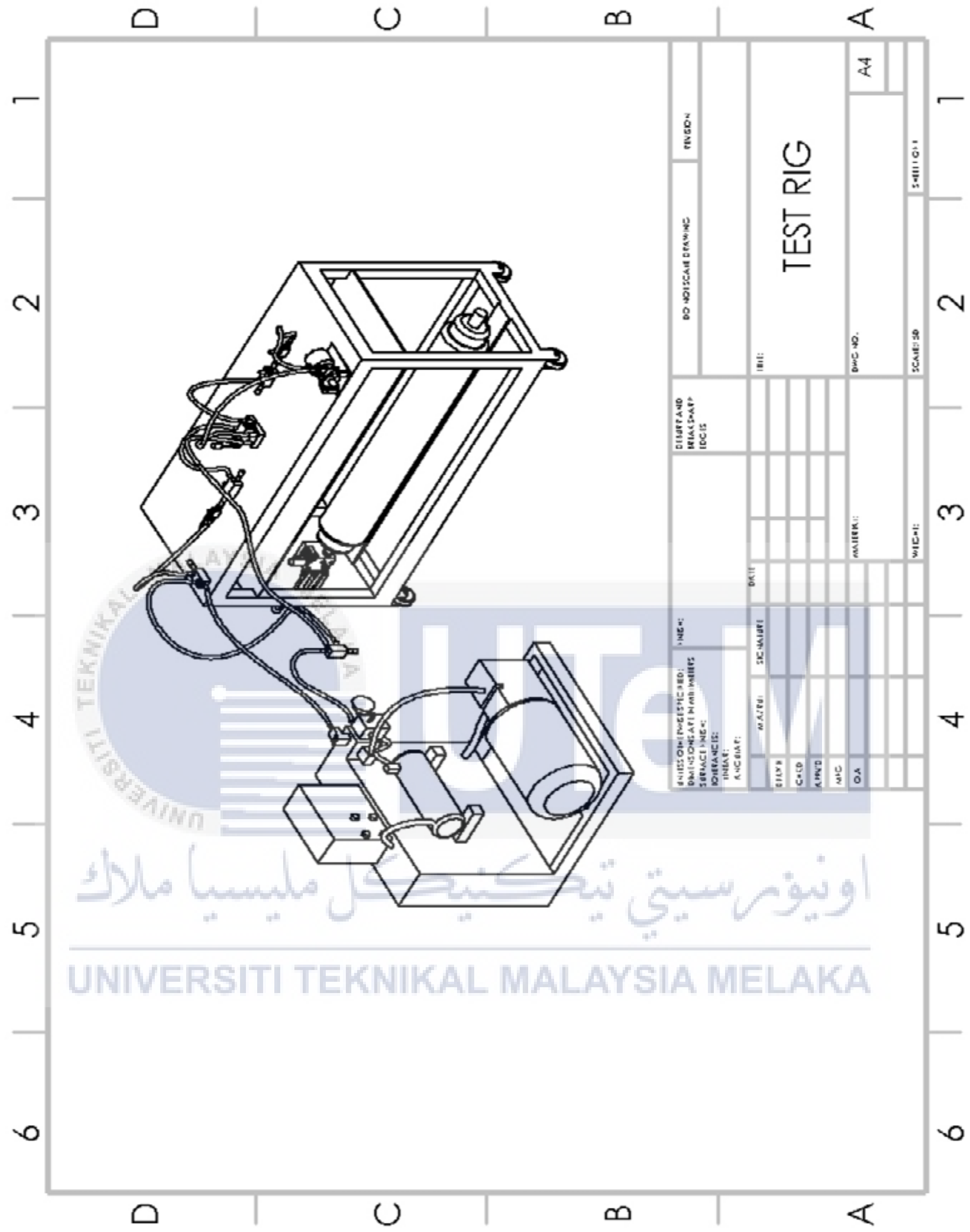
Gantt Chart for PSM 1

No	Activities	Week											
		3	4	5	6	7	8	9	10	11	12	13	14
1	Discuss title with supervisor												
2	Internet and library search												
3	Preparation of progress report												
4	Consultation												
5	Submission of progress report												
6	Preparation chapter 1												
7	Preparation chapter 2												
8	Preparation chapter 3												
9	Consultation												
10	Edit Psm 1 report												
11	Submission Psm 1 report												

Gantt Chart for PSM II

No	Activities	Week											
		3	4	5	6	7	8	9	10	11	12	13	14
1	Experimental set-up												
2	Problem solving												
3	Pre-experiment												
4	Submission of progress report												
5	Experiment												
6	Preparation chapter 4												
7	Preparation chapter 5												
8	Preparation chapter 6												
9	Consultation												
10	Edit Psm 2 report												
11	Submission Psm 2 report												

APPENDIX B: Test-rig drawing



APPENDIX C: Orthographic view