STATIC LOAD TEST FOR HYDRO-PNEUMATIC DRIVELINE PROPULSION SYSTEM

SHAIFUL MOHAMMED TASHMIN BIN HALIM

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STATIC LOAD TEST FOR HYDRO-PNEUMATIC DRIVELINE PROPULSION SYSTEM

SHAIFUL MOHAMMED TASHMIN BIN HALIM

A Project report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering (Hons)

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Faculty of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "Static load test for hydro-pneumatic driveline propulsion system" is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :.................................

Name :.................................

Date :.................................

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient regarding scope and quality as partial fulfilment of Bachelor Degree in Mechanical Engineering with Honours.

Signature :...................................

Name of Supervisor :...................................

Date :...................................

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DEDICATION

To my beloved family for the endless support they had gave, especially to my beloved mother and father, Rokiah Binti Abdullah and Halim Bin Joki.

Supervisor En. Faizil Bin Wasbari.

&

Dear friends

.

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ABSTRACT

The study emphasized the effect of static load on the performance of the hydropneumatic driveline propulsion system. Hydraulic hybrid vehicle (HHV) is a new technology being developed to enhance fuel economy for passenger vehicles. However, this system is still ranked under the research and development stage. Many things regarding the performance of this system are still unclear. Therefore, research related to the effects of the static load is carried out, which is focused on passenger vehicles. In this research, the functional circuit of the charging and propulsion have been designed and simulated by using Automation Studio software. Chassis dynamometer test has been conducted to obtain performance data of hydro-pneumatic driveline propulsion system with the load imposed. Through the project, it was found that the higher the load, the longer will be the running time due to the energy capacity effect. The maximum 88.6 s running time was recorded by 200 bar pressure and 10 Nm load. It was 31% higher compared to the minimum running time recorded by 2 Nm load. The higher torque at 200 bar was 63% greater than the lowest torque at load 2 Nm. However, there was an opposite effect on the RPM where the higher the given load, the slower the revolution of the wheel. The differential percentage is about 23% slower. Throughout this study, it was concluded that the value of running time under load condition, RPM and torque generated were reasonable, and this system is applicable. For future research, if this technology is to be adopted in the passenger car, the sizing of the accumulator must be taken into consideration so it can fit in the car.

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ABSTRAK

Kajian ini memberi penekanan mengenai kesan beban statik terhadap prestasi sistem pendorong hibrid hidro-pneumatik. Kenderaan hibrid hidraulik (HHV) merupakan teknologi baru yang dibangunkan untuk menjimatkan penggunaan bahan bakar kenderaan penumpang. Bagaimanapun, sistem ini masih berada di peringkat penyelidikan dan pembangunan. Banyak perkara mengenai prestasi sistem yang masih belum jelas. Oleh itu, penyelidikan yang berkaitan dengan kesan beban statik dijalankan dan difokuskan pada kenderaan penumpang. Dalam kajian ini, litar fungsi pengisian dan pendorong telah direka dan disimulasi dengan menggunakan perisian Automation Studio. Ujian kerangka dynamometer pula telah dijalankan untuk mendapatkan data mengenai prestasi sistem pendorong hibrid hidro-pneumatik apabila beban dikenakan. Didapati bahawa semakin tinggi beban, semakin lama masa pergerakan roda yang disebabkan oleh kesan kapasiti tenaga. Masa pergerakkan maksimum 88.6 s dicatatkan oleh tekanan 200 bar dan beban 10 Nm. Ia adalah 31% lebih tinggi berbanding dengan masa pergerakkan minimum yang direkodkan oleh beban 2 Nm. Tork yang dihasilkan pada 200 bar – 10 Nm adalah 63% lebih tinggi daripada tork terendah pada beban 2 Nm. Walau bagaimanapun, terdapat kesan yang bertentangan di mana apabila beban yang lebih tinggi dikenakan, semakin perlahan revolusi roda. Peratusan perbezaan kesan ini adalah kira-kira 23% lebih perlahan. Sepanjang kajian ini, disimpulkan bahawa nilai masa pergerakkan di bawah keadaan beban, RPM dan tork yang dihasilkan adalah munasabah, dan sistem ini sesuai digunakan pada kenderaan penumpang berskala kecil. Untuk penyelidikan masa depan, jika teknologi ini diterima pakai, ukuran penumpuk mesti dipertimbangkan supaya ia boleh dimuatkan dalam kereta.

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LIST OF ABBREVIATIONS

DCV	Directional Control Valve
PRV	Pressure Relieve Valve
FCV	Flow Control Valve
HHV	Hydraulic Hybrid Vehicle
ICE	Internal Combustion Engine
MIG	Metal Inert Gases
CH_4	Methane
CO_2	Carbon Dioxide
NYC COMP	New York Composite
N_2	Nitrogen
PHEV	Parallel Hybrid Electric Vehicle
PHHV	Parallel Hydraulic Hybrid Vehicle
SHHV	Series Hydraulic Hybrid Vehicle
SUV	Sports Utility Vehicle
SOP	Standard Operating Procedure
MG	Motor Generator

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LIST OF SYMBOLS

E = energy storage of the accumulator (Joule)

K_i = Correction factor

η_M = Mechanical efficiency

$\eta_{overall}$ = Overall efficiency

C = Displacement ($\mathrm{m}^3/\mathrm{rad}$)

η_v = Volumetric efficiency

Δp = Pressure different (N/m^2)

p_{gh} = Gas pressure (Pascal)

p_{op} = Pressure of the oil (Pascal)

p_{in} = Pump input pressure (N/m^2)

p_{out} = Pump output pressure (N/m^2)

P_P = Pump power (Watt)

P_S = Shaft power (Watt)

Q_i = Flow rate (m^3/s)

Q_{out} = Pump output flow rate (m^3/s)

Q_{out} = Pump output flow rate (m^3/s)

t_i = Filling time (s)

T = Torque (Nm)

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LIST OF SYMBOLS

V_2 = Volume after compression (liter)

V_{gh} = Gas volume (m^3)

ΔV_{ideal} = Effective volume (liter)

ω = Nominal speed (rad/s)

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CHAPTER 1

INTRODUCTION

1.1 Background

In this epoch of globalization, hybrid technology advancement has ended up become dominant in the automotive business. To enhance the performance of the vehicle, fuel consumption and greener technology, it was proven by the research and development. The new innovation of the hybrid vehicle types is a hydro-pneumatic hybrid. The combination of hydro-pneumatic hybrid car consists of two or more types of propulsion structure work in a vehicle. The concept of converting hydro-pneumatic into useful energy which reuse losses of energy in breaking. In this automotive field, the meaning of hybrid is a vehicle that has more than one propulsion system to get a motion on the vehicle. There are a many types of hybrid technology which are hybrid electric, hybrid flywheel, hydraulic and pneumatic hybrid. The hybrid technology is popular among the heavy truck, and it is still in a stage of research and development so that this concept can be applied to a passenger car (Wasbari, Anas and Abu Bakar, 2016). Hydro-pneumatic hybrid is a compounding of the internal combustion engine (ICE), the hydraulic system as propulsion and hydro-pneumatic accumulator as an energy source. However, the internal combustion engine consumes more fuel to operate and give small energy efficiency but high performance.

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The increased performance of hybrid vehicles makes hybridization especially useful for city-town passenger cars, local delivery for small trucks and urban buses. When driven on highway, hybrid vehicles do not show a specific advance in fuel consumption (Transactions and Techniczne, 2016). Vehicles which are basically used on highway, downsized diesel engines are best equipped to get minimal fuel use of goods and services. The most prominent hybrid system is a hybrid renewable energy organization. However, based on the research and development stage, the innovation of another hybrid system is called hydro-pneumatic hybrid system. Hydro-pneumatic hybrid is the collaboration of the internal combustion engine, propulsion and pneumatic system which hydraulic system act as the energy source. There are four sub-systems of hydro-pneumatic driveline. First, for the hydro-pneumatic driveline, sub-organizations are driving the organization. It delivers energy from the energy storage to the actuator. The storage device that save energy propulsion called as the accumulator (Wasbari *et al.*, 2018). There are several reasons for considering the use of pneumatic systems over the hydraulic system, such as hydraulic liquid exhibit greater inertia than gases as weight of oil give problem when accelerating and decelerating actuators, hydraulic system requires special reservoirs and no leak system design, the pneumatic system use air that is exhaust directly back to the environment, pneumatic system is less expensive than hydraulic system and the hydraulic liquid exhibit greater viscosity than gas (Yavuz *et al.*, 2014).

During innovation of the automobile, the drastic change has been in the field of automobile testing. It supports in building technologies to make sure that the highest standards are met regarding reliability, safety, durability, and product quality. An engineer has been under scope pressure either to improve engine power or to increase the fuel

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consumption. So it requires a way to test the power output and fuel economy of automobile engines, and continue the dynamometer for innovation. For this research, the focus point is on the field of hydro-pneumatic. One of the vital components of hydro-pneumatic driveline systems is the driving system. The effects of the system load on the performance of hydro-pneumatic drive-line were analyzed. The research will affect the use of Automation Studio tools to simulate the process and experiment. The outcome of this inquiry will lead to assumption, based on the system efficiency.

1.2 Problem Statement

Initial research has shown that the hydro-pneumatic hybrid system improved the fuel consumption and environmentally friendly, but there is no specific research about the detail drive subsystem of the car section. The crucial part in researching and developing new designs for the automotive industry is testing the powertrain of a vehicle. In this situation, it is a high requirement to further improvement the university's research capabilities by developing automotive research facilities. Besides, there is no previous study related to the performance of hydro pneumatic driveline in term of the test rig experiment.

Therefore, this research, focusing on the effects of the load system based on performance of hydro-pneumatic driveline will be carried out. The data of the experiment will be collected, and it can be referenced in future research. Therefore, experiment will be conducted and simulated via Automation Studio software.

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1.3 Objectives

The objectives of the project are as follow:

1. To find the effect of static load to the system performance (running time, revolution speed (rpm), torque, power and velocity by load).
2. To calculate the system velocity (km/h).

1.4 Scope of Project

The main concern in this project is to design the structure of static load test of hydro-pneumatic driveline propulsion system by using Automation Studio software. Automation Studio software is a totally incorporated program package that enables users to create simulation which need to achieve the expected results. The latest version of hydraulic tools which are Automation Studio software v6.1 which implements for design, functional simulation of complex automation, preparation and documentation. It also contains hydraulic, pneumatic and electrical operative devices as well as a command part diagram. In this research, the static load system will apply on hydro pneumatic driveline propulsion test rig to collect new data as a future reference. To apply research on dynamic load is quite difficult because there is no specific apparatus to fulfill the experimental. Furthermore, there are no data from previous research, so it very tough for us to lead as the first researcher in this research. However, to ensure the experiment as work successful, a lot of steps will be planned by starting from designing, then continued by fabricating and collect all data based on the experiment.

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1.5 Hypothesis

In this study, the effects of static load on the performance of hydro-pneumatic driveline will be proposed. To improve efficiency and performance, the effects of static load have been taken into consideration in the analysis of hydro-pneumatic driveline. At the end of this research, perhaps that the system should be able to outline the specific parameter to optimize the performance of the driveline system.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The beginning of the project as it started, the literature review has been taken place as a references. The purpose of this operation is to search and collect more information and data required to make sure that the project goes greatly and successfully. Since data and knowledge are required throughout the evolution of this project, this process was very helpful continuously until this project accomplished. In this literature review, the structuring of the chapter includes an introduction to the hybrid system, loading of driveline system, propulsion system, type of load and innovation in driveline system which retrieved from previous studies in this area. Moreover, the important parts in this research are keeping the functionality of the system to be clearly. In a nutshell, a very important part of this research is by the theories, journal, internet, article, and thesis from past researched.

2.2 Hybrid System Background

Theoretically, hybrid system studies the behaviour of dynamical systems, technological systems, dynamical of hybrid systems comprises heterogeneous dynamics that interrelate with each other and investigate their behaviours over time. Systems containing two different forms of dynamics: time-driven continuous variable dynamics,

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usually recognized by differential or difference equations; and outcome-driven separate variable dynamics, the progresses of which be determined by on the if-then-else type of rules, commonly defined by automata or Petri nets. These dynamics relate with each other and create complex dynamical behaviours, like a switching once the value of a continuous variable passes over a threshold, or state jumping upon a certain separate event occurring to remark (Hai and Antsaklis, 2014).

The hybrid system can shift between many operating modes where its characteristic dynamic laws govern each style. More evolutions are triggered by variables passage specific thresholds (state cases). The car is one of a simple model of the hybrid system. The dynamics of the car can change when a gear shifted, either because the driver transports the stick shift (input event) or because the state variable "speed" surpasses a specified threshold (state event) in the situation of an automatic transmission.

A mathematical definition of hybrid systems first presented in computer science in this context. Alternative simple example of a hybrid system would be a linear system under response control with actuator constraints (Camacho, 2007). Lastly, consider a metabolic network, where the disappearance of an enzyme turns a particular reaction step on or off. Its behavior can also be modeled as a hybrid system (Pourmovahed and Otis, 1990).

The first type of hybrid system is the electric hybrid system. In electric hybrid vehicle system, energy will be kept in a battery or capacitor storage layer. Commonly, energy stored in a battery by electrical and for ultra-capacitor energy will be stored through charge separation. In a battery, it has particular high energy while in capacitor, it have nearly the high specific power and lower specific energy. Battery and capacitor are utilized to stored energy from regenerative braking and any additional power produced by the vehicle power plant. From regenerative braking, the electric generator will be utilized as a

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transformer between rotational motion and the electrical energy. This technology has already been used in Volvo and in a heavy hybrid vehicle.

In the kinetic hybrid system, energy will be stored in the term of kinetic energy with the flywheel and continuous variable transmission (CVT). This function is to transmit energy among flywheel and drivetrain. Moreover, energy is recharged in flywheel instead of battery and ultra-capacitor. This stage is commonly known as "flywheel battery" (Midgley and Cebon, 2014)

$$E = \frac{1}{2} J\omega^2 \tag{2.1}$$

Where E_f = flywheel stores the energy

ω = rotational speed

J=rotational inertia

For the equation 2.1, E_f is the value energy of flywheel. The rotational speed, ω is total of 2π times N (rpm) and J is inertia due rotational by moving vehicle. The hybrid system is a vehicle consisting of two sources of propulsion mainly. Internal combustion engine (ICE) and the energy storage device. In hydraulic hybrids, a hydraulic accumulator stored energy in the form of compressed nitrogen gas by hydraulic fluid. A diaphragm split the gas and fluid. After the gas and fluid are separated in the accumulator, the gas was compressed and one side of the accumulator was forced by fluid.

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There are two accumulators which mainly on the hydraulic hybrid vehicle as shown in Figure 2.1. The first accumulator is at high pressure while the second is at low pressure. The turning power of a wheel is used by the hydraulic pump-motor to pump fluid from the low-pressure accumulator to the high-pressure accumulator during regenerative braking and vice versa to remove energy. This means that fluid is transferred from high-pressure accumulator to low-pressure accumulator to remove the energy from the system and create a torque (Midgley and Cebon, 2014).

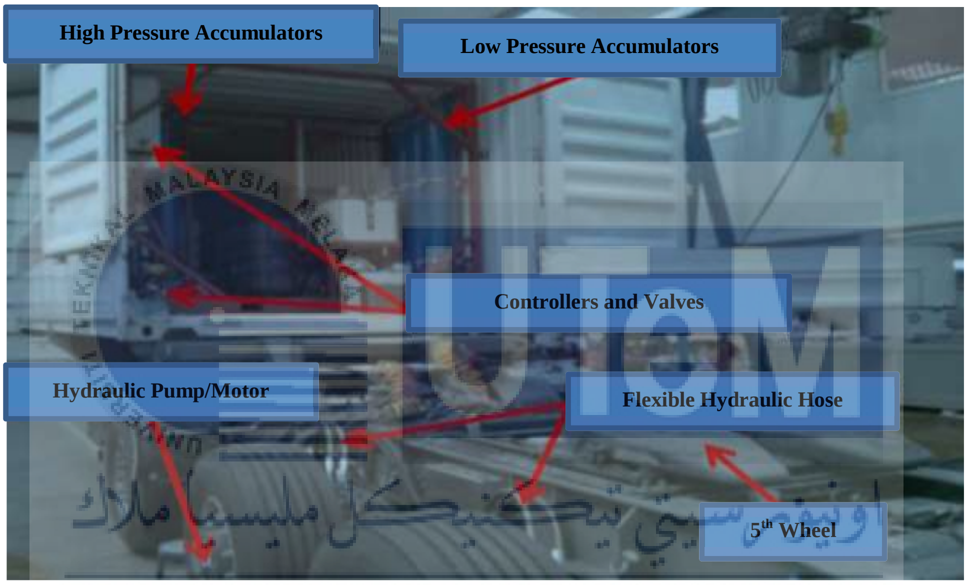

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Figure 2.1: Accumulator in vehicle, (Midgley and Cebon, 2014)

Adiabatic compression and isothermal compression is a standard process that involves in the accumulator. Usually, the adiabatic compression process is related to the process that occurs internal of an accumulator while the isothermal compression process is related to the temperature of working fluid as shown in equation 2.2. Through the compression process, the temperature will increase and can lead to heat losses through the walls of the accumulator. This heat loss can be prevented by thermal insulation on the gas side. This technique has been proven in previous researched done by Pourmovahed and Otis, 1990. Assuming energy stored in the accumulator is adiabatic: -

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$$E_{acc} = \left\{Pcomp\ \frac{1-r_v{}^{\wedge}1-\gamma}{\gamma-1} - Patm(r_v - 1)\right\} v_{comp} \qquad (2.2)$$

Where $Pcomp$ = pressure of gas at its compressed air

r_v = volumetric compression ratio

γ = adiabatic index

$Patm$ = pressure of atmospheric

2.3 Hybrid on Passenger Car

The innovation in the automotive industry now is hybrid technology, since the technology proven to improve vehicle productivity and reduce of fuel usage. Any vehicle is a hybrid when it combined two or more sources of power. It used an internal combustion engine in conjunction with a hydraulic motor to achieve propulsion while hydro-pneumatic accumulator acts as storage. It means a hybrid usually will have a traditional internal combustion engine and a fuel tank, a battery pack, and one or more electric motor. The fuel tank supplies gasoline to the engines and the batteries used to supply power to an electric motor. When the energy in the storage is low, the system operates energy losses in braking and improves into useful energy. Hybrid cars use less fuel and produce fewer emissions. It recharges their batteries by capturing kinetic energy through regenerative braking (Wasbari *et al.*, 2017). In the other hand, there is also a hybrid car that uses the product of electricity which from combustion engine by working a power supply to recharge the battery or straight feed power to an electric motor that moves the vehicle.

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2.4 Hydro-Pneumatic System

The hydro pneumatic system comprises of a pressure pump and a pressure tank. The pressure tank comprises of an elastic bladder encompassed by pressurized air. Fluid being a non-compressible liquid, pressurized air is utilized. When open the throttle of fluid pressure, flow control valve fluid from this pressure tank is utilized. As the fluid used, the pressure in the tank is decreased. The pressure switch detects this pressure drop and the pump is turned ON when the set pressure is attained, the pump stop. It is done as such as to decrease more ON/OFF's of the pump. It will greatly expand the life of the pump. This system works consequently, and no workforce is required (Water and Tips, 2011). A hydraulic accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is contained under pressure that is enforced from an outside source. The external source can be a spring, a raised weight, or a compressed gas. An accumulator enables a hydraulic system to cope with excesses of demand using less powerful pump, to react more quickly to a temporary demand, and to smooth out pulsations. It is a type of energy storage device (Water and Tips, 2011).

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In new technology of hybrid, the vehicle was applied hydraulic system which consists of accumulator as power storage instead of battery, hybrid of electricity. There may be more than one accumulator in a system. The precise category and procedure of each may be a compromise due to its effects and the costs of fabrication. An accumulator is set to close the pump with a non-return valve avoiding flow back to the pump. Based on case of piston-type pumps, the storage (accumulator) is put in the perfect area to absorb pulsations of energy from the multi-piston pump (Alto, 2001). Also, it also helps to prevent the system from a fluid hammer. This guards system components, particularly pipework, from both actually destructive forces. A further benefit is an additional energy that can be

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saved while the pump is subject to low demand. An engineer can use a smaller-capacity pump. The large excursions of system components, such as moving gear on a large aircraft, that require a significant volume of fluid can also benefit from more than one accumulator. The internal flow of energy from a discharging accumulator is augmented, for a short time, then even large pumps could produce (Water and Tips, 2011). An accumulator can switch the pressure in a system for periods when there are slight leaks without the pump being cycled on and off frequently. The gas collected in an accumulator is set so that the separating bladder, diaphragm or piston does not spread or strike either end of the mechanism cylinder. The low quality maintenance of precharge can terminate an operating accumulator. A best designed and maintained accumulator must maintenance trouble-free for years (Alto, 2001).

2.5 Propulsion System

There is an increasing concerned in electric and hybrid-electric vehicles due to environmental anxieties. Determination is focus toward developing an upgraded propulsion system for electric and hybrid-electric vehicle applications. The word of propulsion is a means of creating force leading to movement (Ehsani, Rahman and Toliyat, 1997). Additional components such as clutches, gearboxes and so forth may be required to connect the power source to the force generating component.

The vehicle dynamics are considered in an effort to find an optimal torque-speed profile for the electric propulsion system. This investigation exposes that the vehicles operational constraint, such as initial acceleration and grade, can be encountered with less power rating if the powertrain can be worked mostly in the constant power region (Ehsani, Rahman and Toliyat, 1997).

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2.6 Type of Load System

Nowadays, there is a lot of technology machines dynamometer is the best device to estimate the torque and brake control needed to perform the work. A dynamometer system is likely to be utilized as a test instrument to test the speed and torque abilities of an engine and controller arrangement. An instrument which electro-mechanical dynamometer was used to arrange mechanical load on torque producing devices such as engines. It can be utilized to describe engine torque as a component of movement. A dynamometer is a break yet furthermore it has a device to quantify the frictional resistance. By knowing the frictional resistance, the torque transmitted and thus, the intensity of the motor can be obtained (Vong, Wong, and Li, 2006). There are two types of dynamometers can be broadly categorised:-

1. Power Absorption Dynamometers; it identifies and measure the power output of the engine to which they are connected. The power absorbed is normally dissipated as heat by a few means (Vong, Wong, and Li, 2006). For examples of the power absorption dynamometers are Prony brake dynamometer, Hydraulic dynamometer, Eddy current dynamometer, Rope brake dynamometer, etc.

2. Power Transmission Dynamometers; the power transmitted to the load coupled to the engine after it is indicated on some scale by the power transmission dynamometers. These are also called torque meters (Morawska *et al.*, 1998).

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2.6.1 Prony Brake Dynamometer

The present innovation, for the most part, identified with turning load engagement devices for determining the power output of a prime mover and all the species is concentrating to an enhanced Prony brake-type load absorption device, or dynamometer providing a long working lifetime, expanded load estimating capacity and more secure, and more economic activity. A Prony brake for the most part incorporates a turning brake drum or disc connected with the external shaft of a prime mover, for example, an internal combustion engine, and stationary friction pads or brake shoes that are connecting with the drum or disc in using a retarding force there to by frictional contact (G.G. Liversidge, K.C. Cundy, J.F. Bishop, 1980). The degree of delaying achievement is dictated by the force which this frictional contact is functional. A Prony brake as defined may be used simply as a power engagement device or, in combination with torque determining means, as a dynamometer for testing the under-load performance characteristics of the prime mover.

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A dry brake need more requirements to work, that friction material is envisioned to be operated in that a specific measure of the breakdown of both the friction block, or material, and the metal casting itself occurs. This breakdown procedure disclosures new contact points of both members in continuing a reasonably constant and real coefficient of friction until either one or both members require either reconditioning or replacement. The process of dry brake will cause the problem relating to particle friction of material which called as dust. This dust is very damaging to bearings and seals, and its accumulation reasons recirculation problems and a rather unstable loading characteristic (G.G. Liversidge, K.C. Cundy, J.F. Bishop, 1980).

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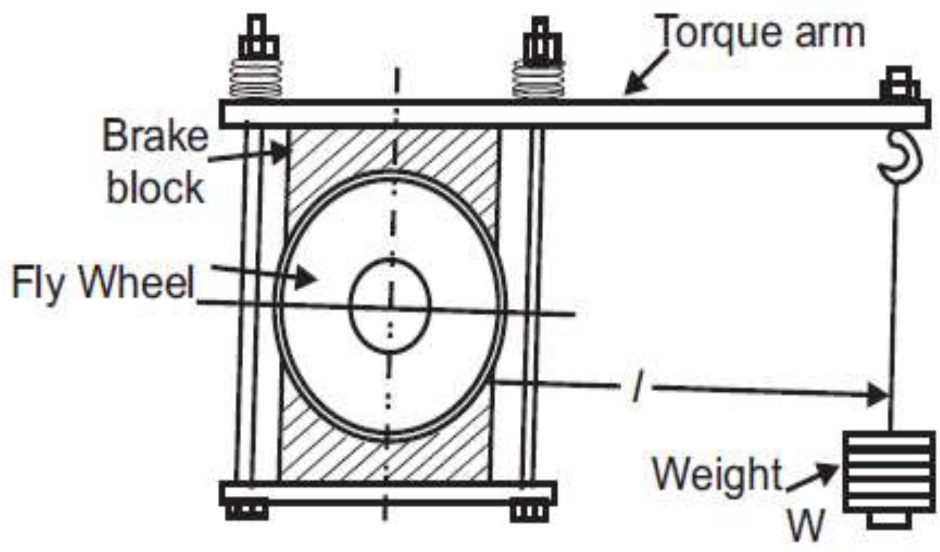

Figure 2.2: Prony brake dynamometer (G.G. Liversidge, K.C. Cundy, J.F. Bishop, 1980)

The Prony brake shown in Figure 2.2 comprises of brake shoes, wooden block, frame, rope, and flywheel. It operates along the standard of converting power into heat by dry friction. Spring-loaded bolts are offered to upsurge the friction by the wooden cube. The entire of the power absorbed is changed into heat and hence this type of dynamometer cannot run frequently. The brake power equation:-

$$Brake\ Power\ (bp) = 2\pi NT \qquad (2.3)$$

Where T = weight applied (W) x distance (l)

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2.6.2 Hydraulic Brake Dynamometer

The hydraulic brake system nowadays innovation is a combination of a master brake cylinder, wheel brake cylinders, a brake slip or antiskid control apparatus, a valve device controlling a fluid flow from a fluid cause to a pressure chamber of the master cylinder. The valves actuated by the brake slip control apparatus controlling in the imminent locked condition of a wheel the pressure in the associated wheel cylinder independently of the pressure chamber. The valve device released in need of a differential between the chamber and the pressure in the wheel cylinder associated with the pressure chamber (Rotman, 1979). The principle of dissolving the power in fluid friction rather than in dry friction is functional by hydraulic brake dynamometer as shown in the Figure 2.3.

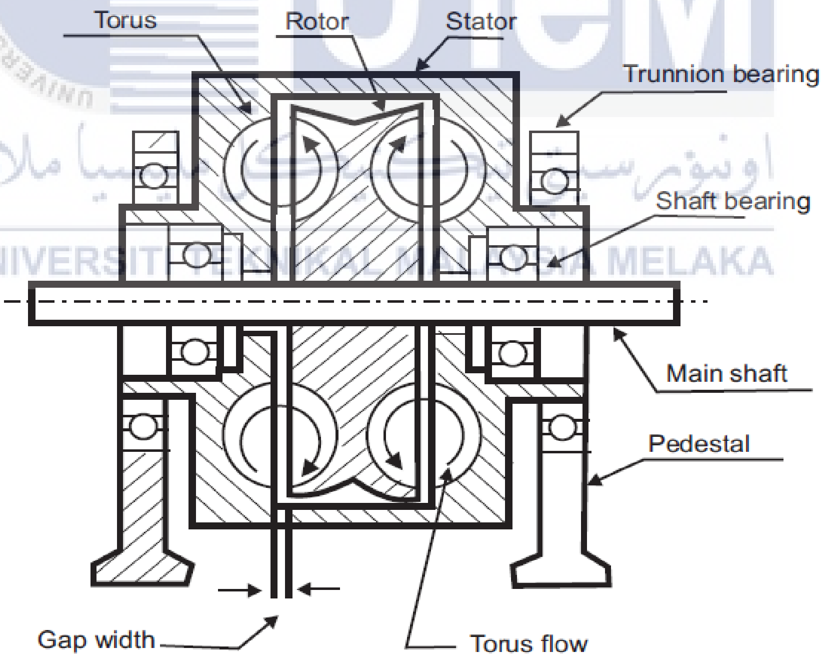

Figure 2.3: Hydraulic brake dynamometer (Rotman, 1979)

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2.6.3 Eddy Current Brake Dynamometer

An eddy current brake dynamometer working principle as shown in Figure 2.4. It consists of a stator which is fitted with electromagnets and a rotor disc made of copper or steel and combined to the external shaft of the engine. When the rotor turns, the eddy currents are created in the stator due to magnetic flux produce by the passage of field current in the electromagnets (González, 2004). These eddy currents are degenerate in making heat so that this type of dynamometer needs some cooling arrangement. The torque is investigated precisely as in other types of connection dynamometers, i.e., with the support of a moment arm. The load on internal combustion engine (ICE) testing is measured by changeable the current in the electromagnets.

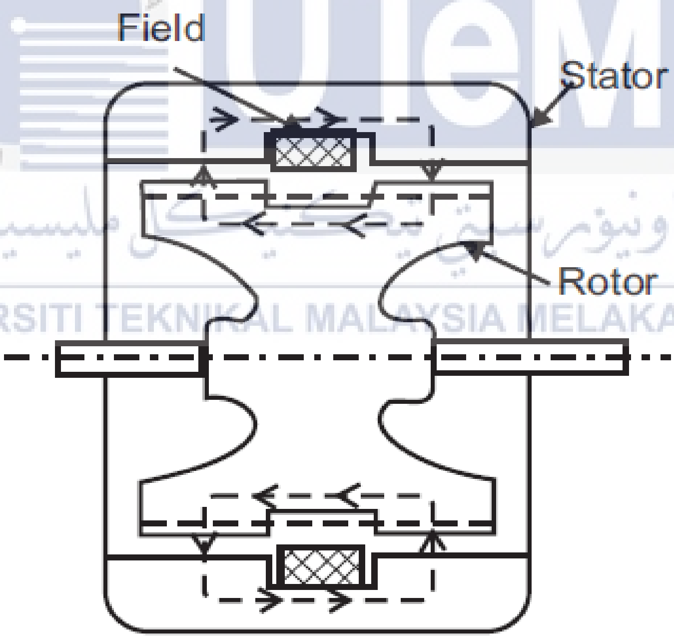

Figure 2.4: Eddy current brake dynamometer (González, 2004)

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2.7 Dynamic Load of Vehicle System

2.7.1 Introduction

Vehicle dynamics are stressed with the activities of vehicles such as automobiles, buses, trucks on a road surface. The movements of attention are braking and acceleration, ride and rotating. Dynamic concept is approached by the forces contacted on the vehicle from the tires, gravity, and aerodynamics. The vehicle and its parts are determined to study what forces will be formed by each of these sources at a specific maneuver and trim condition, and how the vehicle will action to these forces (Gillespie, 2006).

For the solitary mass demonstration, the vehicle is preserved as a mass concentrated at its center of gravity (CG) as shown in Figure 2.5. The point mass at the CG, with suitable rotational moments of inertia, is dynamically equivalent to the vehicle itself for all motions in which it is practical to assume the vehicle to be rigid.

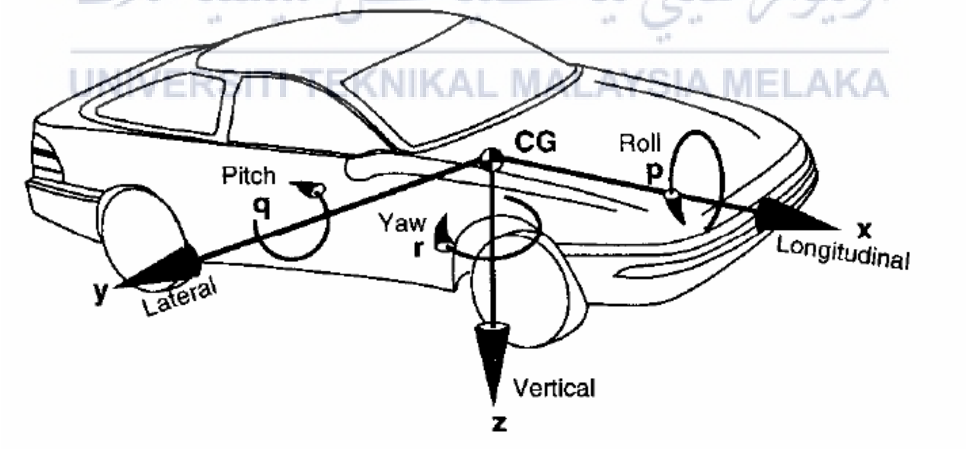

Figure 2.5 : Vehicle axis system (Gillespie, 2006).

The vehicle basically defined forces and moments. Thus an optimistic force in the longitudinal (x-axis) route of the vehicle is forward. The force conforming to the load on a

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tire acts in the upward direction and negative in magnitude (in the negative z-direction) (Gillespie, 2006).

2.7.2 Newton's Second Law

The essential law from which all vehicle dynamics studies begin is the second law formulated by Sir Isaac Newton (1642-1727). The law used to both translational and rotational system. The translational system is the total of the outer forces acting on a body in a specified direction are equivalent to the product of its mass and the acceleration in that direction (supposing the mass is fitted) (Gillespie, 2006). The equation of Second Newton is given as:-

$$F = m\,.\,a \tag{2.4}$$

Where F = Directional of force

m = Mass of the object

a =Direction of acceleration

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The rotational system is the total of the torques applying on a body about a specified axis is equivalent to the product of its rotational moment of inertia and the rotational acceleration approximately that axis. The equation as shown below:-

$$T = I\,.\,a \tag{2.5}$$

Where T = Torques about the axis

I = Moment of inertia about the axis

a =Acceleration about the axis

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2.7.3 Loading of Vehicle System

In this research, an analytical algorithm is established to search the best size of the power train of a hybrid vehicle design. The primary theorem of the algorithm is based on the maintenance of energy in the control volume. All of the sink or source terms of the energy in the important equation were assessed experimentally and numerically. When a vehicle turned on the road, it behaviours a resistance force from outside of the vehicle (Park and Kim, 2009). It is called a running resistance of the vehicle on the road. If the driver wants to keep constant, equivalent power needs to the running resistance, but requires more power for acceleration to overwhelm the acceleration resistance. Based on braking case, the inertia energy of the vehicle can be restored by the inertia recovery system of the vehicle. The engine power compulsory for driving changes at all-time due to the difference of moving condition on the road (Park and Kim, 2009). The car performance formula has been obtained which consists of rolling resistance (R_R), aerodynamic resistance (R_A), gradient resistance (R_G) and tractive resistance (R_{trac}).

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A common form of sum running resistance force of a vehicle can be stated as the total of the above relations as given below:

$$R_{tot} = R_R + R_A + R_G + R_{trac} \tag{2.6}$$

By the change of driving state, the general equation 2.6 would be changed. If a vehicle travels at a constant speed on a level road, the terms, R_G are discounted. For the deceleration of the vehicle, R_I must be negative signed (Park and Kim, 2009).

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Table 2.1: Rolling resistance coefficient with road surface condition (Park and Kim, 2009).

Conditions of surface	μ_R
Asphalt paved road	approx. 0.010
Concrete paved road	approx. 0.011
Stone block paved road	approx. 0.020
Well-maintained unpaved road	approx. 0.04
Unpaved road	approx. 0.08
Pebble-stone road	approx. 0.12
Sand and pebble-stone road	approx. 0.16
Sand road	approx. 0.2 -0.3

Table 2.1 illustrates the rolling resistance coefficients for different kind of conditions. The frictional resistance road with tire surface is called as rolling resistance of a vehicle. It is influenced by the surface roughness of the road. Based on the principle of physics, the rolling resistance of a running vehicle can be approached from equation 2.7:

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$$R_R = \mu_R \, x \, (W_{car} + W_x) \quad (2.7)$$

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Where W_x = A running vehicle of induced lift or down force

W_{car}= Gross weight of a vehicle

μ_R = Rolling resistance coefficient

Besides, when a vehicle run in a road, the virtual air movement happens opposite to the driving direction of the vehicle even without wind in the air. Theoretically, the vehicle was involved aerodynamic resistance, R_A like drag and lift on the body by air flow. Aerodynamic drag force happens when a vehicle travelling at a certain speed in air encounters a force resisting its motion. It principally results from two components which

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are skin friction and shaped drag (Lajos, 2002) (Park and Kim, 2009). Shape drag is the forward motion of the vehicle which pushes the air in front of it. Figure 2.6 illustrates the pattern of shape drag.

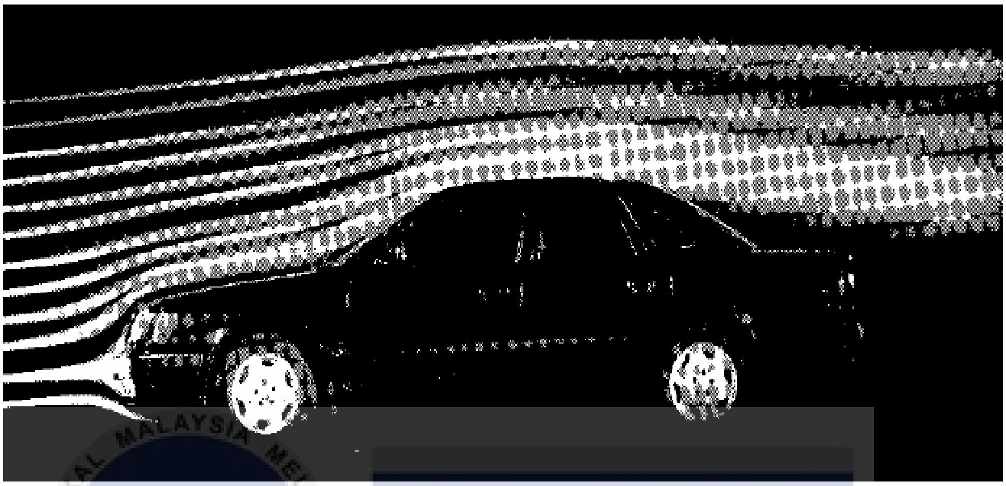

Figure 2.6: Shape drag of a vehicle (Lajos, 2002).

While skin friction is the air near to the skin of the vehicle travels practically at the speed of the vehicle while air that distant from the vehicle remains still. In this case, air molecules move at a broad range of velocities (Park and Kim, 2009). The change in speed between two air molecules creates friction that results in the second element of aerodynamic drag. Table 2.2 indicates the coefficient of aerodynamic resistance for a few types of vehicle (Lajos, 2002).

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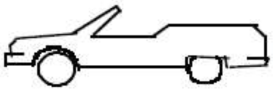
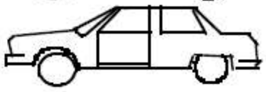
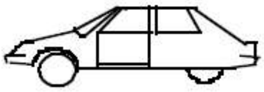
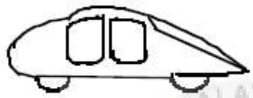
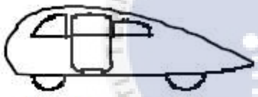
Table 2.2: Types of vehicle body shapes due aerodynamic drag (Lajos, 2002)

Vehicle Type		Coefficient of Aerodymanic Resistance
	Open convertible	0.5–0.7
	Van body	0.5–0.7
	Ponton body	0.4–0.55
	Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4
	Headlamp and all wheels in body, covered underbody	0.2–0.25
	K-shaped (small breakway section)	0.23
	Optimum streamlined design	0.15–0.20
Trucks, road trains		0.8–1.5
Buses		0.6–0.7
Streamlined buses		0.3–0.4
Motorcycles		0.6–0.7

Next, the details of gradient resistance R_G were explained. As a vehicle moving up or down the hill gradient, it involves gravitational resistance due to body weight and it is called gradient resistance of the vehicle. When a vehicle moves up or down a slope, its weight produces an element, which is constantly sent to the downward direction, as indicated in Figure 2.7 (Park and Kim, 2009).

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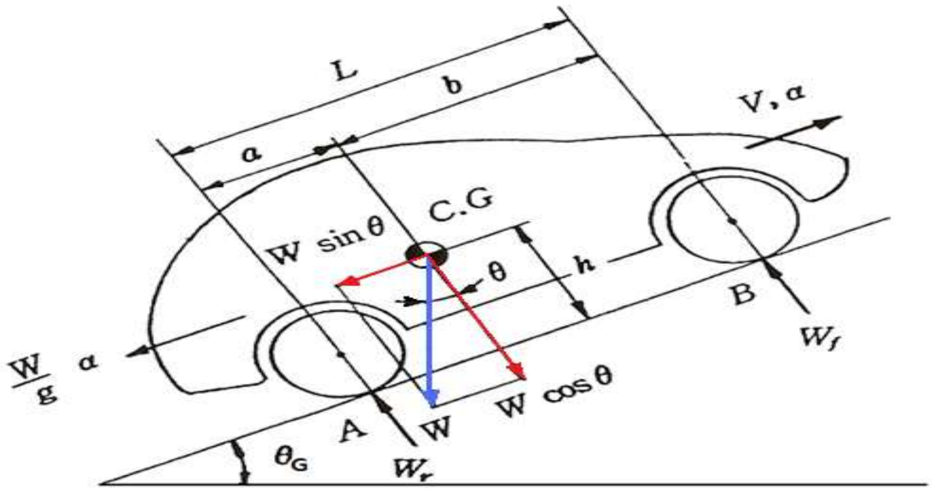

Figure 2.7: Vehicle in slope condition (Park and Kim, 2009).

An analysis of vehicle performance, the only uphill operation is measured. This gradient force is generally called gradient resistance, R_G. The gradient resistance from Figure 2.7 can be expressed as

$$F_g = M_v \, g \sin a \quad (2.8)$$

When goes down a hill by car, it was negative value of the gradient, which is the total resistance power needed is decreased and instead the inertia energy can be reinstated with an energy recovery system. The gradient resistant is calculated by equation 2.9:

$$R_G = \pm W_{car} \, x \, sin \, \theta_G \quad (2.9)$$

Where θ_G is the gradient angle.

Furthermore, the forces acting on a car also been analyzed. Engine power is conducted to the tires through power transmission unit, driveshaft, and axle in a vehicle. The force needed to overwhelm the total running resistance at a given driving state on tires is called the traction force of the vehicle. There are four forces as shown in Figure 2.8.

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The traction force is due to the road while the resistance force is due to air and the road (Park and Kim, 2009).

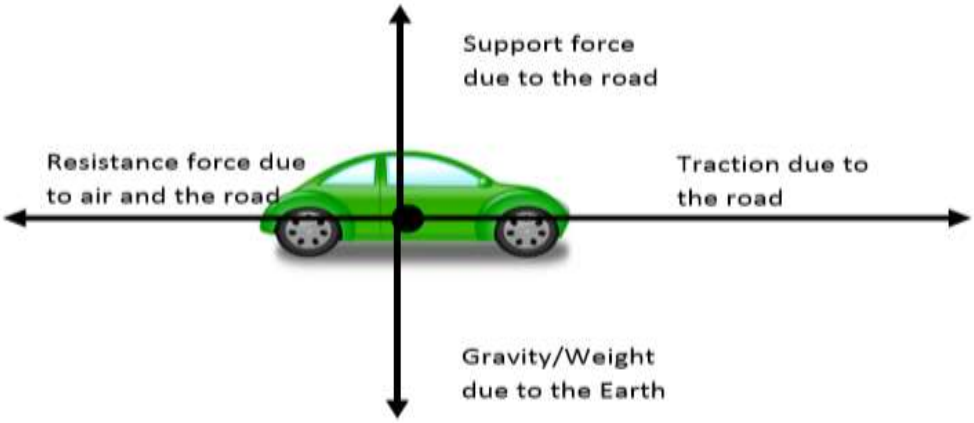

Figure 2.8: Forces are acting on a car (Park and Kim, 2009).

To find the value of torque, the following equations must be taken.

$$P = T\,\omega \tag{2.10}$$

$$\omega = \frac{2\pi N}{60} \tag{2.11}$$

$$P = T\left[\frac{2\pi N}{60}\right] \tag{2.12}$$

$$P = \frac{2\pi N\,T}{60} \tag{2.13}$$

When the value of torque was found, and by using the following formula, the force applied to a car can be obtained.

$$T = F\,r \tag{2.14}$$

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Where T is the torque, F is the force applied, r is the radius, P is the power, N is rotational speed (RPM), and ω is angular velocity. Also, there is another way to find the value of force as (Park and Kim, 2009).

$$F = ma = mg \tag{2.15}$$

Where F is a force, m is mass; a is acceleration and g is the gravitational force.

2.8 Experiment Set Up (Chassis Dynamometer)

The chassis dynamometer is very important indoor bench test equipment in the automotive product development process. A dynamometer, or "dyno" for short, is a device for generally measuring torque and power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (RPM) (Jirawattanasomkul and Koetniyom, 2012). The chassis dynamometer detects the vehicle dynamics, emission targets and fuel consumption of multiple loading conditions through vehicle simulating road driving conditions on indoor bench.

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Chassis dynamometer for Hybrid Electric Vehicle can synthetically test hybrid car vehicle include batteries, motors, energy management system and braking energy recovery system. In the trial, establishing the relationship between the bench and the real vehicle, and simulating the rolling resistance, air resistance and acceleration resistance of Hybrid Electric Vehicle can simulate hybrid vehicle road test indoor to shorten the test cycle (Othman and Daniyal, 2015) (Torque-calculation, 2001). Hybrid vehicle chassis dynamometer test bench can analyse and evaluate the pros and cons of control scheme, is the infrastructure for hybrid electric vehicle development.

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2.8.1 Chassis Dynamometer Operation System

Performance of a Vehicle under Test (VUT) can be measured through simultaneous operation of load variation and parameter measurement. Load variation refers to the process of manipulating dynamometer drum‟s inertia to emulate road load condition, while parameter measurement is about the power, torque and speed measurements using various sensors; mostly installed at the load cell. Chassis dynamometer implicates an absorbing power output from the test vehicle‟s engine to allow different loads to be applied on drum for various testing procedures (Othman and Daniyal, 2015).

A conventional dynamometer operates by absorbing the power and energy produces from the vehicle and dissipates the absorbed power usually as heat as shown in Figure 2.9. The absorbing power flow is shown in Figure 2.9, where the flow originated from the VUT on a chassis dynamometer drum to the load (Zhao *et al.*, 2013). Conventional chassis dynamometer is focused on measuring power delivered by vehicle that is dependent on road condition. Several chassis dynamometer that could emulate the physical system configuration, inertia and friction calibration techniques, and control software have been developed; however the testing is applicable for Internal Combustion Engine (ICE) vehicles.

Figure 2.9: Conventional chassis dynamometer (Zhao *et al.*, 2013)

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2.8.2 Power Requirement/Driving Resistance Simulation

This section investigates the limitation of a conventional chassis dynamometer. The direction of force applied during chassis dynamometer testing is illustrated in Figure 2.10. The inertia from the vehicle and the force on the chassis dynamometer assist in the emulation of actual road condition on chassis dynamometer drum (Othman and Daniyal, 2015). As different vehicles have different mass, inertia simulation must be employed to provide realistic loading during transient proceedings.

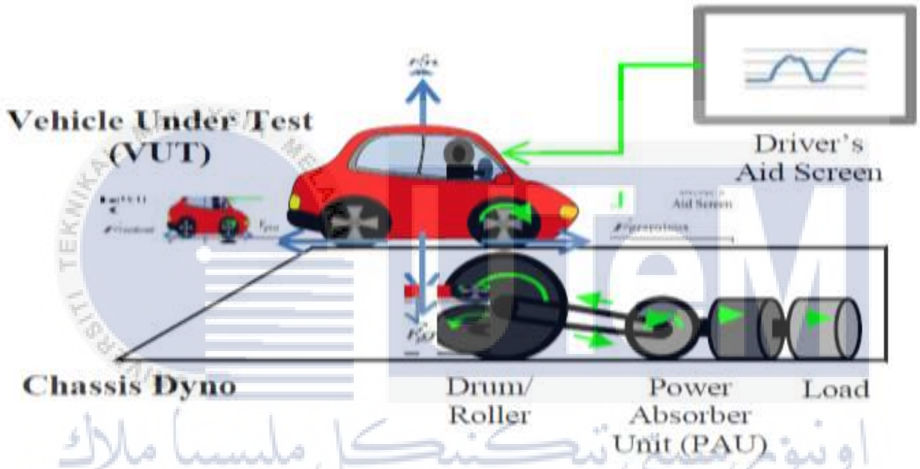

Figure 2.10: Direction of force applied on dynamometer (Othman and Daniyal, 2015).

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When the car is running, the electricity is transformed to kinetic energy to overcome the driving resistance. Driving resistance includes rolling friction resistance, drag force, moment of inertia, and uphill resistance and so on. Figure 2.11 is showing the driving resistance of car; where in the rolling friction resistance-force F_R is expressed in equation 2.16:

$$F_R = \mu M g \cos \theta \quad (2.16)$$

In equation 2.16, μ is the coefficient of rolling friction resistance, M is the total mass of the vehicle and rider, g is the acceleration of gravity, and θ is the included angle of

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the road surface and the horizontal line. But as the friction between wheel and ground is transfer to the internal friction, in power-train system of a car. Therefore F_R is not considered in car testing with chassis dynamometer (Jirawattanasomkul and Koetniyom, 2012).

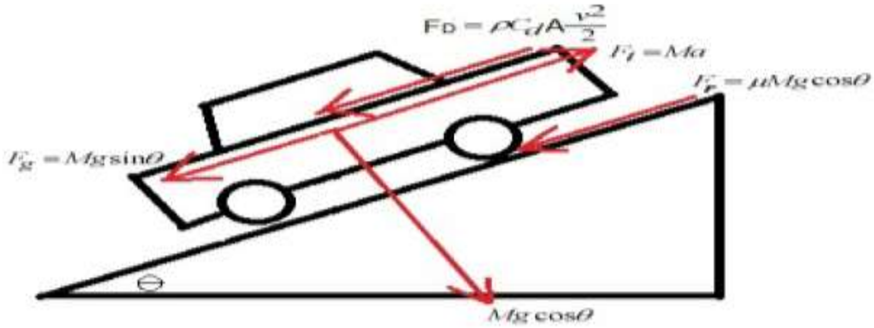

Figure 2.11: Direction of force applied (Jirawattanasomkul and Koetniyom, 2012).

When the car is running forward, the resistance produced from the vehicle external surface and the air is the drag force F_D , as expressed in equation 2.17:

$$F_D = \rho C_d A \frac{V^2}{2} \quad (2.17)$$

In equation 2.17, ρ is the air density; v is the vehicle speed, C_d is the coefficient of drag, and A is the orthogonal projection area of the rider to the vehicle moving direction. Because the car shape is irregular, the shape of the rider, riding posture and the clothes worn by the rider all affect the orthogonal projection area and the coefficient of drag. The uphill resistance is expressed in equation 2.18:

$$F_g = Mg\, sin\, \theta \quad (2.18)$$

As the driving force of the motor overcomes the rolling friction resistance, air resistance and uphill resistance, the remaining driving force represents the moment of inertia, which is expressed in equation 2.19, wherein a is the driving acceleration.

$$F = Ma \quad (2.19)$$

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CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology is stated as the investigation of the principle of methods, rules, and hypothesises employed by a discipline. It is also stated as a procedure or set of procedure that refers to more than a simple set of methods. This chapter explains and elaborates furthermore about the test procedure for the preparation of the raw data until conducting the analysis. Details of explanation on how the project will be carried out start with literature review, schematic diagram, model/equation, simulation data, experiment setup, testing and it ends with the discussion and conclusion.

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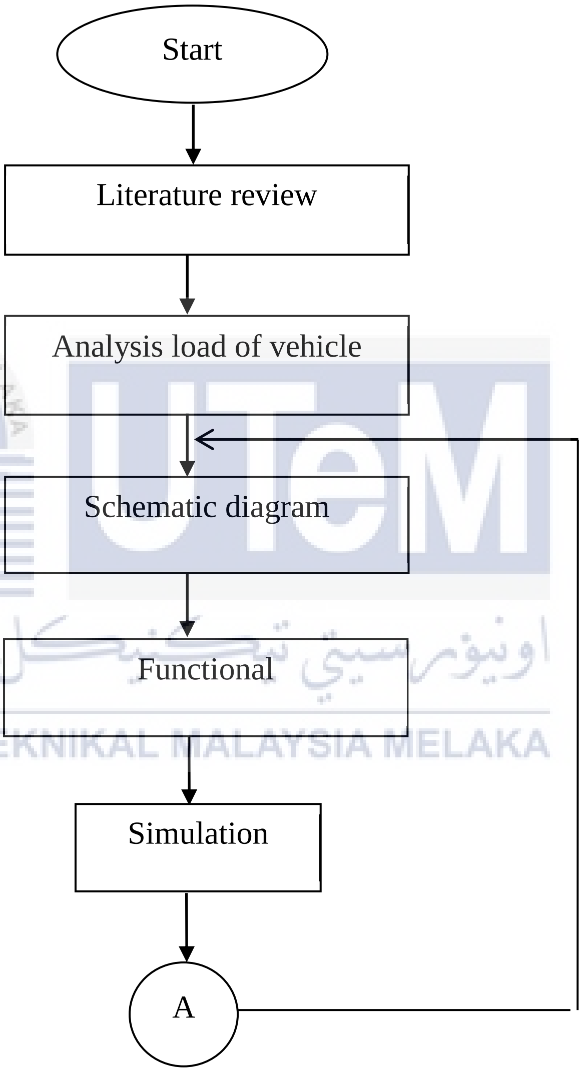
3.2 Flow Chart

This flow chart shows the activities that need to be carried out to accomplish the objectives in this research.



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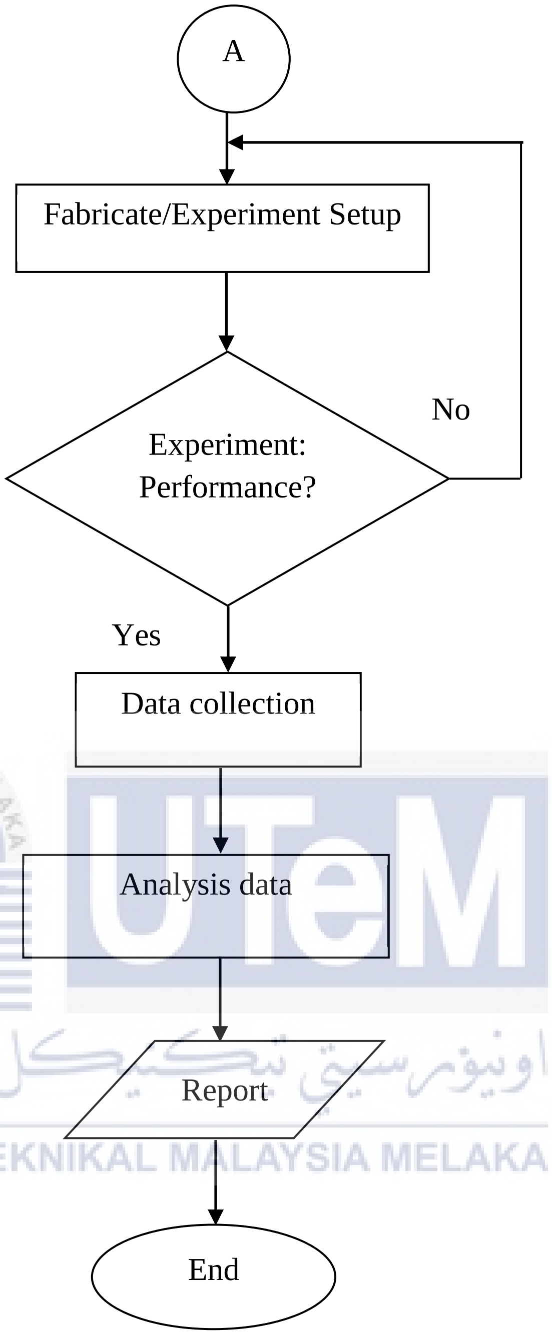

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Figure 3.1: Process of flow chart

Figure 3.1 shows the flowchart of the project. It is to make sure that the work has been done smoothly by following the systematic and the right path.

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3.3 Analysis Load of Vehicle

By using the details and features of a new Toyota Prius Prime 1.8 Standard Automatic Transmission (AT) 2018, the concept of loading vehicle system can be analyzed thoroughly. The Prius Prime is completed with a gasoline-electric plug-in hybrid drivetrain built around a naturally-aspirated 1.8-liter four-cylinder engine. It generates 95 horsepower at 5,200 RPM and the torque, T is 142.361 Nm at 3,600 RPM. The turning circle is 10.18032 m while its weight is 1530.874 kg. The electric part comes from a compact electric motor that source from a lithium-ion battery pack. Working together, the two power sources send 121 horsepower to the front wheels via a Continuously Variable Transmission (CVT). The force of a car can be obtained by vary Second Newton Law as equation 2.19:-

$$F = mg$$

$$F = 1530.874 \text{ x } 9.81$$

$$F = 15017.874 \text{ N}$$

Besides, the aerodynamic drag force can be calculated which expressed as:

$$F_W = 0.5\, \rho\, A_f\, C_D\, (\, V + V_W\,)^2$$

Where C_D is the aerodynamic drag coefficient can be obtained by referring to Table 2.2. The vehicle type is k-shaped (small breakaway section); therefore, the value for C_D is 0.23. Moreover, the frontal vehicle area, A_f can be found by multiplying length and width. As the length of the car is 4.387 meter and the width is 1.722 meter. Therefore, the frontal area, A_f is 7.554m^2. By assuming vehicle speed, V is 90 m/s, and the V_w is the velocity of drag force depends on shape of vehicle body.

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Assuming the car is on the flat, smooth ground and the need of wind force which to overcome rolling resistance of the wheels.

$$F\text{(rolling resistance)} = Cr\text{(coefficient of rolling resistance)}\ x\ m\text{ (mass of car)}\ x\ g\text{ (gravitational force)}$$

Therefore,

$$F_{rr} = 0.03 \text{ x } 1530.874 \text{ kg x } 9.8 \text{ m/s} = 450.536 \text{ N}$$

$$F\text{(wind)} = 0.5 \text{ x } \rho \text{ x } V^2 \text{ x } C_D \text{ x A}$$

Where ρ is the density of air,

$$F\text{(wind)} = 0.5 \text{ x } 1.2041\text{kg/m}^3 \text{ x } V^2 \text{ x } 0.23 \text{ x } 7.554\text{m}^2$$

$$\text{Force from wind, } F_W = \text{force require to move the car, } F_{rr}$$

Therefore,

$$450.536 = 1.046\ V^2$$

$$V_w = 20.75 \text{ m/s}$$

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So, the V_w is 20.75m/s.

Then, the aerodynamic drag can be calculated.

$$F_W = 0.5\ \rho\ A_f\ C_D\ (\ V + V_W\ )^2$$

$$F_W = 0.5 \text{ x } 1.2041 \text{ kg/m}^3 \text{ x } 7.554 \text{ m}^2 \text{ x } 0.23 \text{ x } 90 \text{ m/s x } 20.75 \text{ m/s}$$

$$F_W = 1953.44 \text{ N.}$$

There are four types of resistance which have been mentioned in the previous chapter. The resistances are related to each other and took part in several scenarios. There are four types of scenario which also known as cases. The first cases interpret that the car

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has a constant velocity on a level road which faces on rolling resistance, R_R while the second cases indicate that the car have a constant velocity on a gradient at up or down condition which experiences on aerodynamic resistance, R_A . Moreover, for case three, it is when the car is accelerating or decelerating on a gradient for up or down states, R_G and lastly, fourth case shows the car is in acceleration or deceleration on a level road which face on traction resistance, R_{trac} . Furthermore, all the analysis will be calculated to see the pattern of accumulated value based on both which are passenger condition and without passenger condition. This analysis to collect data of resistance force against both scenarios. The torque value will be calculated in the ideal case and the worst case based on the data from each scenario. The analysis of all scenarios which related will use this formula:-

$$R_{tot} = R_R + R_A \quad (3.1)$$

$$R_{tot} = R_R + R_A +/- R_G \quad (3.2)$$

$$R_{tot} = R_R + R_A +/- R_{trac} \quad (3.3)$$

$$R_{tot} = R_R + R_A +/- R_G +/- R_{trac} \quad (3.4)$$

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3.4 Schematic Diagram

A schematic diagram shows that the representation of the elements of a system using abstract, graphic symbols rather than realistic pictures. It will explain how the system will operate of hydro-pneumatic driveline propulsion for drive system based on the schematic diagram. There are three types of the schematic diagram which is a pictorial schematic diagram, functional schematic diagram, and fluid schematic diagram.

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3.4.1 Pictorial Schematics Diagram

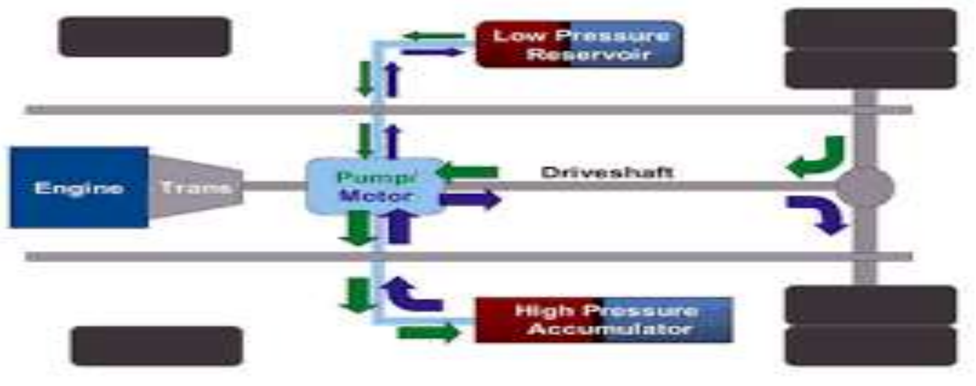

Figure 3.2: Hydro-pneumatics driveline propulsion system in vehicle.

Figure 3.2 shows a simplified diagram which shows the various components of the hydro-pneumatic driveline propulsion system. It shows how the component is connected. In this system, there is pump/motor, engine transmission, and driveshaft at the rear of the car. Besides that, there are two tanks used in this system which is low-pressure accumulator (tank/reservoir) and high-pressure accumulator (storage).

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3.4.2 Functional Schematics Diagram

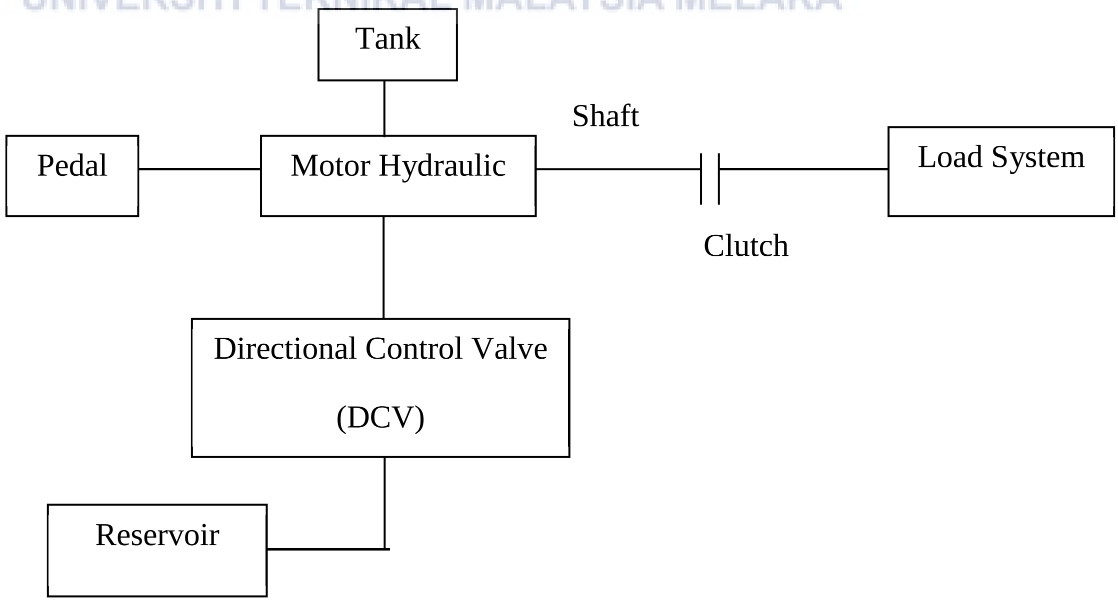

Figure 3.3: Functional of driveline propulsion system

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Figure 3.3 shows a functional schematic diagram shows how the system will be operated and function which the flow of a drive system which is starting with pedal and end with the load system. The motor hydraulic will move and rotates the shaft when the pedal is pressed. Hydraulic oil in the reservoir is at high-pressure state while in the tank is at low-pressure state. In details, hydraulic oil which stored in the reservoir (high pressure) will be in a compressed condition of the directional control valve (DCV) while waiting for DCV to be opened. When the pedal is pressed, DCV will open straight based on the number of forces applied to the pedal. Hydraulic oil will flow to motor hydraulic, and motor hydraulic will operate.

3.4.3 Fluid Schematics Diagram

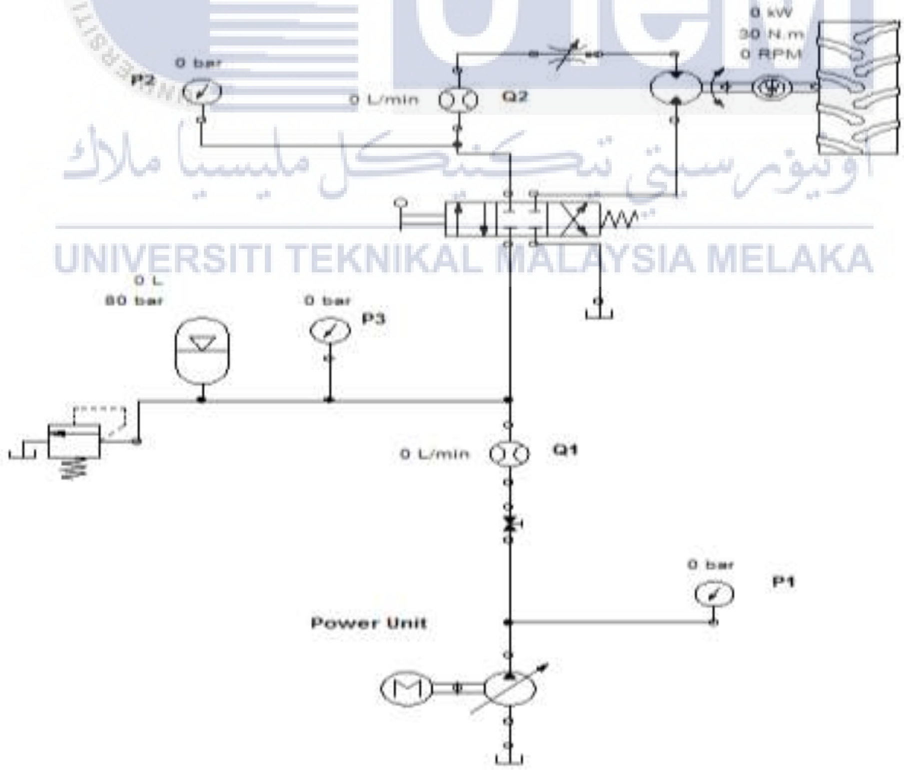

Figure 3.4: Diagram propulsion drive system

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Figure 3.4 shows that the fluid schematics diagram of the propulsion drive system. This diagram consists of several components which are stored, fluid control valve (FCV), direct control valve (DCV), pump, hydraulic motor (M), pressure gauge; pressure relief valve (PRV) and lastly reservoir. The hydraulic oil will evacuate directly to the tank (low pressure) and the amount of hydraulic oil received will be as same as the amount of hydraulic oil transferred from the reservoir. The force applied to the pump influenced the load system.

3.4.4 Test Rig Design

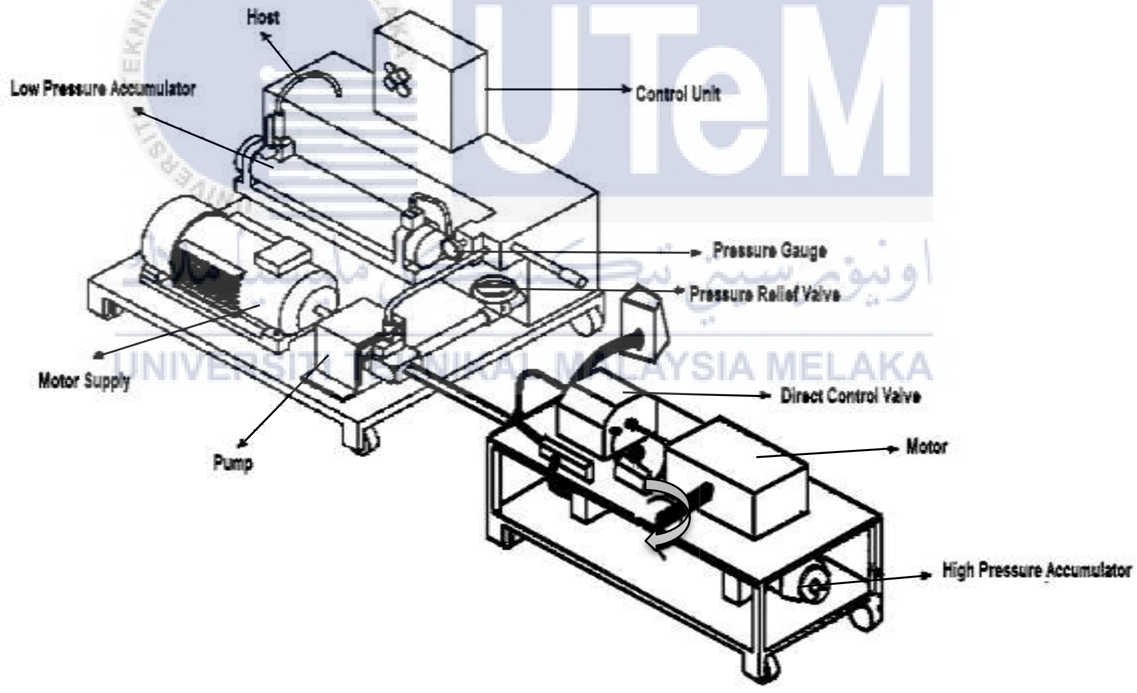

Figure 3.5: Isometric view of test rig

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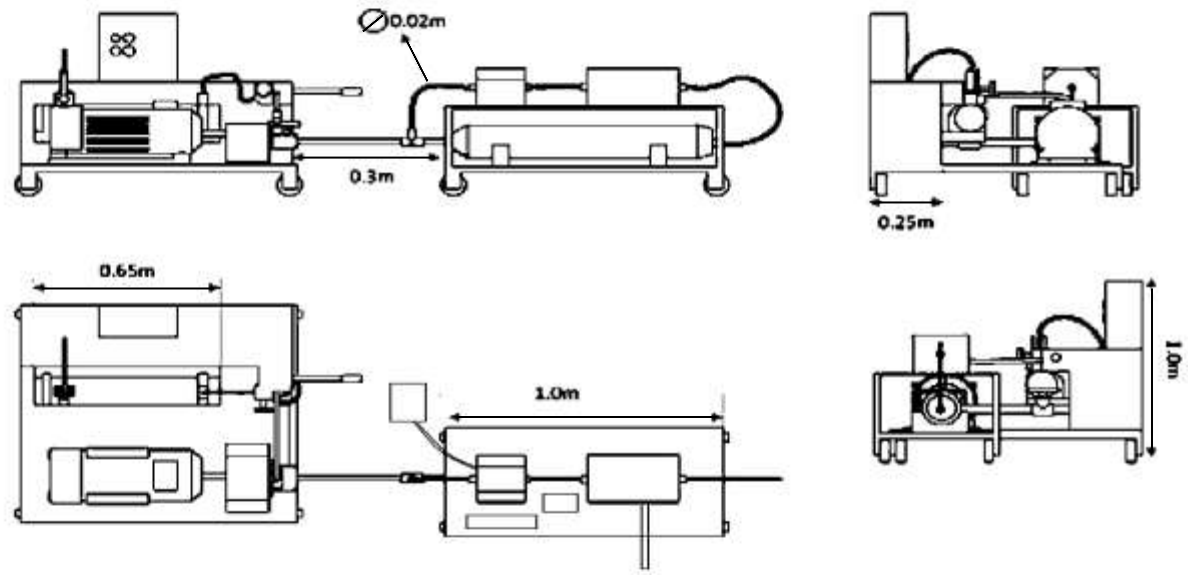

Figure 3.6: Orthographic view of test rig

Figure 3.5 shows that the isometric view of the full test rig in the 3D diagram. Meanwhile, Figure 3.6 shows that the orthographic (top, front, side) view of the test rig. There are divided into two parts, which are power unit and test rig. The power unit is a component that consists of a pump, motor, pressure gauge, reservoir, and a control unit. While test rig consists of a high-pressure accumulator, fluid control valve and direct control valve.

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3.5 Model / Equation

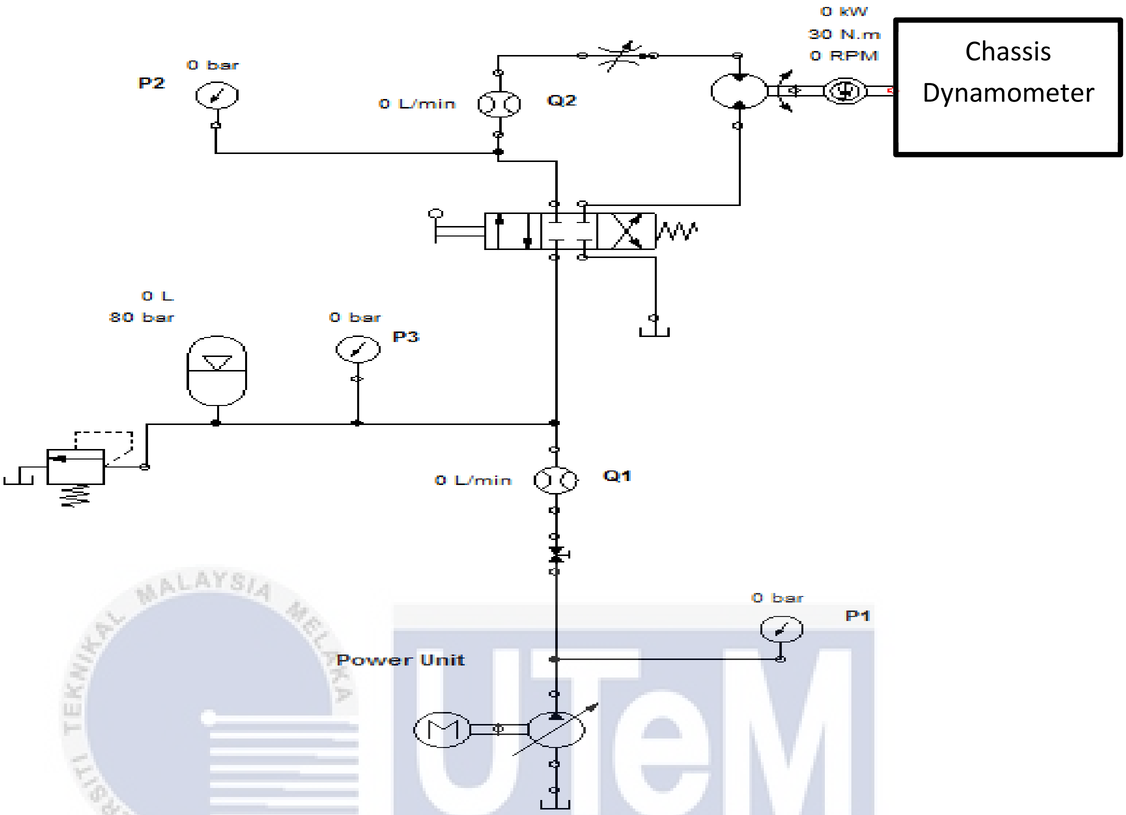

Figure 3.7: Schematics diagram

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Figure 3.7 shows that the schematic diagram that will be used to simulate in the experiment. The equation that related to this schematic diagram is fluid power, the torque required by the pump, shaft power and lastly energy in the accumulator. The details of the equation are listed on equation 3.5.

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The fluid power required for the system can be expressed as,

$$P_P = Q_{out} \cdot \Delta p \cdot \eta_{overall} \tag{3.5}$$

Where P_P = Pump power (Watt)

Q_{out} = Pump output flow rate (m^3/s)

Δp = Pressure different through the pump

$\eta_{overall}$ = Overall efficiency

Power also can be expressed as,

$$P = \frac{2\pi NT}{60} \tag{3.6}$$

Where P = Power (Watt)

N = No of revolution per minute (rpm)

T = Torque (Nm)

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Meanwhile, to find the torque required by the pump, the equation can be expressed as

$$T = \frac{C \times \Delta p}{\eta_M} \tag{3.7}$$

Where T = Torque (Nm)

C = Displacement ($\mathrm{m}^3/\mathrm{rad}$)

Δp = Pressure different through the pump

η_M = Mechanical efficiency

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Lastly, the shaft power can be calculated through,

$$P_S = T_A \cdot \omega \cdot \eta_{overall} \tag{3.8}$$

Where P_S = Shaft power (Watt)

T_A = Torque (Nm)

ω = (rad/s)

$\eta_{overall}$ = Overall efficiency

3.6 Simulation Parameter

Simulation parameter will be taken into consideration to obtain the correct result of the experiment. The two cases below shows each parameter type whether it is the dependent variable, independent variable, constant variable and the control variable of the system is stated in Table 3.1 and Table 3.2.

Table 3.1: Case 1 the propulsion with real time

No.	Parameter	Parameter type
1.	Volume effectiveness	Dependent parameter
2.	Flow rate	Dependent parameter
3.	Time taken	Independent parameter

Table 3.2: Case 2 the effect of pressure with fix load 30Nm

No.	Parameter	Parameter type
1.	Power	Dependent parameter
2.	Pump output flow rate	Dependent parameter
3.	Load	Constant parameter
4.	Pressure	Independent parameter

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3.7 Simulation

Simulation of hydro-pneumatic driveline propulsion for load system was run on Automation Studio software. The simulation achieved the expected results. It is because Automation Studio implement for design, functional simulation of complex automation, preparation, and documentation. The software contains hydraulic, pneumatic and electrical operative devices as well as a command part diagram. It has also provided technical and commercial data for simulation. The result shows that the pre-charge pressure affected the fluid power parameters which are powerful, effective energy storage capacity, and variation of the load system.

Furthermore, Automation Studio has the benefit about circuit design, functional simulation, fluid power component sizing, system design, validation, and virtual simulation. The simulation has been run by using a variable displacement pump and fixed displacement pump. For the first run, simulation has been run with a pressure relief valve (PRV) for both pumps. For the second run, the simulation was run without a pressure relief valve (PRV). The function of pressure relief valve acts as a safety valve used to control or limit pressure in the system. The result was then compared.

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3.7.1 Specification for The System Equipment

For this system, the loads become an independent variable, while power, pressure elevation, and radial speed become dependent variable. Meanwhile, a control variable for this system was pre-charge pressure, and the constant variable was volume displacement. As for this research, the specification for the equipment that used in the system was stated in Table 3.3, and the constant variable was presented in Table 3.4.

Table 3.3 Data specification for the system‟s equipment

No.	**Equipment**	**Specification**	
1.	Flow control valve	Operating Pressure	345 bars
		Maximum temperature	100℃
		Minimum temperature	-20℃
		Flow rate	364 l/min
2.	Safety block	Operating pressure	330 bars
		Maximum temperature	80℃
		Minimum temperature	-15℃
3.	Pressure relief valve	Size	Port PT: 3/4”
		Pressure range	70 – 250 kg/cm^2
		Maximum flow	180 l/min
4.	Vane pump	Flow rate	8.0 cc/rev
		Drive speed	Maximum: 1800 rpm Minimum: 750 rpm
		Maximum pressure	210 kg/cm^2
		Displacement	8 – 31 ml/rev

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No.	Equipment	Specification	
5.	Accumulator	Operating pressure	330 bars
		Maximum flow	900 l/min
		Maximum temperature	80°C
		Minimum temperature	-15°C
		Charging gas	Nitrogen
		Gas filling pressure	80 bar
		Size	30 liters
6.	Directional control valve 2/2 ways	Operating pressure	Port A, B, P: 315 bars Port T: 160 bars
		Maximum flow	60 l/min
		Maximum temperature	80°C
		Minimum temperature	-30°C
		Viscosity range	2.8 – 500 mm^2/s
7.	Hose	Nominal size	8 mm, 5/6”
		Operating pressure	215 bars
		Maximum temperature	100°C
		Minimum temperature	-40°C
8.	Motor	Voltage	415 V
		Current	20.5 A
		RPM	1460 rpm
		Power	11 kW
		Frequency	50 Hz
		Efficiency	89%
		Power factor	0.84
		Maximum temperature	155°C

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Table 3.4 Simulation parameter

Motor rotational speed	1460 RPM	**Initial liquid volume**	0 liter
Pump thermal efficiency	89%	**Accumulator int. diameter**	225 mm
Pump heat transfer coeff.	10 W/m2K	**Type of process**	Isothermal
Hydraulic oil	Hyd. AW-32	**Gas type**	Nitrogen
Ambient temperature	25 ^{o}C	**Gas temperature**	25 ^{o}C
Cracking pressure	300 bars	**Hydraulic line**	Steel
Port 1 (C_v)	12	**Line type**	NPS ¼-DN8

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3.8 Calibration

The experiment were runned by lab scale on the test rig as a process of calibration. The main equipment for analyzing the test result will be utilized through Hydrotechnik Instrument as in Figure 3.8. The output from this equipment were temperature, pressure, flowrate and speed (RPM) which then analyzed to obtain the power used by the accumulator that mounted on the test rig.

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Figure 3.8: Calibration of hydrotechnik instrument

The system calibration was critical to ensure system accuracy as in Figure 3.9. The calibration method was to measure the known parameter, bias between the display and actual value will meet the accuracy requirements through various regulation means.

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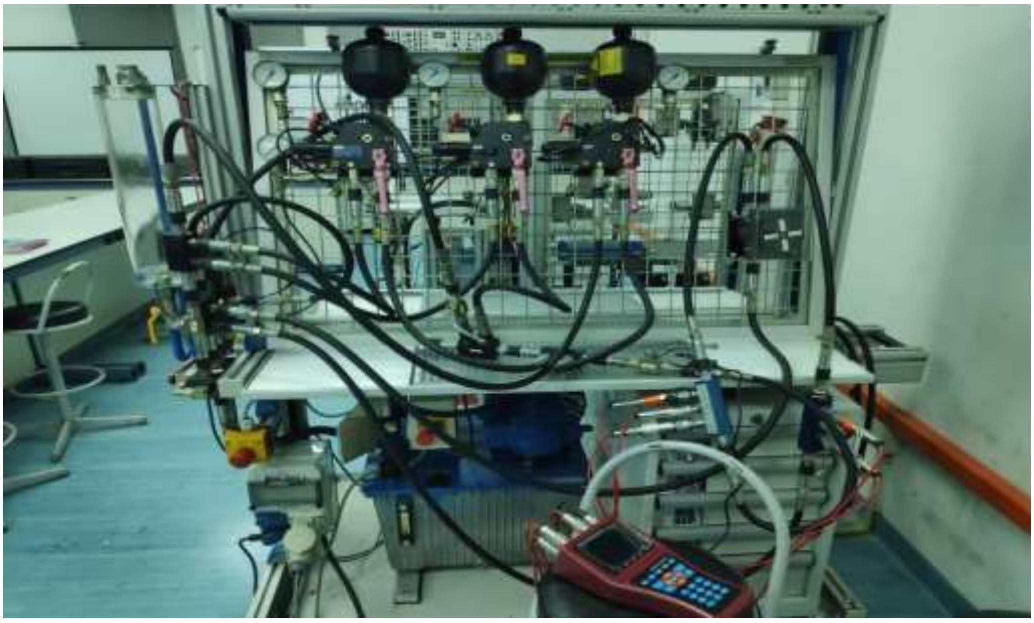

Figure 3.9: System calibration in lab scale

This paper choose calibration pressure as the calibration method, it can obtained higher calibration accuracy than One-Point Calibration. The selection of the calibration points was according to size of the drum surface traction force range, and the calibration pressure falls on the best accuracy pressure range of the force sensor. Thus, the linear equation was obtained after the data processing.

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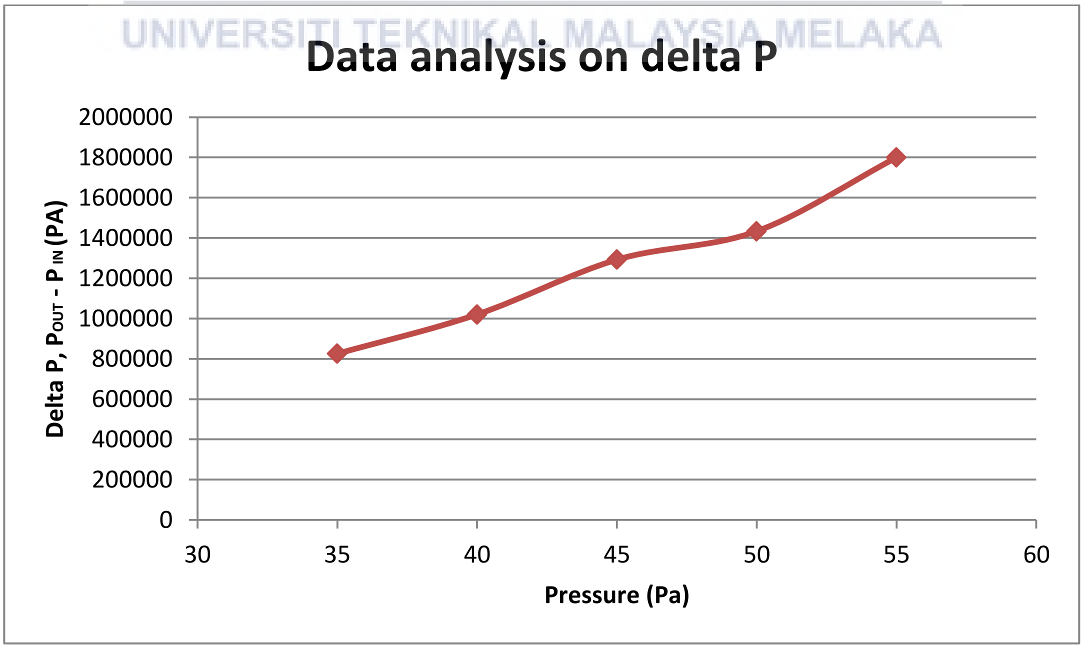

Figure 3.10: Pressure sensor calibration data analysis on delta P (Pa)

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The calibration curve showed in Figure 3.10 was good linearity and repeatability of the pressure sensor which calibration method was successful and it has been proceed to get data from experiment.

3.9 Fabrication

Fabrication of the design has been constructed as shows in Figure 3.11.

Figure 3.11: Design of static load system for hydro-pneumatic driveline propulsion test

The fabrication processes for this test rig were cutting, joining, finishing and assembly which involved of welding, machining and drilling. The type of welding used in this fabrication process was Arc and Metal Inert Gas (MIG).

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This process was used for making a permanent connection as Figure 3.12. Other than that, another process that involve was machining. In this fabrication process the machining was used to mill, lathe and drill. Lastly, painting process was used to obtain the nice in test rig before conducted the experiment as showed in Figure 3.13.

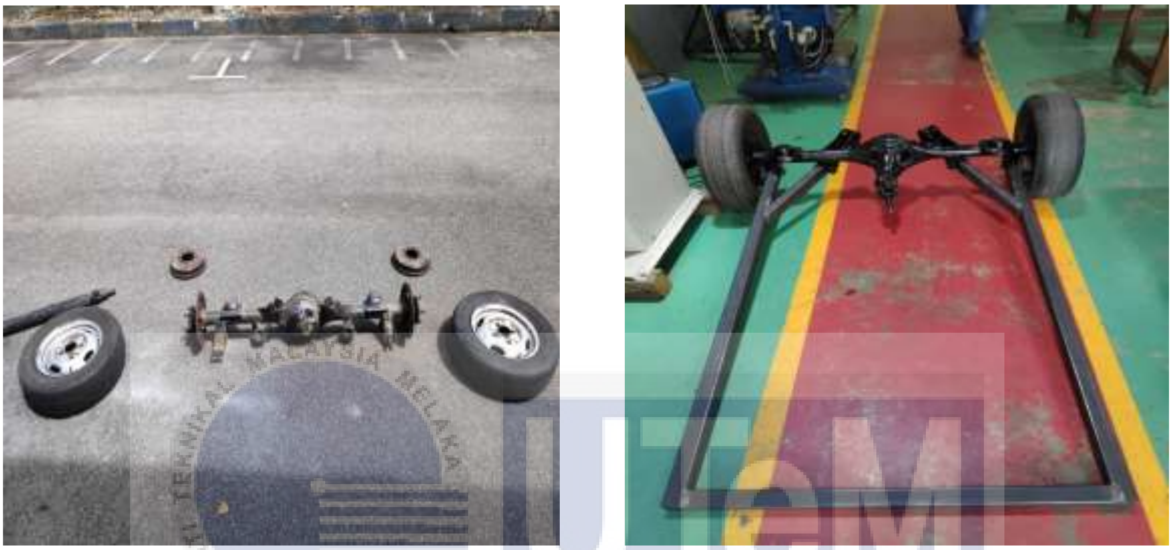

Figure 3.12: Before and after making permanent joining.

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Figure 3.13: Before and after painting on rig.

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3.10 Test Rig (Experimental – Chassis Dynamometer)

Vehicle performance depends on many factors such as vehicle velocity, rpm, torque, and power, load system, horsepower and operation condition. Such load system decides the relation between vehicle velocity and horsepower. Also, the performance factors reflect the recent advance of the vehicle technology and the development of engine related to fuel consumption, which also manifests the direction of vehicle development.

A chassis dynamometer is a device that can simulate the resistance imposed to the wheel of a vehicle according to different driving cycles depends on load exerted show in Figure 3.14. During the testing, the vehicle was tied and running on loading controllable rollers keeping a stationary state. According to the predefined time-velocity curve shown on a monitor, the accumulator operated by different pressure to the axle to match the curve in different driving cycles. For this experiment, load system was exerted from free load (0nm) to 10 nm which different pressure from 100 bar to 200 bar as shown in Figure 3.15.

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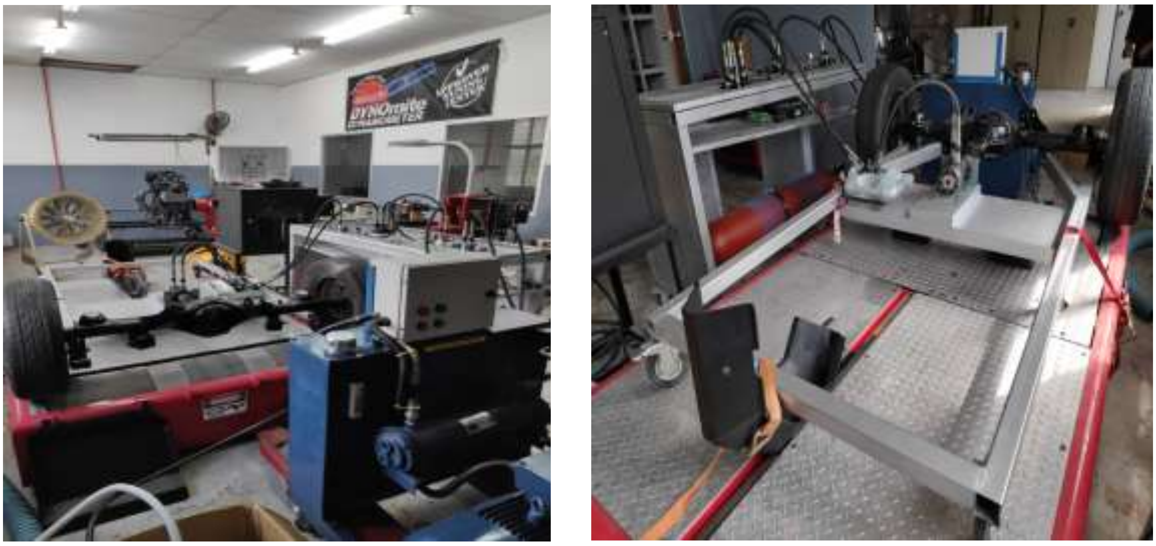

Figure 3.14: Test rig by chassis dynamometer for load system by different pressure

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Figure 3.15: Power unit of hydro-pneumatic control the different pressure

The purpose of the chassis dynamometer testing for the static load system for hydro-pneumatic driveline propulsion lies in three aspects which were testing the performance of a specific load exerted, assessing horsepower by different pressure and analysing the different performance between free load and highest load, respectively. This paper aims to provide different testing methods for load system on vehicle by hydro-pneumatic driveline with the help of the chassis dynamometer listing the advantage and disadvantage of such a measurement.

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3.11 Operating Procedure (Chassis Dynamometer – Load by Eddy Current)

3.11.1 How To Configure The Load (Nm)

1 Flip the switch on the Eddy-Current controller to computer mode

2 Click the "Electronic Dynomite Control"

3 Determine "Rate, Gain and Drift" to synchronize/apply according to engine tested. The detail info… click "Help" on top of console panel and search " Electronics-Configure DYNOmite Controls" and see "Determining Rate, Gain and Drift)

4 Push down the button that says "Hold % Position" and click "OK"

5 Click the "Electronic Dynomite Control"

6 Push down the button that says " Hold Engine RPM" and click "OK"

7 Now with a run open and push the "Hold" button to green on the console

3.11.2 How To Apply The Load (Nm)

1 Click „Console" on top of screen and select „ Edit Console Setup"

2 Click „ Smart Record"

3 unlike „ Enable Smart Record"

4 Click „Electronic" and select „ Configure DYNOmite Controls"

5 Push down the button that says "Hold % Position" and click "OK"

6 Click the "Electronic Dynomite Control"

7 Push down the button that says " Hold Engine RPM" and click "OK"

8 Closed the main console and open „New Run" or press F12

9 Open main console of DYNO-MAX Software or press F11

10 Control RED button as control load setting as shown in Figure 3.16

11 Start the engine (Hydro-pneumatic motor with axle – experimental)

12 Increase the throttle up to gray needle

13 After throttle is stable, increase the throttle for full opened.

14 PRESS „AUTO TEST RUN"

15 Waiting the test complete automatically.

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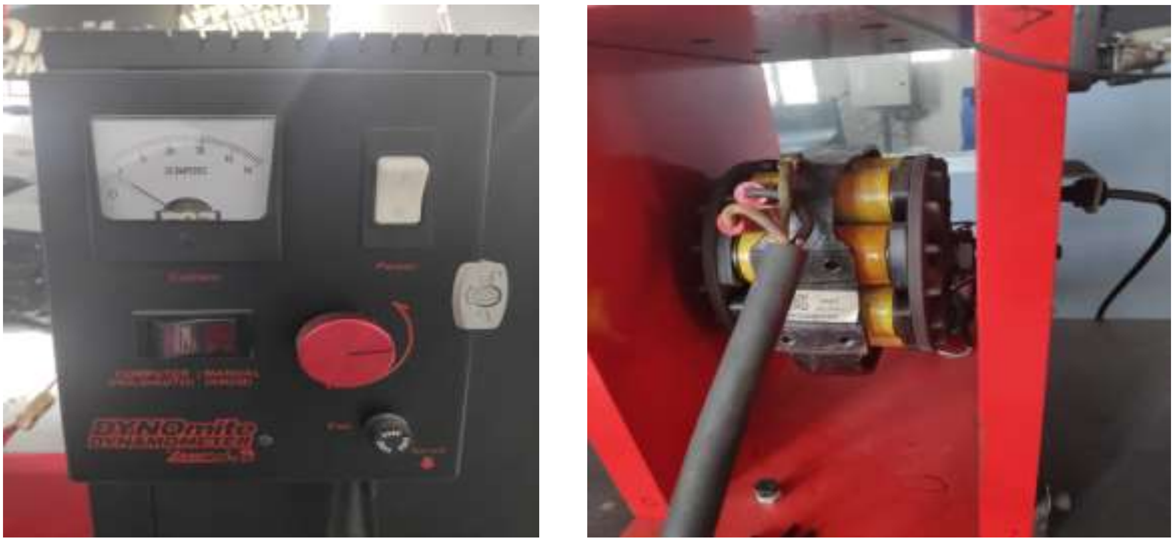

Figure 3.16: Control load setting and eddy current as a load system

3.11.3 How To Switch “ Off ” The System

1. Stop the engine using the “Emergency Stop” on Pro Console
2. Flip the switch to “Manual mode” for Eddy-Current Controller
3. Switch “OFF” Eddy Current Controller
4. Switch “OFF” Pro Console
5. Switch “OFF” power supply for Eddy-Current controller
6. Switch “OFF” power supply for water pump
7. Switch “OFF” Engine
8. Closed all valve for water supply
9. Disconnect the battery terminal

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Data and Result by Chassis Dynamometer

Table 4.1, Table 4.2, Table 4.3, Table 4.4 and Table 4.5 show the information needed for the analysis. The data and result obtained will be tabulated. It shows the information regarding the propulsion system which will be investigated precisely in a different condition such as at pressure constant, load constant and time constant.

Table 4.1: Chassis dynamometer data at load (2 Nm)

Pressure, Bar	Running Time (Second)	RPM	Torque, Nm	Power (kW)	Speed (km/h)
100	14.62	273	13.9	0.397	18.52578
120	30.335	325	14.1	0.478	22.0545
140	60.861	317	14.2	0.47	21.51162
160	62.478	354	17.3	0.639	24.02244
180	64.774	381	16.8	0.669	25.85466
200	67.777	408	17.5	0.747	27.68688

Table 4.2: Chassis dynamometer data at load (4 Nm)

Pressure, Bar	Running Time (Second)	RPM	Torque, Nm	Power (kW)	Speed (km/h)
100	12.917	261	17.4	0.476	17.71146
120	33.048	302	18.8	0.595	20.49372
140	59.504	287	20.1	0.604	19.47582
160	63.994	340	22	0.784	23.0724
180	70.39	365	23.3	0.89	24.7689
200	71.286	391	24.8	1.014	26.53326

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Table 4.3: Chassis dynamometer data at load (6 Nm)

Pressure, Bar	Running Time (Second)	RPM	Torque, Nm	Power (kW)	Speed (km/h)
100	11.116	257	17.3	0.465	17.44002
120	30.976	267	20.4	0.571	18.11862
140	59.68	277	21.4	0.621	18.79722
160	65.489	331	25.1	0.87	22.46166
180	73.909	352	26.2	0.965	23.88672
200	75.111	382	27.3	1.11	25.92252

Table 4.4: Chassis dynamometer data at load (8 Nm)

Pressure, Bar	Running Time (Second)	RPM	Torque, Nm	Power (kW)	Speed (km/h)
100	15.616	254	21.1	0.56	17.23644
120	35.961	271	23	0.652	18.39006
140	61.501	267	22.4	0.641	18.11862
160	66.586	327	27.2	0.929	22.19022
180	75.641	345	27.8	1.003	23.4117
200	82.117	347.2	28.1	1.153	23.560992

Table 4.5: Chassis dynamometer data at load (10 Nm)

Pressure, Bar	Running Time (Second)	RPM	Torque, Nm	Power (kW)	Speed (km/h)
100	12.112	250	22	0.577	16.965
120	33.238	262	24.6	0.676	17.77932
140	60.686	257	23.8	0.645	17.44002
160	67.398	324	27.5	0.984	21.98664
180	77.803	329	28.1	1.006	22.32594
200	88.664	332.2	28.5	1.2	22.543092

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4.2 Condition of Experimental Graph

4.2.1 Maximum Load and Maximum Pressure

Figure 4.1 shows the relationship between torque and RPM against run time produced by chassis dynamometer of DYNOmite. At the beginning of the peak at 329RPM, the graph shows that the pulse occurred due to the pressure. Pressure pulsations were the fluctuations of the basic pressure/head being developed by the pump. The physical properties of hydraulic fluid were very easy to transmit shock and vibration through the pipes, tubes and hoses of the system. Some of pump for example, creates pulses of pressure when the pistons or gears reach their outlet port. These pulsations can sometimes be very severe and cause damage to the piping or other components in a hydraulic system. The pulse of pressure usually happens between 0 to 0.901 s.

Besides, after 1 s, the graph showed the phase of stable power which starting point at torque, 25.8 Nm and 323 RPM. In this phase, an ideal power of pressure in accumulator would be able to supply an infinite amount of liquid without allowing supply pressure to drop. Keeping the power of pressure constant is important because it keeps the gain of the horsepower of the car constant. The horsepower of the car gain determines how fast the hydro-pneumatic push the oil pressure in accumulator when a control valve fully opens. The range of stable power occurs on this condition around 88.664 s.

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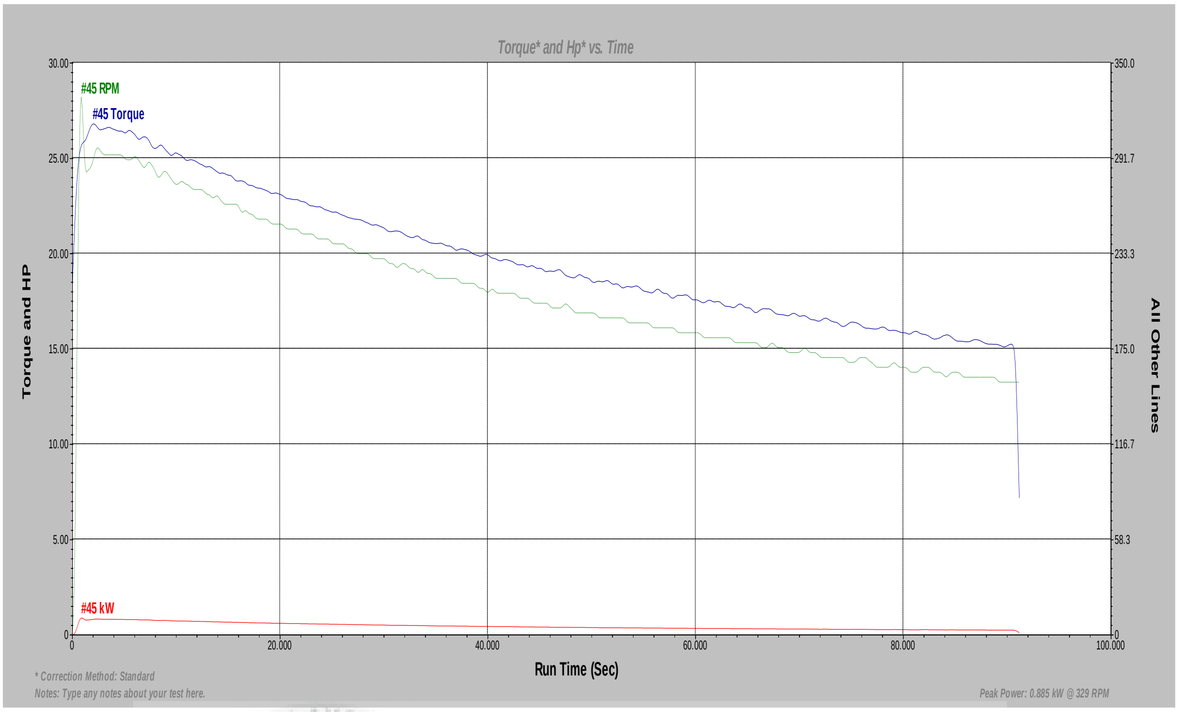

Figure 4.1: Torque and RPM vs. Run Time (Sec) for 200 bar with load 10 Nm

This condition was selected because the vehicles required high force to move. This graph shows the behaviour of accumulator by hydro-pneumatic which the maximum pressure by 200 bar will help to move the vehicle, at the same time, reduce the fuel consumption. The condition was exerted load by 10 Nm which equal 1.0192 kg on the vehicle. The behaviour of this condition stated the lower of torque, the RPM will high.

4.2.2 Maximum Load and Minimum Pressure

Figure 4.2 shows that the graph torque and RPM against run time. For this graph, it has three (3) phases. The first phase is pulse because of pressure, which starting point at 0 s to 2.602 s. The phase pulse for this condition is longer than previous test at Figure 4.1 because it has minimum pressure with high load, 10 Nm. With the lower pressure, it needs a few second to get a stable power based on load exerted.

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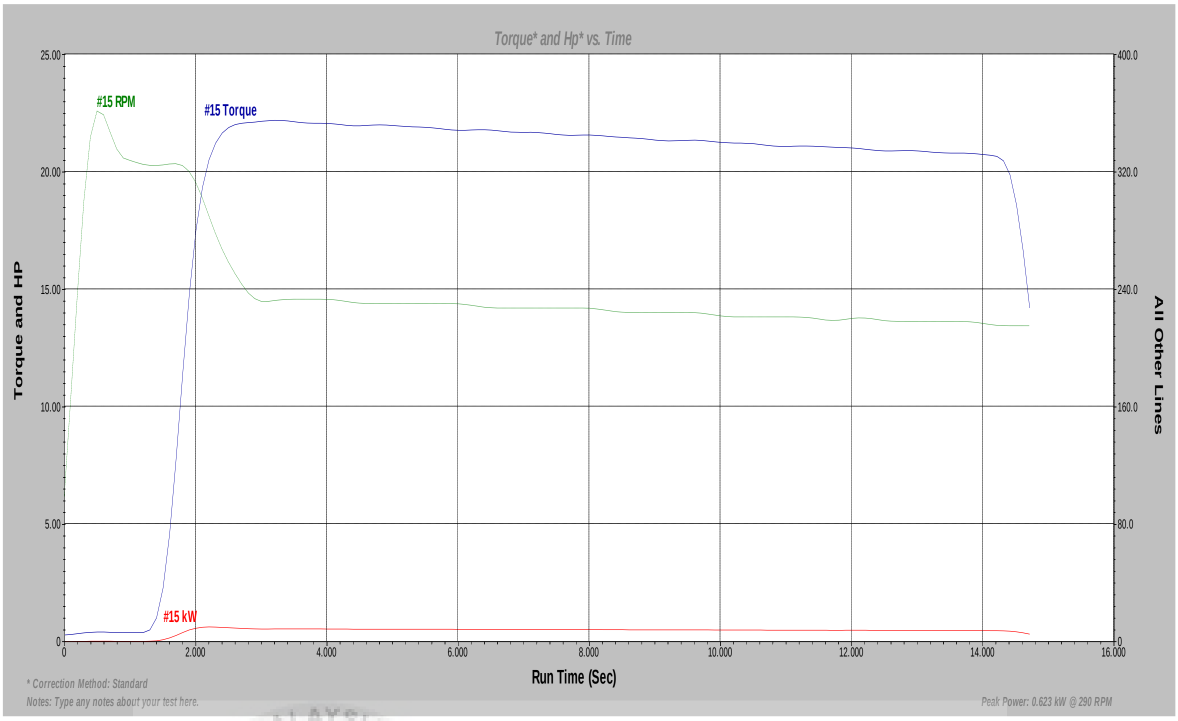

Figure 4.2: Torque and RPM vs. Run Time (Sec) for 100 bar with load 10 Nm

After 2.71 s at torque, 243 Nm, the power is stable as an ideal power of pressure in tank (accumulator) which would be able to provide higher pressure of hydro-pneumatic to move the vehicle at the starting point. This behaviour called as phase two (2). The range of second phase operates on this condition around 11.504 s. After 14.4 s, it called as third phase which will be the inertia of wheel. The inertia was occurred because of the power supply by accumulator before. Besides, the condition of this graph stated the lower of torque; it will be high of RPM. This condition might be happen if the vehicle has a lower pressure on their accumulator (tank) when their apply hybrid of hydro-pneumatic.

4.2.3 Minimum Load and Maximum Pressure

Figure 4.3 shows the behaviour between torque and RPM against run time, for load 2 Nm with the maximum pressure, 200 bar. The first phase behaviour at range 0 s to 3.203 s, it shows the pulse because of pressure. The peak of pulse is 567 RPM at torque 0.7 Nm. The transmission hydro-pneumatics based on pressure will influence the increase or

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decrease pulse effect. These pulse will effect on vehicle when it have high pulse of pressure, the vehicle will move faster on starting point then the lower pressure such as Figure 4.2.

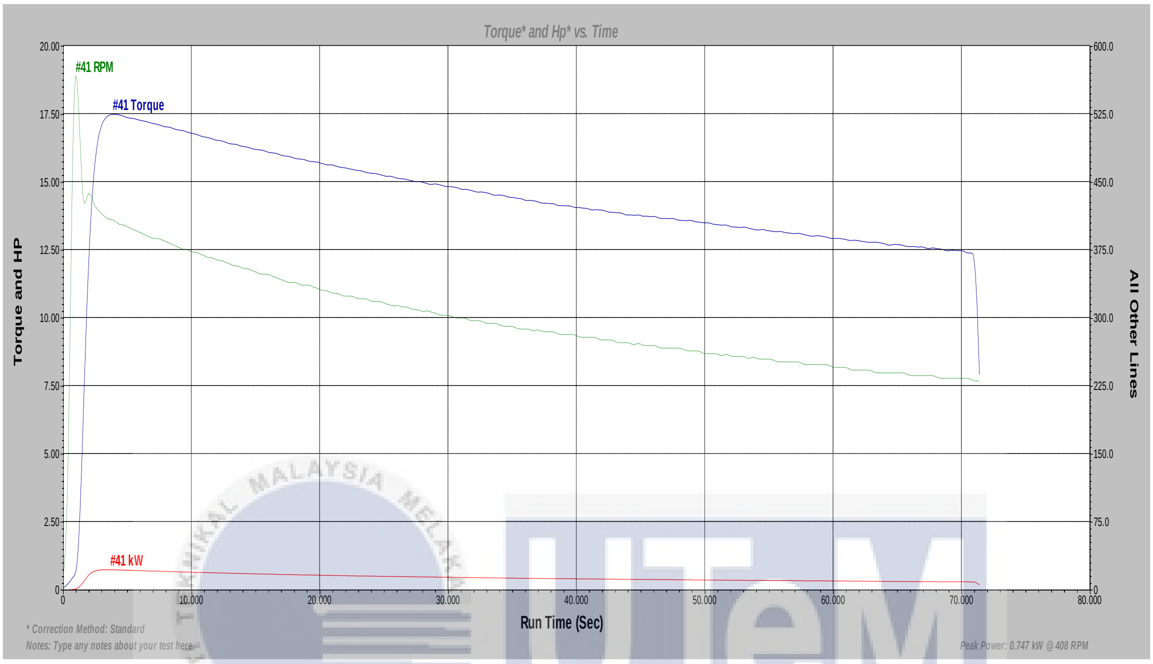

Figure 4.3: Torque and HP vs. Run Time (Sec) for 200 bar with load 2 Nm

Next, after 3.5 s the graph behaviour was in second phase which means in stable power. Pressure changes occur in a hydraulic system when the liquid is subjected to rising or falling temperatures. Also, there may be pressure drop due to leakage of hydraulic fluid. An accumulator compensates for such pressure changes by delivering or receiving a small amount of hydraulic fluid. If the vehicle should fail or be stopped cause of fuel, the accumulator would act as an auxiliary power source, maintaining pressure in the system. These phase stop until 70.781 s which torque at 12.4 Nm at 231 RPM. These were very good condition because the hybrid vehicle will fully access the power of accumulator which supply by hydro-pneumatic pressure with small load 2 Nm.

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4.2.4 Minimum Load and Minimum Pressure

Figure 4.4 shows the pattern of graph run times with minimum load and pressure. At the beginning, the peak at 330 RPM, the pulse happened because of pressure at run times between 0 s to 0.501 s. The pressure of hydraulic system on an accumulator generates the required power to be used in the vehicle. The pressure deliver as a power in a hose flow and commonly need a high pressure capability can produce motion of the vehicle. Hydro-pneumatic accumulator incorporates a gas in conjunction with a hydraulic fluid. The fluid has little dynamic power-storage qualities which typical hydraulic fluids can reduce in volume about 12% under pressure of 200 bar. This relative incompressibility makes them ideal for power transmission, providing quick response to power demand.

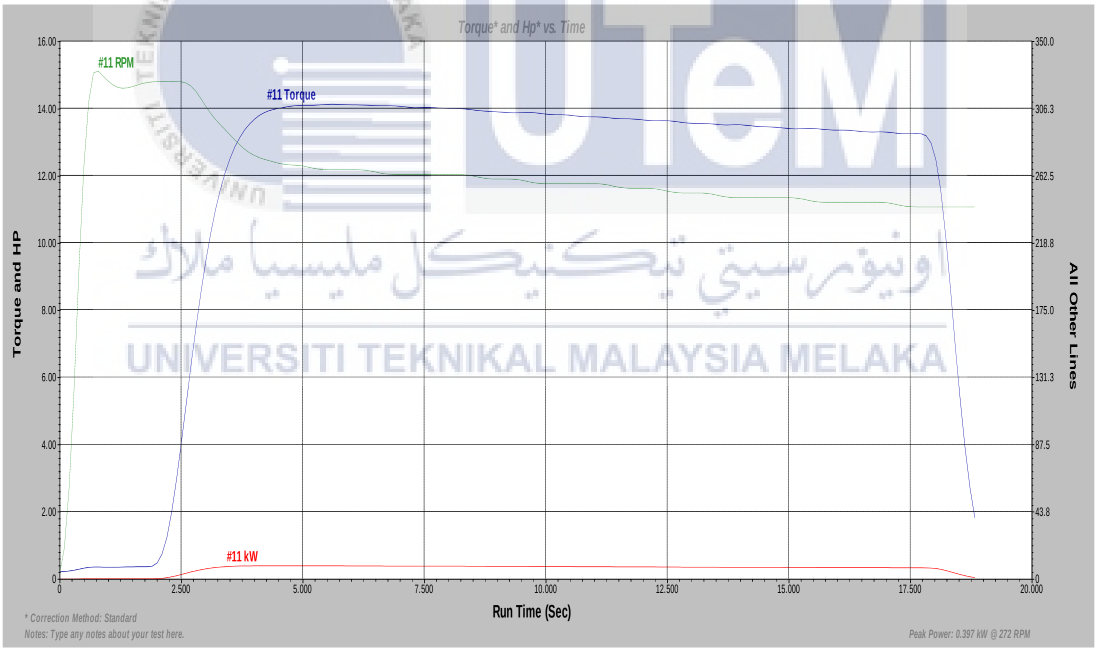

Figure 4.4: Torque and HP vs. Run Time (Sec) for 100 bar with load 2 Nm

For the second phase around 0.601 s to 17.823 s, the behaviour of the graph shows constant of RPM and torque. The highest torque is 13.3 Nm at 245 RPM, the stable of power was reflected by pressure. The highest the pressure, the power to stable will be

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faster. An accumulator also depends on precharge. For this project, the precharge of accumulator is 80 bar. Correct precharge involves accurately filling an accumulator gas side with a dry inert gas, such as nitrogen, while no hydraulic fluid is in the fluid side.

Accumulator charging then begins when hydraulic fluid was admitted into the fluid side, and occurred only at a pressure greater than the precharge pressure. This phase will measure time required for the power of accumulator to support the vehicle to move from starting point. This hybrid concept will help to reduce the fuel consumption. After 18.023 s, the torque was decreased because there was no more pressure power from accumulator, just the inertia of wheel which power supply before. For this condition, still supports the vehicle to move while the load also in minimum around 2 Nm.

4.3 Effect of Accumulator Pressure Different by Running Time

The effect of accumulator pressure to the discharge time is shown in Figure 4.5. The longer the discharge time is better because more work will be done. The starting is almost similar because the pressure has just surpassed the precharged pressure at 80 bar. At pressure 100 bar until 140 bar, the pattern of graph is not significant, because the relation between the patterns is very closed which at 100 bar the maximum running time 15.616 s and the lower running time is 11.116 s. The different running time is 4.5 s. Next, At 160 bar, the graph start shows the pattern which the running time at load 10Nm is highest then others load. At 200 bar, the behavior of graph show obviously which the maximum running time is 88.664 s at 10 Nm and the minimum is 67.777 s at 2 Nm.

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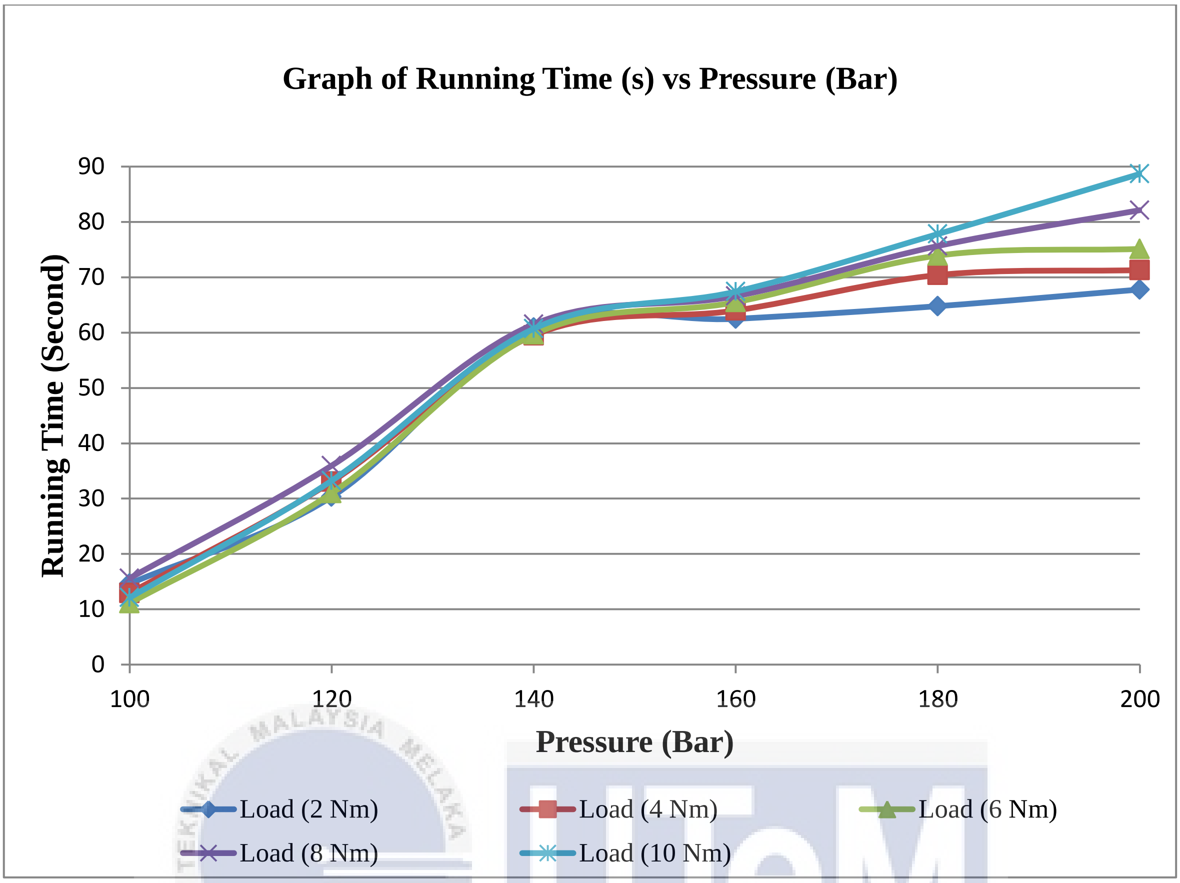

Figure 4.5: Effect of accumulator pressure different and running time

Therefore, the volume flow rate of the accumulator is necessary to be controlled. Higher volume flow rate results in power increase but lower in discharging time. It is vice versa to the lower volume flow rate. It shows that the higher the accumulator pressure, the longer running time to support vehicle move. Also, the higher the load exerted on vehicle, the longer running time to finish the pressure on the accumulator. A proper selection of accumulator‟s volume flow rate is crucial and it can be controlled by adopting flow control valve.

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4.4 Effect of Pressure Changes to The Rotational Speed (RPM)

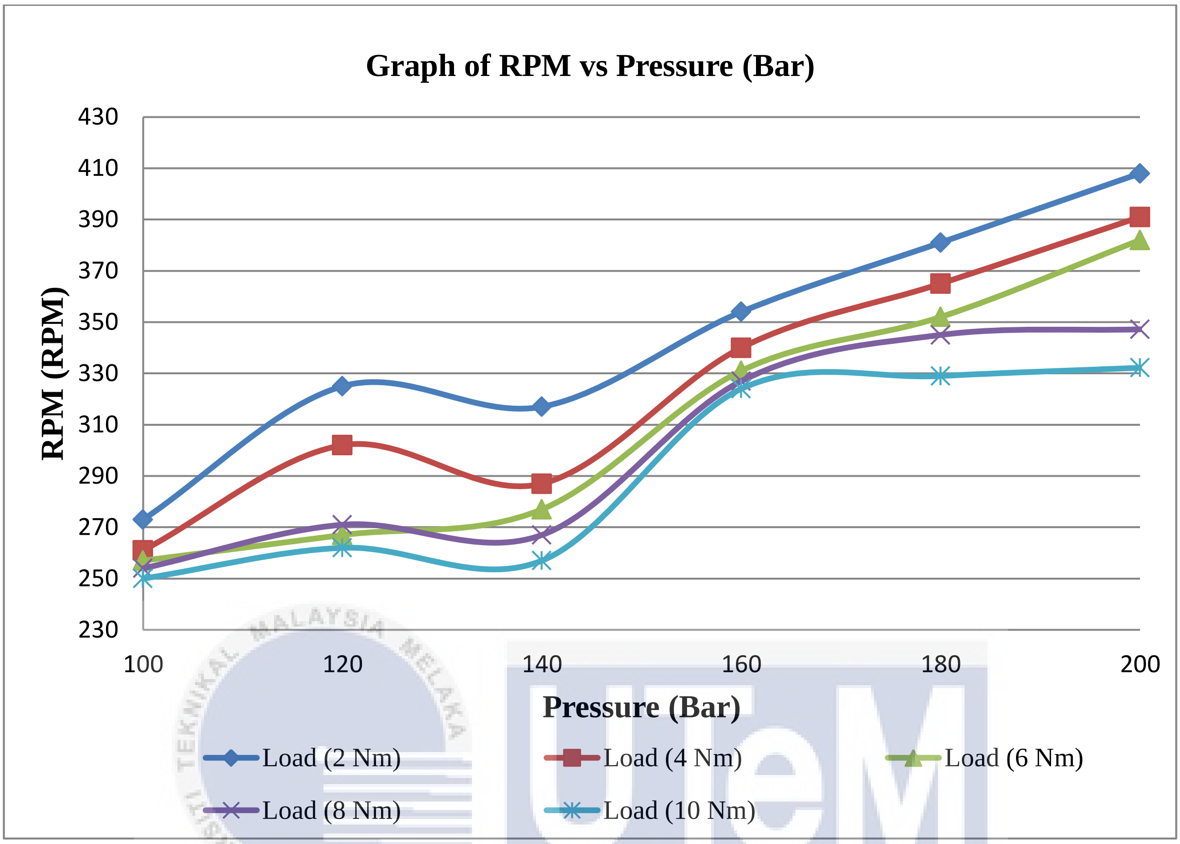

Figure 4.6: Effect of pressure changes to the vehicle speed

The effect of pressure on the rotational speed was illustrated in Figure 4.6. An accumulator pressure was setting to produce RPM from 250 to 408 which based on the exerted load by different pressure. The vehicle speed started by slight acceleration at 100 to 120 bar. The pattern at 120 bar to 140 bar shows decrease of speed but not too obvious. The acceleration increased sharply from 140 until 200 bar which the maximum of acceleration is 408 at load 2 Nm and the minimum of RPM is 332.2 at load 10 Nm. At 200 bar, the different of acceleration by exerted load between 2 Nm and 10 Nm is 78.8 RPM. Therefore, the higher the accumulator pressure, the higher the acceleration will produce. Also, the lower the load exerted on vehicle, the higher the acceleration produced depends on pressure.

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4.5 Effect of Pressure Changes to The Torque

The effects of torque with respect to the pressure change for accumulator was shown in Figure 4.7. The starting torque was high, and it is very usable to be applied in vehicle application. At 100 bar, the higher torque is 22 Nm at load 10 Nm and the minimum torque is 13.9 Nm at load 2 Nm. The different torque at starting point is 8.1 Nm. When the valve is open (fully throttle), the discharge pressure is extremely high, and forming pressure spike causes the torque to increase. This usually happen in low speed because the lower speed swept more volume displacement per revolution.

The torque speed started increase slightly at 100 to 140 bar. The torque increased sharply from 140 until 160 bar and continues increase slightly from 160 bar to 200 bar. The higher torque at 200 bar was 28.5 Nm at load 10 Nm and the lower torque was 17.5 Nm at load 2 Nm. Therefore, the different torque at 200 bar depend by load is 11 Nm. It clearly shows that the more an accumulator pressure added to the system, the higher torque it may produce due to the higher load exerted on system.

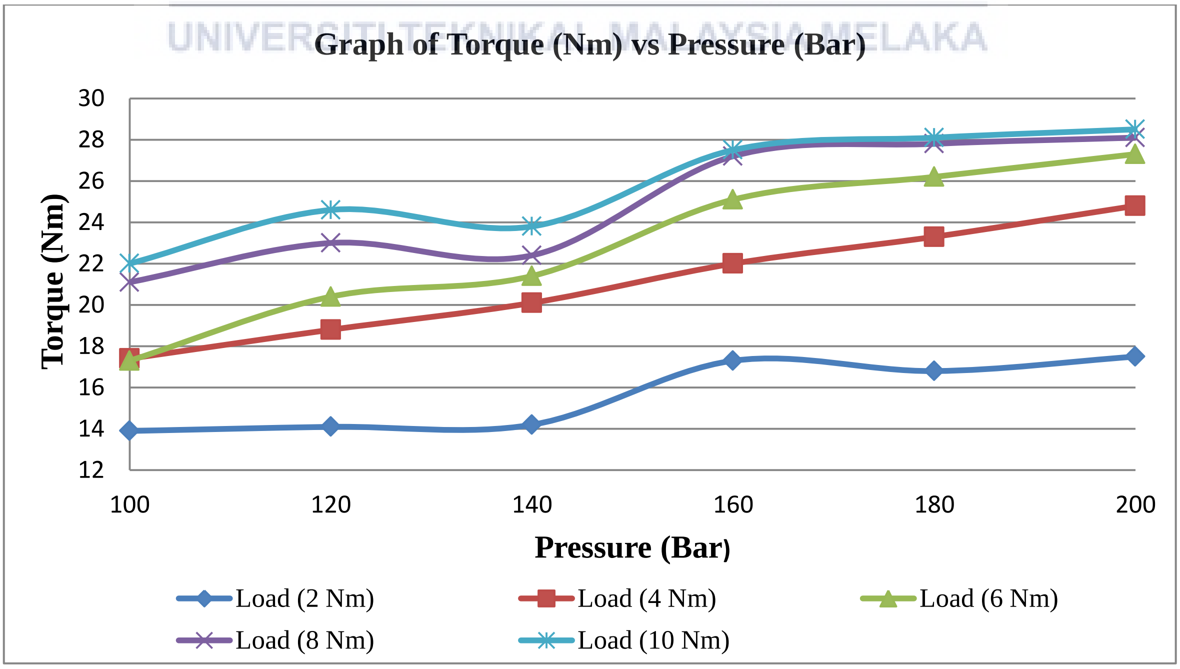

Figure 4.7: Effect of pressure changes to the torque

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4.6 Effect of Pressure Changes to The Power

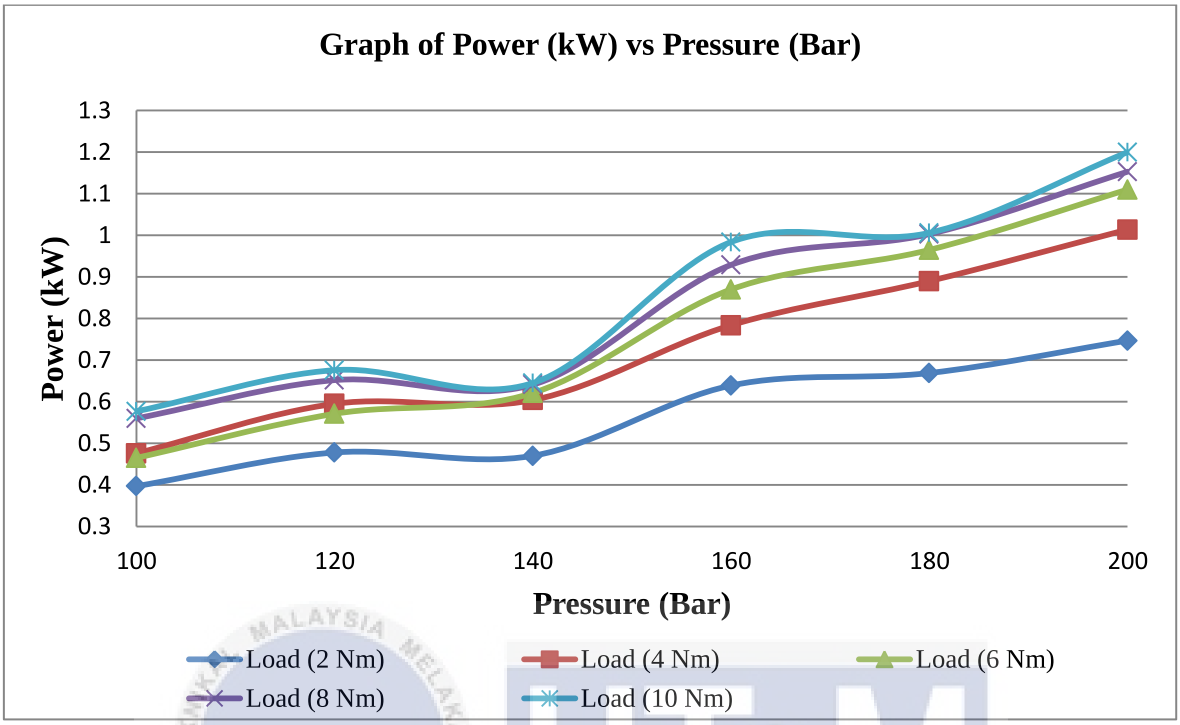

Figure 4.8: Effect of pressure change to the power

Figure 4.8 shows that the power generated by the vehicle was proportional to the pressure change. The highest power generated at 200 bar by the maximum pressure on accumulator. Meanwhile, the lowest power generated at 100 bar. At 100 bar, the higher power is 0.577 kW at load 10 Nm and the lower power is 0.397 kW at load 2 Nm. The different between both is 0.18 kW.

The power of system started by slight increase at 100 to 140 bar. Then the power increase sharply from 140 to 200 bar. It has shown that the power has correlation to the capacity of the accumulator. The higher the accumulator capacity will produce more power in return. At 200 bar, the higher power at 200 bar was 1.2 kW at load 10 Nm and the lower power was 0.747 kW at load 2 Nm. The different power depended by load was 0.453 kW. There is tendency that the profile will remain increase if the higher pressure is given.

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4.7 Effect of Load System to The Velocity

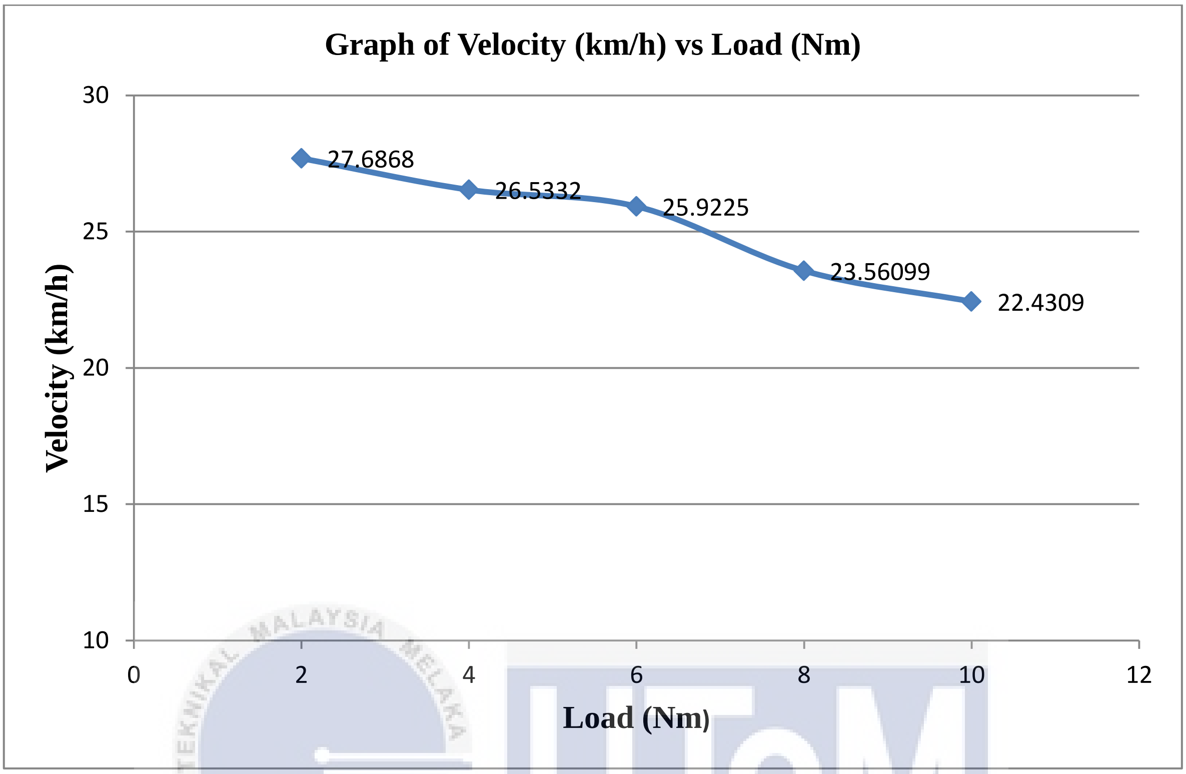

Figure 4.9: Effect of load system to the velocity at constant pressure 200 bar

Figure 4.9 shows the effect of load system to the velocity at the constant pressure, 200 bar. The velocity is proportionally decreased to the increase of load exerted on the system. The velocity result in 10 Nm of load was lower in 22.43 km/h compared to the 8, 6, 4, 2 Nm of load. The continuity equation was proven by $v = \omega r$ which ω is the 2π time RPM and r is the radius of tire. The higher velocity at constant pressure 200 bar is 27.68 km/h which at 2 Nm and decrease slightly until 10 Nm. The different velocity between higher and lower load is 5.25 km/h. In this situation, at the orifice, the kinetic energy was increased but the pressure energy was reduced. Therefore, it can be conclude that the more load exerted on the system, the lower velocity produce based on constant pressure.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the experiment result has managed to show some of the effects of the fluid parameter on the charging system of the hydro-pneumatic driveline. The effective volume relationship has shown that pre-charge pressure has contributed more significant influence on the level of volume in the accumulator. Therefore, the higher the accumulator pressure, the higher the acceleration produced. Also, the lower the load exerted on vehicle, the higher the acceleration produced depend on pressure. The increase in pressure value in accumulator gives an increase effect on the speed of vehicle. Meanwhile, as for acceleration, it remains constant when the time increases until it arrives at the cracking pressure which is 200 bars. The higher the accumulator pressure, the longer running time to support vehicle move. Besides, the higher the load exerted on vehicle, the longer running time to finish the pressure on the accumulator. Regarding power produced by the accumulator, it can conclude that the higher the pressure the accumulator produced higher the power. Lastly, for the more load exerted on the system, the lower velocity produce based on constant pressure.

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5.2 Recommendation for The Future Work

5.2.1 Schematic Diagram

The schematic diagram needs to improvise so that the consequences of the simulations will be more precise. The schematic diagram can be designed in several ways. The existing schematic is more on a single charging, so for the future work, it can improvise to continuous charging and then study how the energy is harvested during car movement.

5.2.2 Experimental

The experiment already done but still has the limitation of time. The fabrication and data collection for the equipment consuming more time during the research. So, for the future work, the experiment needs to run out at the beginning of the research to validate the data simulation and to obtain more beneficial outcomes.

5.2.3 Accumulator of Hydro-Pneumatic

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Nowadays, the hybrid technology has been used for heavy truck and further work has been directed to accommodate the passenger car. There are a few criteria need to be considered during the design and fabricate the model. The most important criteria are weight and size. The weight and size of the accumulator need to conceive due to the limited space inside the automobile.

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APPENDICES

Table A: Gantt chart PSM I

No	Task	Week														
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Project Title Selection	■	■					M								
2	Discussion with Supervisor	■	■	■	■	■	■	I	■	■	■	■	■	■	■	■
3	Research The Project			■	■			D								
4	Meeting				■	■		T	■			■	■	■	■	
5	Submission of Progress Report						■	E								
6	Abstract	■	■	■				R								
7	Introduction			■	■	■	■	M								
8	Literature Review					■	■		■	■	■	■				
9	Methodology							B	■	■	■	■	■	■		
10	Fluid Power Laboratory			■				R			■	■				
12	Automation Studio Laboratory							E				■		■	■	
13	Presentation							A								■
14	Submission of Report							K							■	

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Table B: Gantt chart PSM II

No	Task	Week														
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Learn Hydro-pneumatic Lab Scale	■	■							M						
2	Preparing Design of Jig-Experiment	■	■	■						I						
3	Discussion/ preparing progress report			■	■			■		D		■	■	■	■	
4	Fabricate					■	■	■	■	T	■	■	■			
5	Submission of progress report							■		E						
6	Meeting	■			■	■	■	■	■	R	■	■	■	■	■	
7	Find Supply and Material						■	■	■	M	■					
8	Welding			■								■				
9	Run Experiment-Chassis Dynamometer									B			■	■		
10	Analysis Data and Graph									R				■	■	
12	Preparing/Edit Final Report				■	■	■	■		E			■	■	■	
13	Submission Final Report									A					■	
14	Final Presentation									K						■

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