LOW-COST RETROFIT HYBRID SYSTEM FOR MYVI

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DECLARATION

This work is the result of my own investigation, except where it is state and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

(Signature of Student)

Date:

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ABSTRACT

Depletion of fossil fuel sources has become a concern to humankind as it is one of non-renewable energy that has been use over years. One of the alternative way to overcome the problem is the development of hybrid vehicles. Hydraulic Hybrid Vehicle (HHV) is one of the hybrid though it is uncommon compared to Hybrid Electric Vehicle (HEV), however the hydraulic hybrid technology has found its way to emerge itself into automotive industry. One of the configuration of hydraulic hybrid is parallel architecture, in which a conventional vehicle can be retrofitted into this architecture. The purpose of this project is to retrofit a conventional vehicle, Perodua Myvi 1.3L, with a hydraulic hybrid system with minimal cost. This is achieved by modification of the rear axle hub to placed hydraulic motor and pump on the rear axle of non-driven wheels. Upon retrofitting, a simulation of fuel economy on MATLAB is used to determine a suitable component sizing of hydraulic component and to determine the fuel economy improvement of the system.

ABSTRAK

Pengurangan sumber bahan bakar memberi kerunsingan kepada manusia sejagat kerana ia merupakan salah satu tenaga yang tidak boleh diperbaharui yang telah digunakan sejak bertahun-tahun dahulu. Antara kaedah alternatif ialah, pembangunan kendereaan hibrid. Kenderaan Hibrid berkuasa Hidraulik ialah salah satu kenderaan hybrid yang kurang popular jika dibandingkan dengan Kenderaan Hibrid berkuasa Elektrik, akan tetapi teknologi hibrid hidraulik telah menemui jalan untuk mengkomersilkan dalam industri automotif. Salah satu konfigurasi hybrid hidraulik ialah seni bina selari yang mana kenderaan konvensional boleh diubah menjadi kenderaan hybrid. Projek ini bertujuan untuk mengubahsuai kereta konvensional, Perodua Myvi 1.3L, dengan mengaplikasikan sistem hidraulik dengan kos yang rendah. Hal ini dapay dicapai dengan pengubah-suaian hab gandar belakang untuk meletakkan motor hidraulik dan pam pada gandar belakang tayar. Pada masa yang sama, simuasi dilakukan dalam MATLAB untuk mendapatkan saiz komponen hidraulik yang bersesuaian dan tentukan peningkatan ekonomi bahan bakar untuk sistem hidraulik.

CHAPTER 1

INTRODUCTION

1.0 Overview

A constrained supply of sources of energy combined with an ever-expanding request for energy have led to an extended alertness for the usage of energy efficiency. According to Energy Commission of Malaysia in its Malaysia Energy Statistics Handbook 2017 (Figure 1.1), the sector that is major energy consumption produce in Malaysia is transportation sector which is around 45.2% of total energy 51,806 kilotonne of oil equivalent (ktoe) in the year of 2015 [1]. The consumption of energy produced is the most than the other sector such as industrial, residential and commercial, agriculture, and non-energy use. The data provided by the Energy Commission of Malaysia for final use of energy consumption for sector (Figure 1.2) over the last thirty-eight years depict that the energy consumption rate of transportation sector is increasing at high rate and predicted to be increased in the future [1]. In transportation sector, most of the total energy is consumed by vehicles specifically ground vehicles. Various attention has been given by automotive industry and on the field of efficient energy management for vehicle systems.

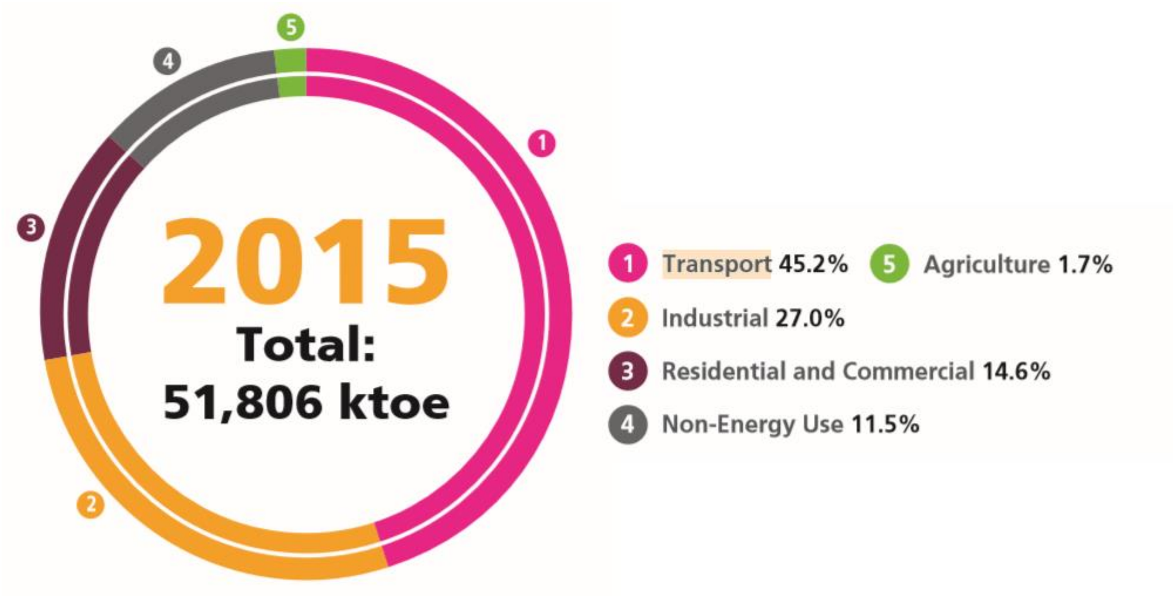

Figure 1: Energy Consumption by Sector in year 2015

Energy Commission Malaysia. (2018). *Energy Statistics Handbook*, *1–174*. Retrieved from http://www.statcan.gc.ca/pub/57-601-x/57-601-x2012001-eng.pdf%5Cnpapers2://publication/uuid/792EFC7D-A6CF-40B5-A139-8FA59714AA41

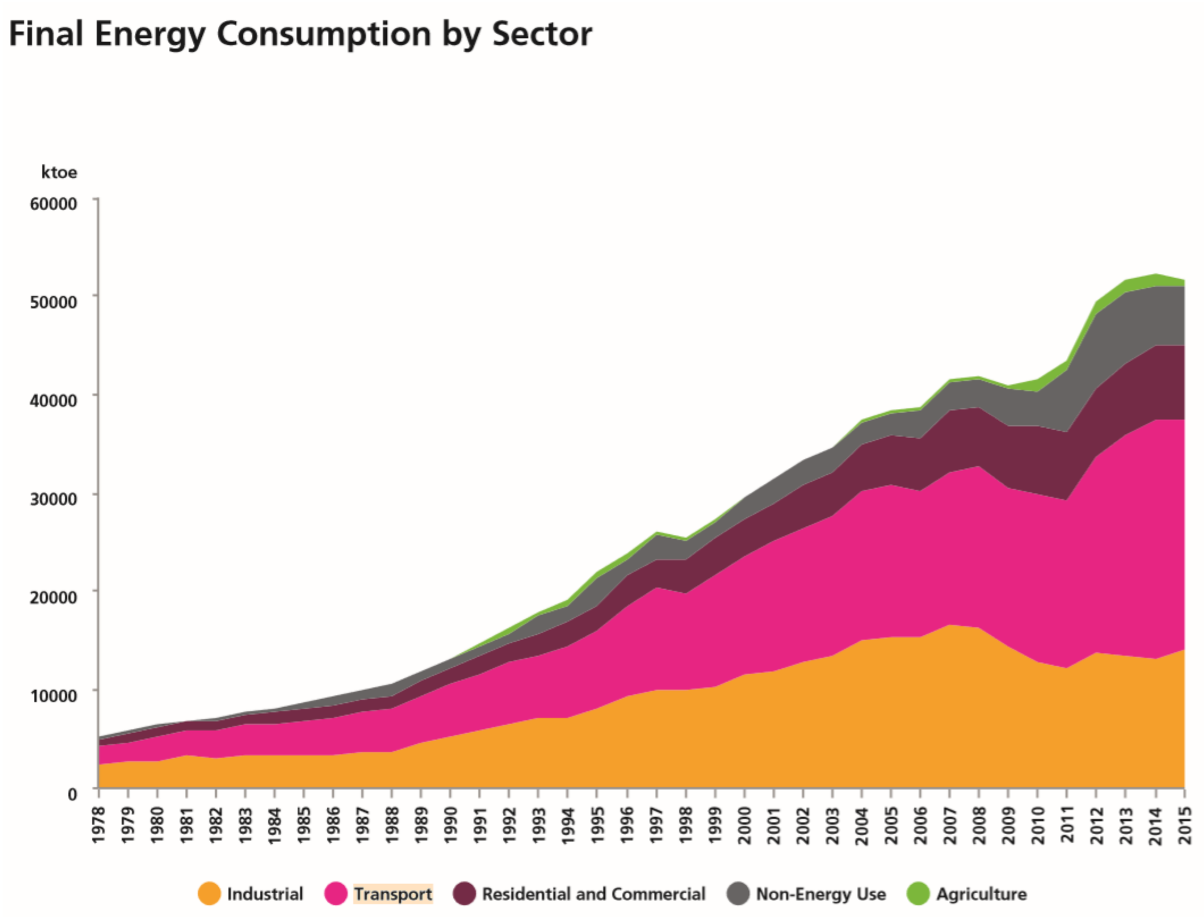

Figure 1.2: Final Energy Consumption by Sector from 1978 to 2015

Energy Commission Malaysia. (2018). *Energy Statistics Handbook, 1–174*. Retrieved from http://www.statcan.gc.ca/pub/57-601-x/57-601-x2012001-eng.pdf%5Cnpapers2://publication/uuid/792EFC7D-A6CF-40B5-A139-8FA59714AA41

The solution for energy management in transport sector is the substitution of mechanical internal combustion engine for vehicle to electrical motor drive system generally referred as electric vehicle. Electric vehicle has a higher efficiency compared to the internal combustion engine when it comes to conversion of energy into a useful work – driving a vehicle [2]. However, it is unable to completely replace conventional vehicle as the lack of development in infrastructure in Malaysia and technical advancement.

Electric vehicles exhibit diverse advantages such as reduced noise pollution and emission-free compared to the conventional vehicles. The main drawback of electric vehicles is the distance travelled is limited. The energy storage capacity of the battery is depended on the total travel distance. The battery needs to be recharged after a certain distance and recharging the battery takes up to several hours. In addition, the state of charge (SOC) have significant impact to the battery life; repeated deep discharges reduce its battery life, whereas to achieve maximum range, deep charge is required [3]. These two requirements of long battery life and maximum range before recharging are conflicting with each other. Hence, the reliability of conventional vehicle never fails to meet large portion of transportation needs.

The limitations of convention vehicle are its emission such as carbon monoxide (CO_2), hydrocarbons, Nitrogen Oxide (NO_2) are high, the internal combustion energy (ICE) has a low efficiency about 20% [4], the flow of energy is unidirectional which is from engine to the wheel, and failure of the engine such as knocking and vibrations. Despite of the drawbacks, practicable large scale of alternatives to conventional vehicle is unavailable.

Short while ago, engineers have developed a feasible solution to problems which is the implementation of hybrid vehicle technology. With the positive features of an internal combustion engine together with the electric motor drive propulsion, the efficiency of a vehicle is higher compared to conventional vehicle, emissions can be controlled, the engine can operate in higher efficiency region and the component size is reduced, as a result, higher gas mileage [5]. Yet, in electric hybrid vehicle the main disadvantage is higher purchase cost; the initial cost of a hybrid vehicle is generally higher than a conventional vehicle due to the additional parts of the electric propulsion system.

Nevertheless, this shortcoming of hybrid can be covered by using a hydraulic propulsion system which is cost-effective; the low cost to manufacture combined with reduced brake maintenance and significantly improve fuel economy [6]. The main feature that contribute hydraulic hybrid vehicle (HHV) to achieve maximum fuel efficiency which is through regenerative braking; the vehicle will capture and store kinetic energy due to friction from the wheels during braking and the stored energy will be used to accelerate the vehicle, shutting engine off when unnecessary, as well to provide an optimum engine control [7]. Furthermore, hydraulic hybrid has greater amount of stored energy density compared to electric hybrid [8].

1.2 Hybrid Hydraulic Vehicle

Hybrid vehicles are vehicles that use two power sources for propulsion. Internal combustion engine with the aid of hydraulic power source are use in hydraulic hybrid vehicle (HHV). Hydraulic hybrid system consists of two main components which are high pressure hydraulic fluid vessels called accumulators, and hydraulic drive pump/motors. The accumulator stored the pressurize fluid. The motor uses the energy from fluid to rotate the wheels and the pump uses the energy due to braking to pump the low-pressure fluid to the accumulator. It converts kinetic energy and energy loss as a form of heat due to friction into reusable potential energy which is called regenerative braking [7]. In hydraulic system, the weigh can be optimized and reduce to be lower than the electric system. This will impact the overall efficiency.

Based on the electric hybrid system, there are several possible drivetrain architectures:

1. Parallel hydraulic hybrid vehicle (PHHV)
2. Series hydraulic hybrid vehicle (SHHV)
3. Power split or series-parallel hydraulic hybrid vehicle

1.2.1 Parallel Hydraulic Hybrid vehicle

In a parallel hydraulic hybrid, the engine is mechanically connected to the driveshaft but with the addition of hydraulic system to assist in propulsion through a standard transmission. For a typical parallel hydraulic hybrid, the pump/motor are attached to the driveshaft and operate during braking and acceleration event. [9]

During light acceleration, when the drive pedal is pressed, pressurized fluid stored in the accumulator pushes hydraulic fluid to the pump/motor then acting as a motor uses the pressure to provide power to the driveshaft. The unpressurized fluid is stored in a low-pressure tank or reservoir. This process spares the engine from burning as much fuel to accelerate the vehicle.

When it is undergoing an extended acceleration, the pump/motor is acting as a motor to provide power to the driveshaft with the additional power from the engine. This process helps to reduce amount of engine power required to accelerate quickly.

During cruising, the engine supplies full power to the wheels through the driveshaft and transmission without the additional power of hydraulic system

When the brake paddle is pressed, the pump/motor is acting as a pump, uses the energy loss due to friction from braking to pump fluid from the low-pressure reservoir to the high-pressure accumulator. Figure 1.3 shows the typical configuration of parallel hydraulic hybrid system [10].

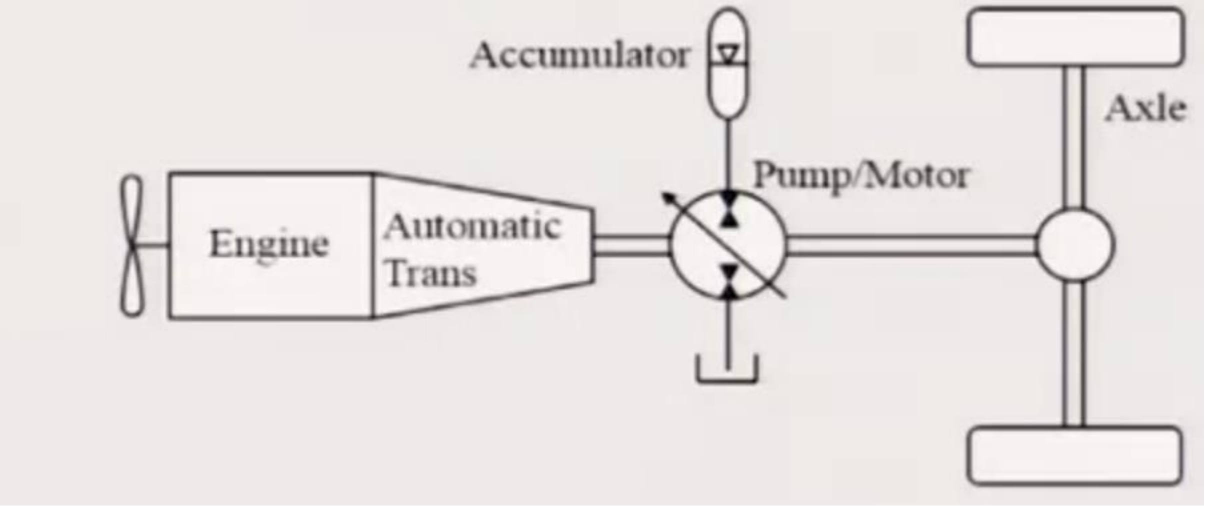

Figure 1.3: Typical Configuration of Parallel Hydraulic Hybrid

Fundamentals of Fluid Power - Hydraulic Hybrid Vehicles: Component Sizing & System Simulation | Coursera. (2016). Retrieved May 23, 2018, from https://www.coursera.org/learn/fluid-power/lecture/WIvUr/hydraulic-hybrid-vehicles-component-sizing-system-simulation

1.2.2 Series Hydraulic Hybrid Vehicle

Internal combustion engine is not mechanically connected to the drive shaft of the vehicle. Pump/motor is located between the driveshaft and engine and propel the vehicle. In Figure 1.4 shows the typical configuration of series hydraulic hybrid [10]. There are three modes of operation of a series hydraulic hybrid vehicle:

1. Light Acceleration/Short Cruising

   During this mode, the pump/motor acts as motor transfer the power from the accumulator to provide enough torque for the wheels to rotate and propel the vehicle. The power is provided by the high-pressure fluid. The used fluid is now at a low pressure and stored in a low-pressure reservoir [11].

2. Extended Cruising/Heavy Acceleration

As the vehicle cruising with the assist of hydraulic motor, the volume of accumulator begins to decrease and at a certain state of charge, the engine is turn on. The engine pressurizes the fluid from the low-pressure reservoir and transfer the fluid to the pump/motor. Excess of high-pressure fluid will be stored in the accumulator to recharge the accumulator [11].

3. Regenerative Braking

   When the brake pedal is pressed, the engine shut off and the pump/motor slows the vehicle down by using the vehicle's kinetic energy to pressurized fluid pumping it back into high-pressure accumulator. When the driver wants to accelerate again, only the saved energy will be used to turn the wheels [11].

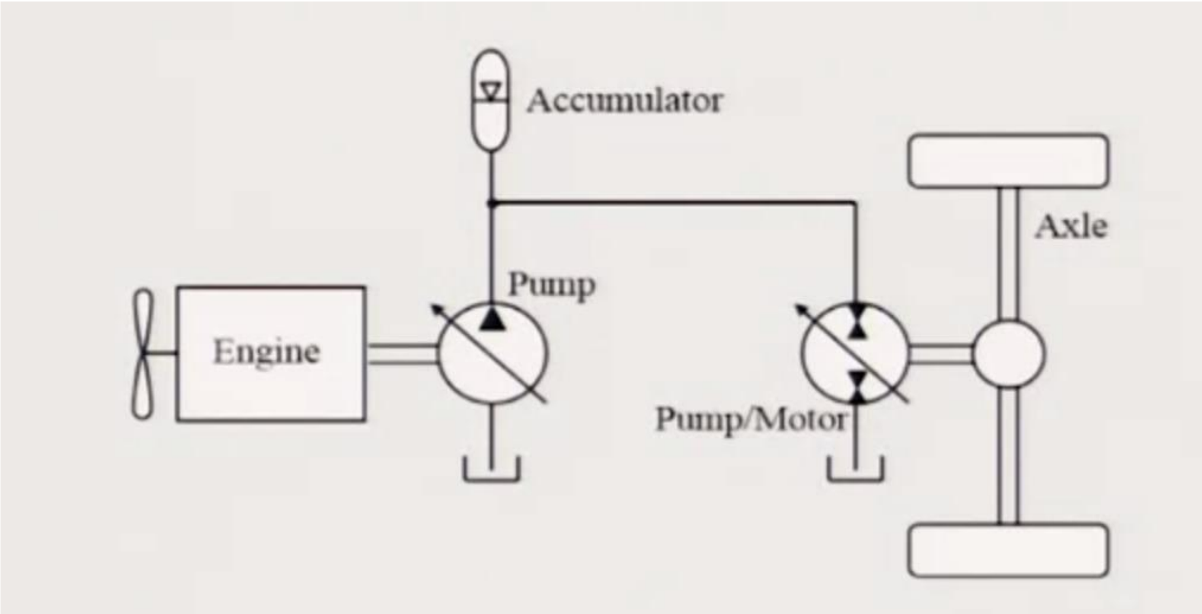

Figure 1.4: Typical Configuration of Series Hydraulic Hybrid

Fundamentals of Fluid Power - Hydraulic Hybrid Vehicles: Component Sizing & System Simulation | Coursera. (2016). Retrieved May 23, 2018, from https://www.coursera.org/learn/fluid-power/lecture/WIvUr/hydraulic-hybrid-vehicles-component-sizing-system-simulation

1.2.3 Power-split or series-parallel hybrid hydraulic vehicle

Power-split hydraulic hybrid architecture combines both series and parallel architecture to create more efficient system. In power-split system, the engine is driving a hydraulic pump and two power paths; one is the hydraulic power path (series system) and then the mechanical power path (parallel system) [10]. Those two paths are recombined in a planetary differential. The benefits of this system are very efficient direct path through mechanical transmission, the engine speed can be decoupled from the wheel speed through the hydraulic branch of this transmission and energy storage in that branch. There are a few different modes of operation where it can be operated as a series system or a parallel system. Figure 1.5 shows the typical configuration of power-split hydraulic hybrid [10].

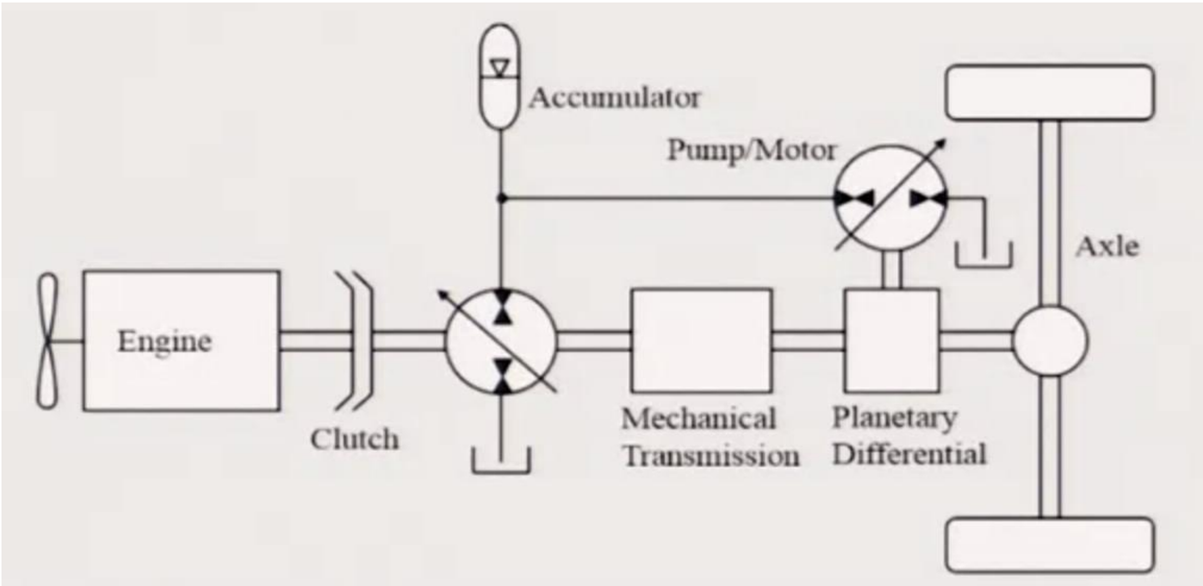

Figure 1.5: Power-split Hydraulic Hybrid Vehicle

Fundamentals of Fluid Power - Hydraulic Hybrid Vehicles: Component Sizing & System Simulation | Coursera. (2016). Retrieved May 23, 2018, from https://www.coursera.org/learn/fluid-power/lecture/WIvUr/hydraulic-hybrid-vehicles-component-sizing-system-simulation

1.3 Problem Statement

Depletion of energy resources such as fuels for the usage of various sectors especially in transportation sector and high price fuel gain more interest of people to reduce the fuel usage. Alternative power systems have been developed to reduce the dependency of fuel and reduce fuel consumption in vehicle such as shown in electric vehicle and electric hybrid vehicle. Although the aforementioned vehicles are proved to improve the situations, consumers preference are still low due to the high price compared to conventional vehicle. Therefore, it is best to retrofit a conventional vehicle into a hybrid vehicle that can reduce the total cost of production and increase fuel economy.

1.4 Objectives

The objectives of this research are as follow:

1. To design components for the rear axle of Perodua Myvi 1.3L to retrofit hydraulic hybrid components.
2. To determine suitable the hydraulic component sizing by simulation.
3. To fabricate and assemble the hydraulic components.

Chapter 2

LITERATURE REVIEW

In the last couple of years, numbers of research have been done on the development of alternative power to propel a vehicle. The research mostly focused on using hybrid technology for vehicles to determine how much fuel is saved and how efficient is the system besides how much emission is reduced.

Early study of hydraulic system for energy recovery was performed by Searl Dunn and Wojciechowski (1975). From this initial research, half of the wasted kinetic energy during braking event can be recuperated by using flywheel-accumulator apparatus of the hydraulic system. Pourmovahed *et al* [12] and Maeda [13] were performing similar research although the results are different. These early studies have provided visions for development of hydraulic hybrids.

Sangjun Park, Hesham A. Rakha, Kyoungho Ahn, and Kevin Moran (2013) used a conventional cruise control (CCC) system to identify the impact on the fuel efficiency of a vehicle. The system provides automatic control the speed of vehicle set by the driver during highway driving cycle. The driving route used in the research is Interstate 81, USA, between 118 and 132-mile marker. Under manual and CCC driving cases, different engine loads are tested on the route as it comprises sloe of uphill and downhill. Six light-duty vehicles and two sport utility vehicles (SUVs) were tested. The fuel consumption rates were determined by using an OBD II reader (DashDaq XL) as it provides the fuel economy with atimestamp. The results show there is enhancement in fuel economy by using the conventional cruise control system with average fuel economy of 3.3% [14]. From the experiment result, the CCC driving scenario is concluded to be more efficient during the vehicle drive at downhill.

Zhu Lijing (2014) designed a parallel hydraulic hybrid system for a heavy terminal tractor consists primarily of engine, transmission, dynamic coupling, high-pressure accumulate, low-pressure reservoir, a variable displacement hydraulic gear pump, and a couple of reversible hydraulic machine operating in two modes, pump and motor. The reversible hydraulic machines are positioned behind the transmission for recovering kinetic energy into accumulator during braking and applying store hydraulic energy during driving phase. The dynamic rule-based control strategy that relied on on/off engine power management according to the state of charge in the high-pressure accumulator was modelled in MATLAB/Simulink according to the actual drive cycle on road. The results of simulation showed that the energy saving effect of dynamic rule-based control strategy is 61.87% and the experiment results show that the fuel economy enhancement is in the range of 38 to 61% [15].

Siriorn Putanuwat and Angkee Sripakagorn (2015) use the driving cycle of route in Bangkok to simulate the fuel economy of hybrid vehicle. The test vehicles used were Toyota Prius and 2015 Toyota Corolla Altis to represent hybrid vehicle and conventional vehicle respectively. The authors used microtip segmentation technique. Microtip is a series of speed between start and stop points and usually used in recognizing driving pattern and construction of driving cycle. The authors concluded hybrid vehicles can improve fuel economy in all traffic conditions of Bangkok with fuel consumption reduction of 56% in city traffic and approximately 46% and 26% in suburban and highway traffic respectively [16].

Ahmed Al-Samari (2017) used software Autonomie to simulate the parallel hybrid electric vehicle and conventional models on standard driving cycles for city and highway activities such as Urban Dynamometer Driving Schedule (UDDS), Federal Test Procedure (FTP), and US06. Moreover, the real-world driving cycle used by the author is Baquba city, Iraq and it was generated from data collection. The results from the simulation shows the hybrid implementation can significantly contribute in increment of fuel economy up to 68% on real world, mostly in city activities [17]. However, on highway drive cycle, the fuel economy improvement is limited up to 10%. This is due to the infrequent usage of braking system. The result shows for an electric hybrid system as it is different from hydraulic hybrid system.

Harun Turker (2015) modelled a program to define the optimal hybridization rate by integrating certain driving cycle to reduce maximum fuel consumption. The optimal hybridization rate is based on the Energy Management Strategy (EMS) of the vehicle. Moreover, the program can reduce the total cost of selected vehicle during the life duration. From the result, low hybridization rates are better in cost effective [18].

Many previous studies have been done on hybrid field to determine its fuel economy, fuel efficiency, energy efficiency, and fuel consumption. Nevertheless, fuel economy on each type of hybrid is different with the additional factors of type of drive cycles used, driver behaviour, type of vehicles, and the configuration of hybrid architecture. Hence, study on hybridizing a conventional vehicle (Myvi) to improve fuel economy is carried out to validate the usage of hybrid system in Malaysia can improve fuel economy.

Chapter 3

METHODOLOGY

3.1 Overview

To retrofit hydraulic system into a conventional vehicle (Perodual Myvi 1.3L), experimental and simulation method needs to be done to obtain desired data. Experiments or fabrications are conducted in Engine Lab and workshop in School of Mechanical Engineering (SoME) while simulation and designed of parts are conducted using MATLAB and Solidworks. For fabrications, materials are obtained at store and workshop of SoME. Throughout the fabrication processes, standard of procedures of every machine are followed and personal protective equipment are used. Supervision from technical stuffs is a must during the fabrication to avoid any accident. Alignment jig and spirit level are used throughout the experiment to ensure accurate data during fabrication process.

3.2 Design of Components and Fabrication

A Perodua Myvi 1.3L (Automatic) is used to be retrofitted. The rear axle of Myvi is detached from its body with both of left and wheel hubs are attached while other parts are detached. Figure 3.1 shows the rear axle of Myvi.

Figure 3.1: Rear axle

3.2.1 Rear Axle

The rear axle of Myvi from the Figure 3.1.1 and Figure 3.1.2 shows there are no rear drive axle for Myvi. The two locations circled with red mark need to be cut so a drive axle for the rear axle can be used.

Figure 3.1.1 and 3.1.2: Original rear axle

3.2.2 Wheel Hub

The wheel hubs of the rear axle are detached from the axle and changed with two spare front wheel hubs.

3.2.3 Brackets

Six brackets for two sets of wheel hubs are designed to hold the new wheel hubs onto the rear axle bar. Designs of three bracket are done using Solidworks and fabricated by using drilling machine and grinding machine. The material used is mild steel. Each wheel hub is hold by three brackets at three different positions which are at top, bottom, and side of the axle bar. The holes for all brackets are the same size that fit a bolt and nut size of M19.

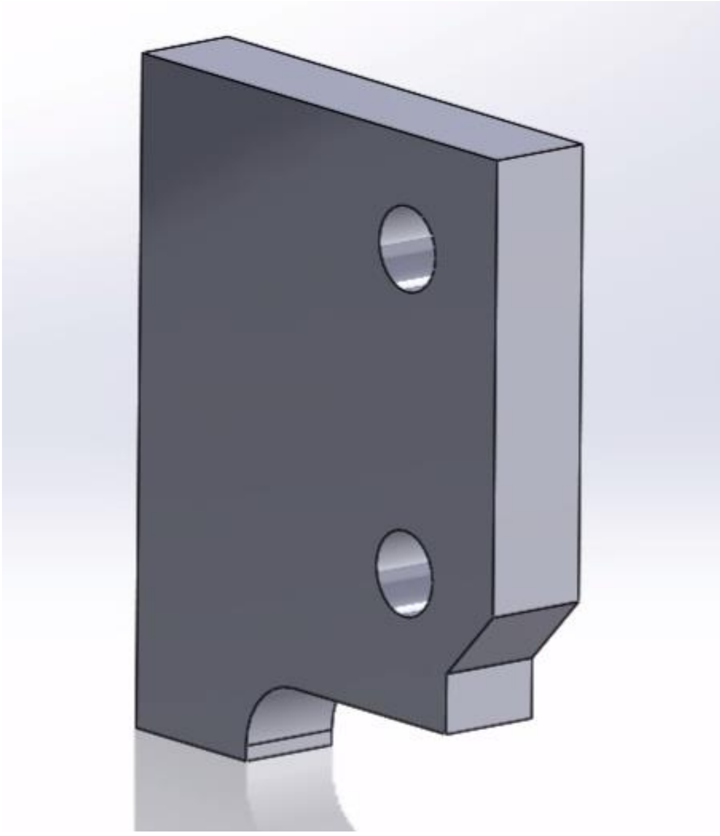

Figure 3.2: Design of Top Bracket

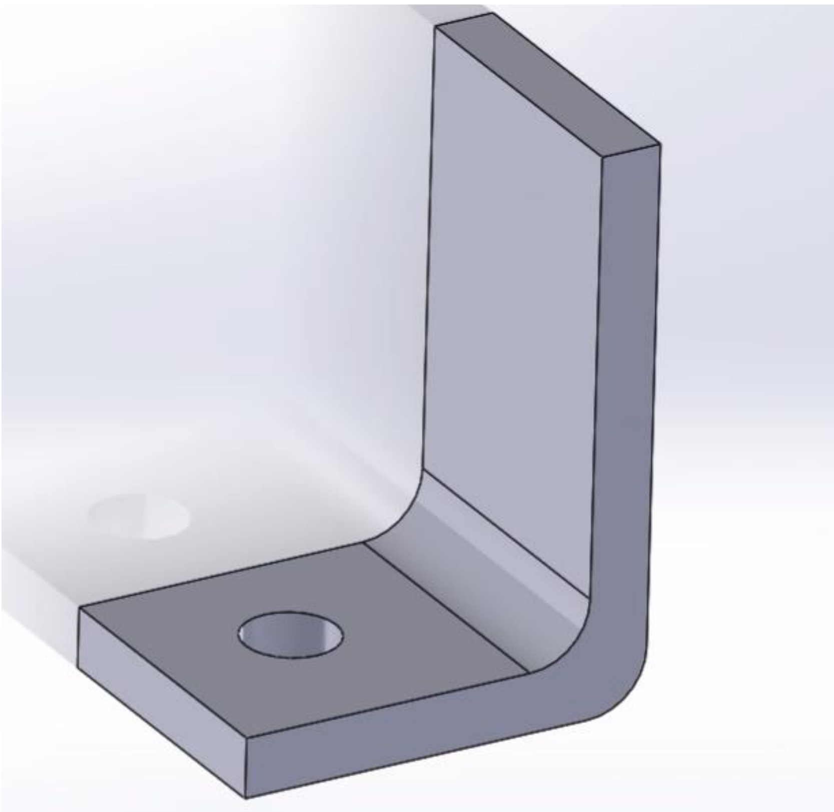

Figure 3.3: Side bracket

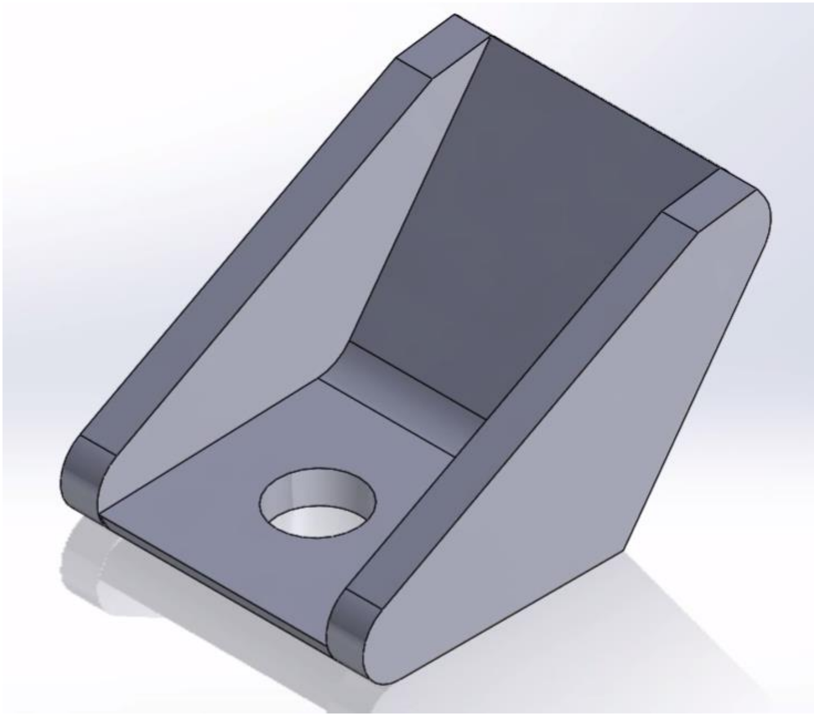

Figure 3.4: Bottom bracket

3.2.4 Mounting of Motor

The hydraulic motor will be attached on the axle bar of rear axle. Hence, housing for the motor and its location are assigned. Figure 3.5 and 3.6 show the design and drawing of motor housing. There are two choices of location of motor housing as shown in Figure 3.7 and 3.8

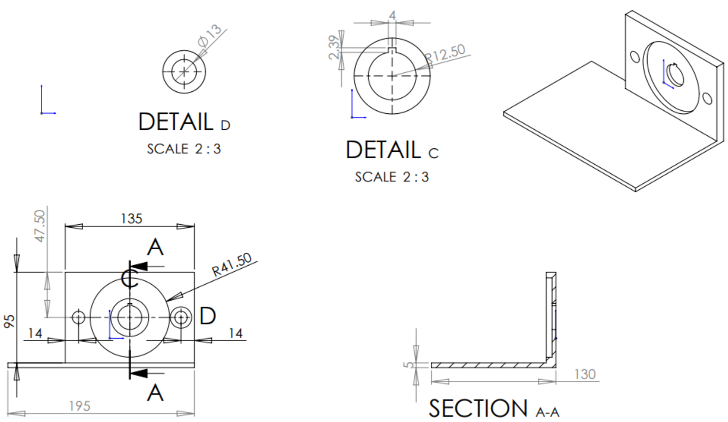

Figure 3.5 Schematic Drawing of Motor's housing

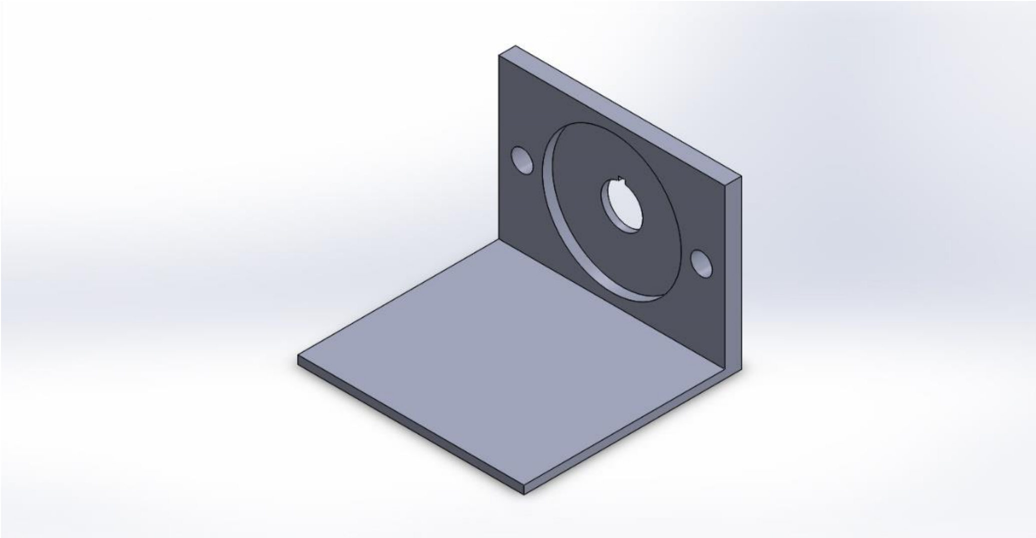

Figure 3.6 Design of mounting of motor

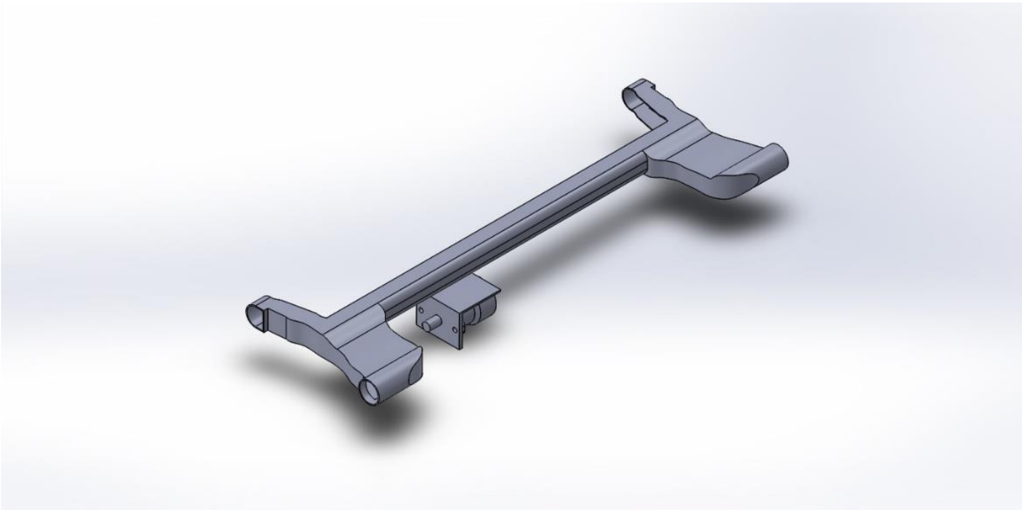

Figure 3.7: Location of motor housing at bottom

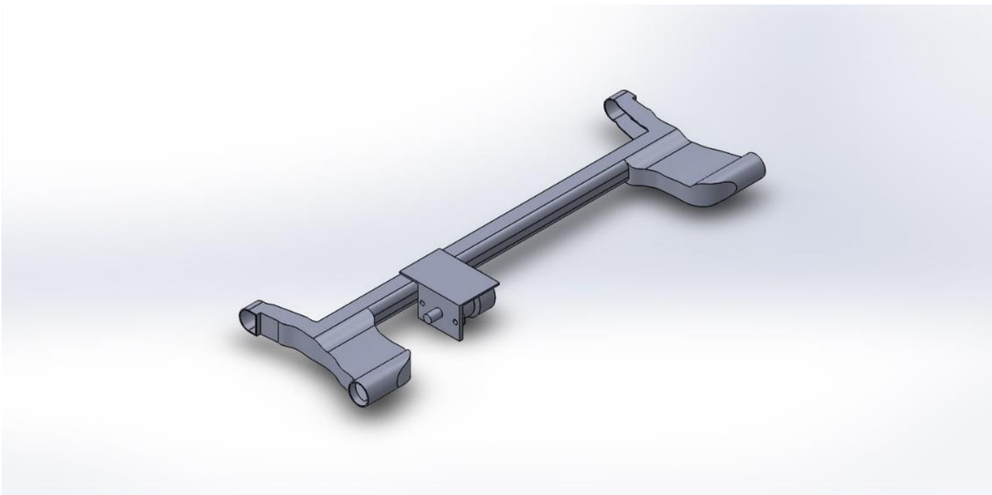

Figure 3.8: Location of motor housing at front side

3.2.5 Axle Shaft

Two rear axle drive shafts are designed for the rear axle. The material used to for both drive shafts is mild steel. The length of each drive shaft is 75 cm. The spline for both end from a front wheel drive shaft is cut. Two sleeves are designed to assist in welding process of the splines and rear axle drive shafts.

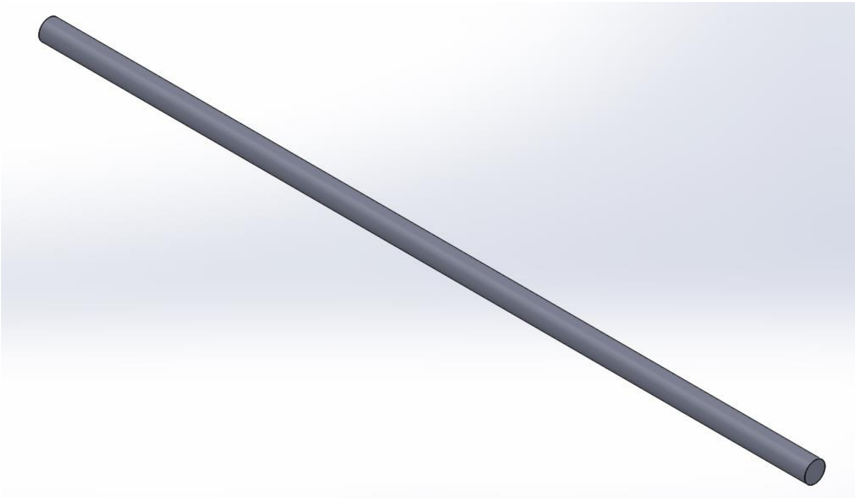

Figure 3.9: Rear axle drive shaft

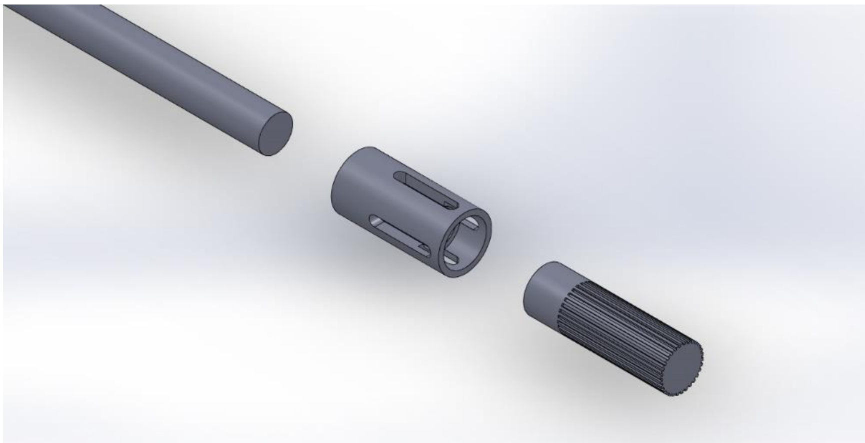

Figure 3.10: Exploded view of axle shaft

Figure 3.11: Assembled View of Shaft

3.2.6 Housing of Bearing

Two sets of bearings are used for both left and right shaft to ensure the shaft is linear to each other. The bearing for both shafts partially enclosed and mounted on housing of bearing. The mounting of bearing is as shown in Figure 3.13.

The pillow of bearings is grinded to ensure the level of both bearing is the same from the base reference. The base reference used is the surface of the table which have been inspected using spirit level.

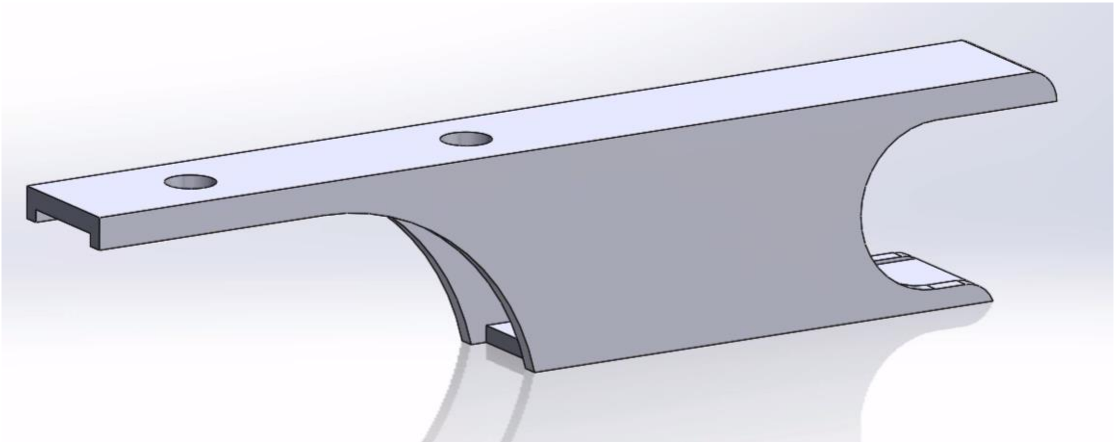

Figure 3.13: Design of Mounting Bearing

3.2.7 Keyway linkage

A keyway linkage is designed and fabricated in the workshop to connect both shafts as shown in Figure 3.14. to connect both rear drive shafts.

Figure 3.13: Keyway Linkage

3.2.8 Sprocket

A sprocket is designed to transfer the torque from the hydraulic motor to the wheels. The sprocket holder is attached with a sprocket holder with a lock and key pin to connect to a motor shaft. Figure 3.14 and 3.15 shows the design of sprocket and its holder respectively.

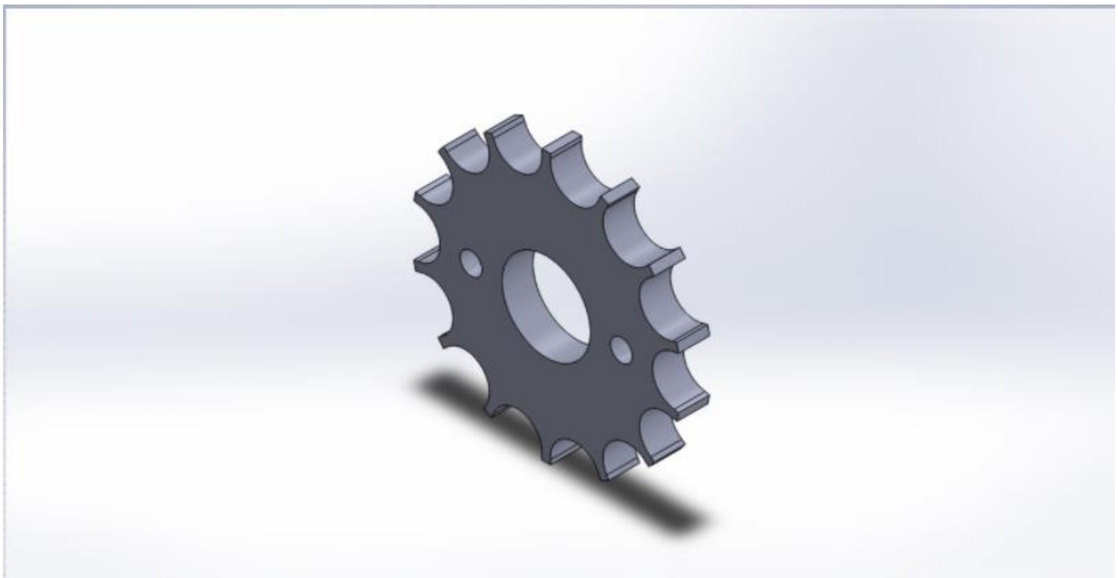

Figure 3.14: Sprocket

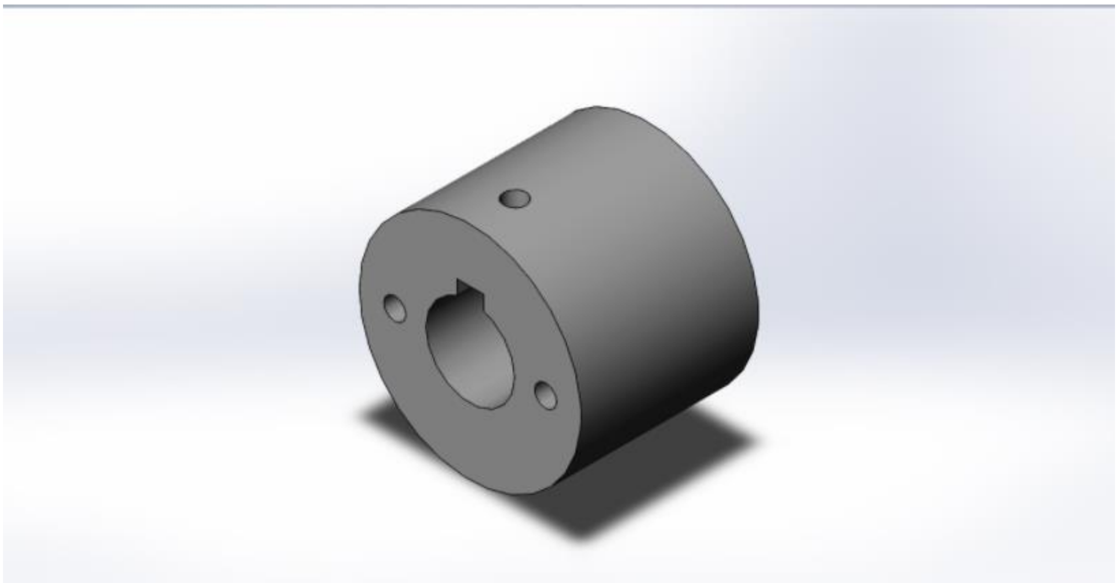

Figure 3.15: Sprocket holder

3.3 Simulation and Mathematical modelling

A conventional vehicle of mathematical modelling is used from previous study and certain modification is made to determine the effect of hydraulic hybrid system towards the fuel economy of a vehicle. The mathematical modelling of conventional Perodua Myvi 1.3L from previous study [19] is used. In every vehicle, the fuel economy is obtained by using equation (1).

$$Fuel\ Economy\ \left(\frac{km}{litre}\right) = \frac{Total\ Distance}{Total\ Volume\ of\ fuel\ consumed} \quad (1)$$

In conventional vehicle, fuel economy is calculated from the total fuel consumption of every time step [19]. The fuel consumption of every certain time step is obtained from the torque and speed of engine. The combination of the torque and speed of engine produced an engine map called fuel consumption engine.

To calculate the fuel economy for a hydraulic hybrid, the sizing of components, engine state, state of charge of accumulator and control strategy must be determined. Torque of motor needs to be considered when calculating the torque required for engine to satisfied with the torque of flywheel. This is because the additional pump to the system contribute in the maximum torque output. The maximum torque can be calculated by using equation (2).

$$Tmax = \frac{Tpm}{\eta hyd} + Tflywheel \quad (2)$$

Where T_{pm} is the maximum torque output of pump, and η_{hyd} is the hydraulic system efficiency. The T_{pm} can be calculated using equation (3).

$$Tpm = P * Disp \quad (3)$$

Where P is the pressure change and Disp is displacement per revolution. Change in pressure can be obtained by using equation (4).

$$P = SOC\ (Pmax - Pmin) + Pmin \quad (4)$$

Where P_{max} is the maximum pressure of accumulator and P_{min} is the minimum pressure of accumulator.

From the ideal gas law in equation (5), volume of usable, V is:

$$V = Vmax * (\left(\frac{Ppre}{P}\right)^{\frac{1}{\gamma}}) \quad (5)$$

Where γ is the adiabatic ratio, in this case it is assume 1.4, and V_{max} is the total volume of accumulator.

To find minimum volume of accumulator, V_{min}, it can be obtained as in equation (6):

$$Vmin = Vmax * (\left(\frac{Ppre}{Pmax}\right)^{\frac{1}{\gamma}}) \quad (6)$$

For the control strategy, the engine torque is ensured not to exceed torque required for the accumulator current state of charge (SOC). The initial state of charge is set to 0.5 where it is half of the full charge and engine state is set to on initially. The SOC determines the engine state to be either on or off. Engine will provide full torque when the SOC fall to a certain level, the hydraulic system is insufficient to provide support. In control strategy, if the value of pump is negative, the pump will discharge the high-pressure fluid from accumulator to assist in propulsion, whereas the positive value of pump, it indicates the pump will charge to fill up the accumulator. When the SOC is high, the pump/motor provide torque to overcome the flywheel torque. During regenerative braking, the pump/motor torque value will be negative to capture the energy from braking event into the accumulator. When there is no flow of hydraulic fluid, the SOC remain the same but when there is flow rate of hydraulic fluid, the volume of nitrogen gas, the current SOC can be calculated using the equation (7).

$$SOC = \left(0.9 * \left(\left(\frac{Vmax}{V}\right)^{gamma}\right) - 1\right) * \frac{Pmin}{Pmax - Pmin} \quad (7)$$

Hence, the fuel consumption can be estimated from the combination of the engine torque and speed after considering the hydraulic system. Fuel economy of the vehicle can be obtained.

The simulation is run to determine suitable the sizing of components such as the displacement of pump/motor, accumulator pressure, and max volume of accumulator.

The fuel economy of calculated sizing component is selected based on the results. The overall simulation is summarized as in Figure 3.14.

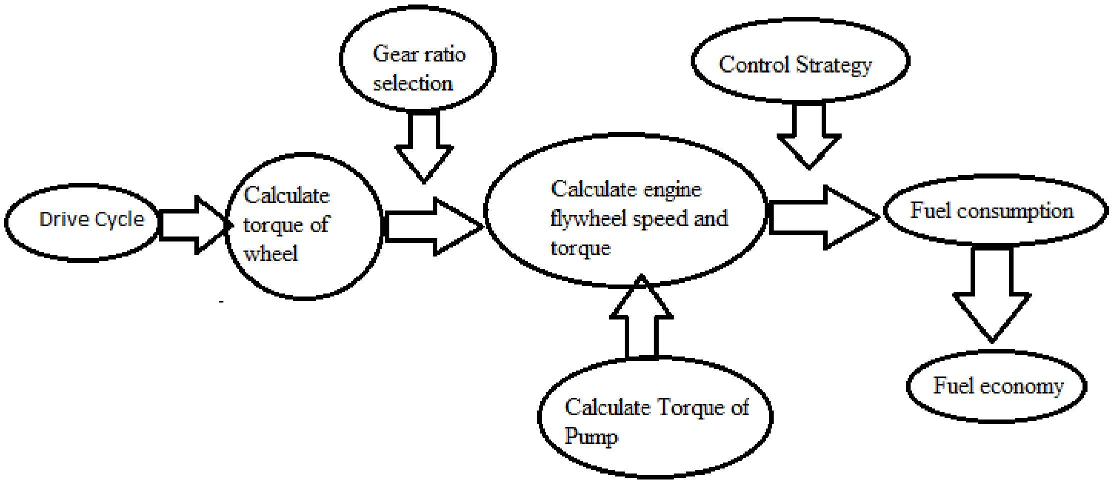

Figure 3.16: Summarize simulation

Figure 3.17: General assembly

Chapter 4

RESULTS AND DISCUSSION

4.1 Overview

The results of fabrication of parts and simulation is taken to is observed and discussed in this chapter. For fabrication, results in the issue of fabricated parts. For simulation, result on fuel economy based on theoretical sizing of components of hydraulic. Hydraulic components that shows the best fuel economy improvement will be selected as suitable component for retrofitting.

4.2 Fabrication

The overall modification of the rear axle is as shown in Figure 3.16. The cutting of original rear axle bar to enable usage of shaft are done on both left and right rear axle. As a result, two shafts can be used to rotate the wheel hub. In original Myvi, the drive axle is located at the front of the vehicle. The rear axle is a tag axle whereby the dead axle is located behind a drive axle. A dead axle is a free-rotating wheel. The usage of shafts is to connect both shafts with hydraulic pump and motor to the rear wheels.

4.2.1 Axle Shaft

The material used for both axle shaft is structural ASTM-A36 steel with Young's modulus of 200 GPa, yield strength of 250 MPa, and shear modulus of 75GPa [21]. It can withstand a massive amount of stress due to shear. Furthermore, it is the cheapest possible material for structural design of vehicle. The price is varied based on the quality, quantity and size. The price of A36 steel is within 300 to 600 USD per tonne (907.185 kg) [23]. A36 steel is chosen because it has high machinability, as the carbon content of ASTM A36 steel is around 0.25% [22]. Theoretically, from the equation of maximum shear stress of A36 steel (8), when maximum torque on the wheel is 2000Nm (forces to overcome air drag force, acceleration, and rolling);

$$\tau = \frac{16T}{\pi d^3} \tag{8}$$

Where d is diameter of steel rod. The diameter of steel rod used is 1.6 cm, T is the maximum torque. Hence, the value of maximum shear stress of the rod is 636.62