DEVELOPMENT OF PLUG-IN AIR POWERED FOUR WHEELS MOTORCYCLE DRIVETRAIN CONTROL UNIT

TAN BENG LENG

Report submitted in partial fulfillment of requirements
for award of the Degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Development of Plug-in Air Powered Four Wheel Motorcycles Drivetrain Control Unit" is written by Tan Beng Leng. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Prof. Ir. Dr. Hassan bin Ibrahim

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this report and in my opinion this report is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Signature :

Name of Supervisor: DR. GAN LEONG MING

Position: Senior Lecture

Date: 26/6/2013

Signature :

Name of Co-Supervisor: Dato Prof. Dr. Rosli Abu Bakar

Position: Professor

Date:26/6/2013

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature :

Name : Tan Beng Leng

ID Number : MH 09015

Date : 26/6/2013

ACKNOWLEDGEMENTS

I would like to show my highest gratitude to the almighty for blessing me in finishing the project. I am grateful and would like to express my sincere gratitude to my supervisor Dr Gan Leong Ming for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to General Laboratory Assistant, Mr Aziha for his excellent co-operation, inspiration and support during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I offer my regards and blessings to all of those who supported me especially my family and friends in any respect during the completion of the project. All of their help are very significant to the success of this project.I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This thesis is related to the development of plug-in air powered four wheel motorcycles drive train system that transfers rotational energy from power train to the driving wheel. The objective of this thesis is to develop an air hybrid drivetrain unit and control the power and torque from the powertrain to the driving wheel by using sequential manual transmission. This thesis describes the process of developing sequential shift-by-wire system to make gear shifting for easier for 4 wheel motorcycle. The controller used in this project was 18F PIC 4550 microprocessor. The system programming performed using FLOWCODE version 4.0. 2 units of electromechanical linear actuator were used in this project as an actuator for gear shifting on a manual transmission. Chain drives were selected as power transfer linkage from air hybrid engine to the driving wheel with under drive configuration. Besides the development of shift-by-wire system, the torque on the driving wheel also had been calculated and analysed. In additional, the maximum speed that can be achieved by four wheel motorcycles was also calculated**.**

ABSTRAK

Tesis ni berkaitan dengan pembangunan sistem pacuan yang memindahkan tenaga putaran ke roda pacuan untuk “plug-in hybrid air powered” motosikal empat roda. Objectif tesis ini ialah untuk membangunkan pacaun “ air hybrid” and mengawal kuasa and tork daripada janakuasa kepada roda paduan mengunakan transmisi manual berturutan. Tesis in menjelaskan proses pembangunan system “sequential shift-by-wire” Untuk menjadikan proses pertukaran gear lebih senang bagi motosikial beroda empat. PIC 18F4550 mikropemproses telah digunakan sebagai sistem kawalan utama untuk sistem “sequential shift-by-wire”. Pengaturcaraan untuk sistem kawalan mengunakan perisisan FLOWCODE versi 4.0. 2 unit penggerak lurus telah digunakan sebagai penggerak untuk pertukaran gear pada transmisi manual. Paduan rantai teleh dipilih untuk menghubungkan kausa dari enjin“ air hybrid” kepada roda pacuan dengan konfigurasi “ under drive”. Selain daripada pembangunan sistem “ shift-by-wire”, tork yang ada pada roda pacuan juga dikira dan dianalisis. Sebagai tambahan, kelajuan maksimum yang boleh dicapai oleh motosikal empat roda juga telah dikira.

TABLE OF CONTENT

APPENDICES

LIST OF TABLES

LIST OF FIGURE

LIST OF SYMBOLS

L	length
m	mass
r	radius
a	acceleration
F	force
ω	Angular velocity
T	torque
v	velocity

CHAPTER 1

INTRODUCTION

1.3 BACKGROUND STUDY

Nowadays, there are many research that had been done to develop a vehicle that can run on the alternative fuel like hydrogen fuel cell, bio-fuel, electric propulsion vehicle, hybrid system and most recently is a vehicle that totally runs from compressed air. But most of this development of only focuses on car drivetrain and not for motorcycles.

In the early years of development air-hybrid vehicle, the drivetrain system is design base of the passage vehicle platform. It was developed by a French engineer Guy Négre in Luxembourg, French. The compress air vehicle design by the Guy Négre use continuously variable transmission to change the torque constant torque from air hybrid engine to the driving wheels. Over the time, the design of the drivetrain system by Guy Négre was refined and use in many Motor Development International vehicle models. But until now, there doesn’t have any development of drivetrain system that can be used in motorcycle to transmit torque and power to driving wheel effectively.

Although there are already 52 patents have been registered for air hybrid engine since 1979(Singh & Onkar), but there are not any recent development of a drivetrain system that suitable use in motorcycles. The development of an air hybrid drivetrain system is very important to the ASEAN country where most of its population using motorcycles as main transportation (World Health Organization, 2009).

1.4 PROBLEM STATEMENT

The development of the motorcycles drivetrain system is surprisingly fast with the introduction of new technology by motorcycle manufacture. Normally the type of transmission that had used for the motorcycle transmission is a manual sequential transmission and continuous variable transmission (CVT). Both types of transmission are chosen to be used in motorcycles because it has few advantages like light weight and compact. But for hybrid engine, manual transmission is preferable because it has the ability to the handle power and torque from the hybrid engine compare to continuous variable transmission.

By using manual transmission in drivetrain system also will give the driver full control of the motorcycle performance. Manual transmission can increase the fuel efficiency of the motorcycles because it has high mechanical efficiency when transfer the engine power to the driving wheel with minimum losses of energy (Manish Kulkarni, Taehyun Shim, Yi Zhang,2007). But it has a one drawback with the 'H' shift patter which is taking too much of space in the confines of the motorcycle frame.

To overcome this drawback, manual transmission with sequential ability for shifting gear is required to be developed. By developing these type of transmission can reduce the size of motorcycle chassis to more compact due to it can eliminate the use of 'H' patter in gear shifting. It also can reduce the complexity of gear shift patter compare to manual transmission hence give driver ability to select the desired gear without letting go of the handlebars.

1.5 OBJECTIVE

The main objectives of this project are:

a. To develop of air hybrid drivetrain unit.
b. To control the power and torque from powertrain to driving wheel by using sequential manual transmission.

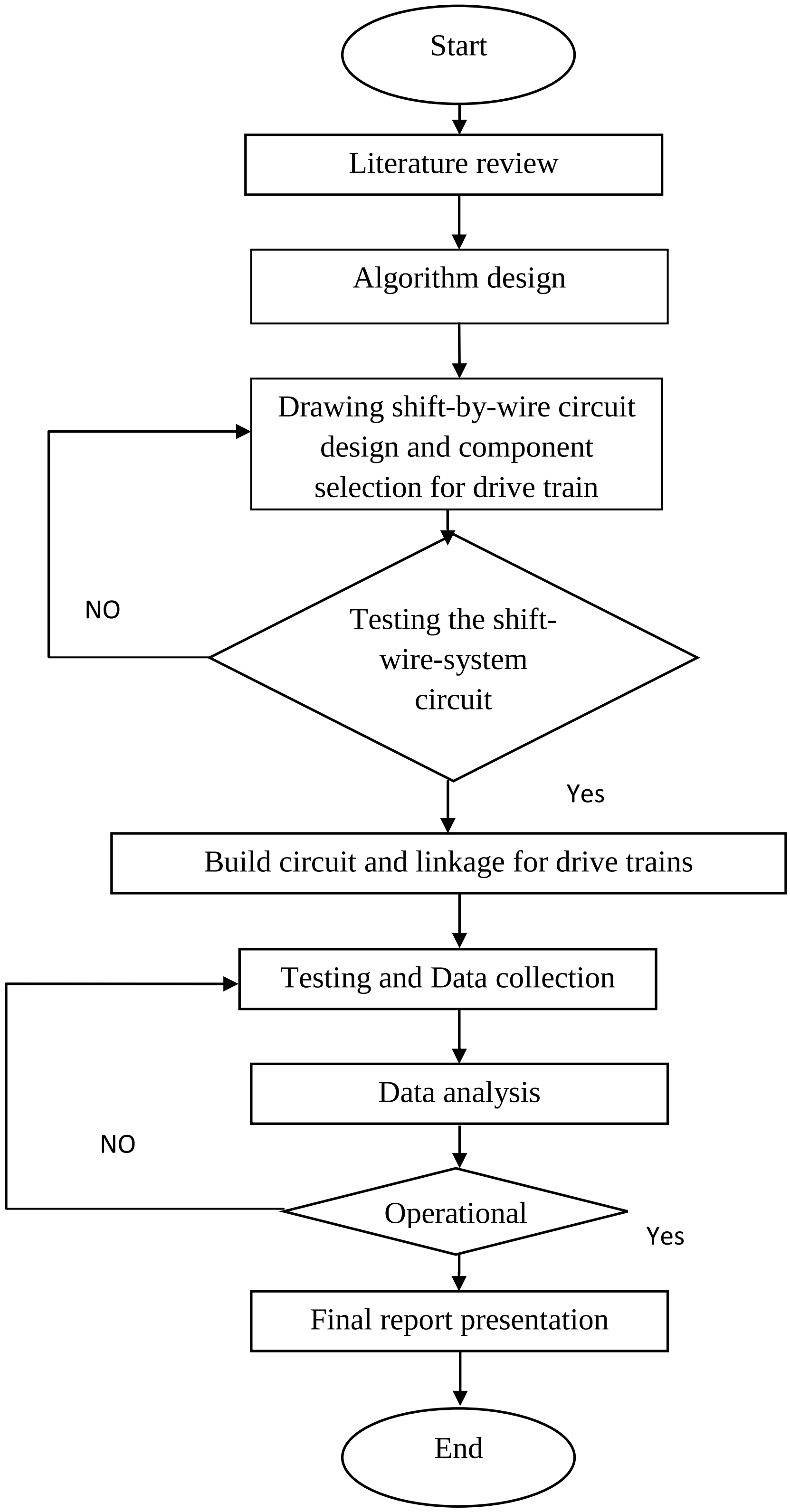
1.6 WORK SCOPES

a. Development of single power transfer linkage unit.
b. Integration between powertrain, drivetrain, power transfer unit and driving wheel.
c. Design a shift by wire sequential manual transmission system to control the gear ratio.
d. Prototype model working analysis.
e. Final report preparation .

1.5 HYPOTHESIS

A manual transmission is changed into sequential manual transmission for use in 4 wheel motorcycle's development. This sequential action is controlled by the control module. By the end of the development, 4 wheel motorcycles can eliminate a drawback of normal H patter manual transmission which is taking a lot of space in the confines of 4 wheel motorcycle frames and give the driver ability to select the desired gear without letting go the handlebars.

1.6 FLOWCHART



1.7 GANTT CHART

Please refer to appendix A1 for reference

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The vehicle drive train system is important because it functions to transfer rotational energy from power train to the wheel. The drive train system mechanical efficiency depends on how the system is designed. Typical vehicle drive train system will have components like clutch, transmission box, drive shaft or chain drive, and wheel, which are controlled by the driveline management system (Magnus, 1996).

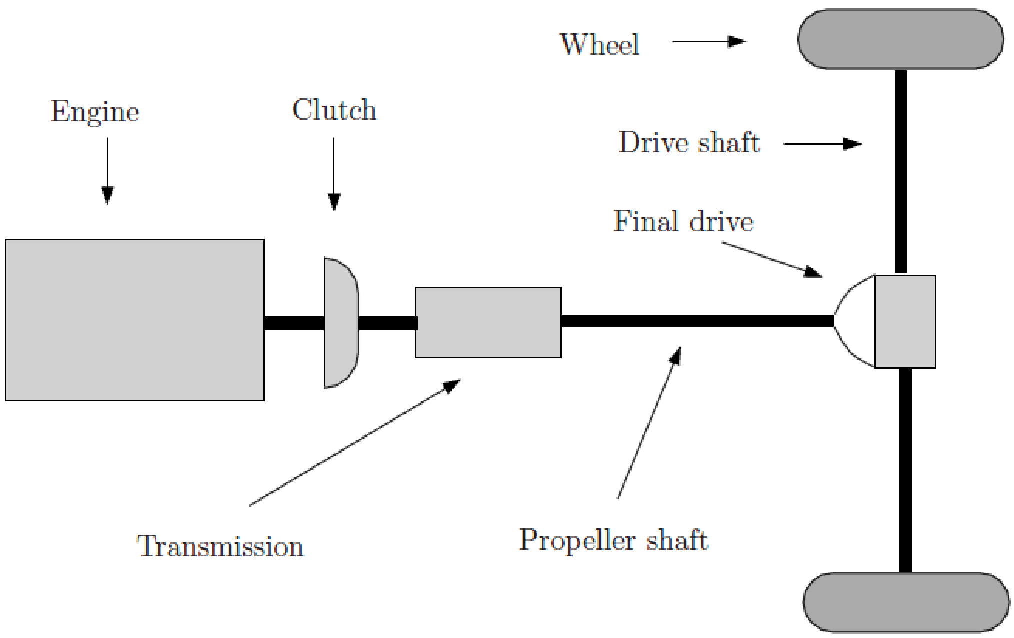


Figure 2.1: Typical vehicle drive train for rear wheel drive

Source: Magnus (1996)

A good configuration of the drive train system needs to customize with the chassis design to ensure optimum performances hence reduces energy consumption and pollutant gaseous emissions. (Sérgio, Jorge, and Paulo,2005).

2.2 POWERTRAIN SYSTEM

Powertrain is the main component in any modern vehicle even for the motorcycles. Most of the motorcycles on the road today use an internal combustion engine as it Powertrain. The internal combustion engine converts chemical energy from the fossil fuel via combustion to the kinetic energy to move the motorcycles (Jack, 2011).

2.2.1 EA71 Engine Model

One of the internal combustion engines that developed in 1970s is EA71 manufacture by Fuji Heavy Industries under 'Subaru' brand. EA71 engine by Subaru is unique due to most internal combustion engine that have 4 piston is using inline engine configuration, but EA71 engine is using flat-4 design or also know as boxer engine. The EA71 engine was used in Subaru Leone or Brat manufacture from year 1976 to 1994 (www.subaru.com, retrieved on 8 November 2012).

The EA71 engine is gasoline internal combustion engines that have 4 cylinders and 2 valves per cylinder. Each cylinder has 3.62 x 2.36 in of bore and stroke setting than make total displacement is 1595cc. For ignition system, EA71 engine uses distributor with firing order 1-3-2-4. EA71engine use overhead valve (OHV) valvetrain technology by using push rod to actuate the rocker arm to actuate the valves. Figure 2.1 shows the picture of EA71 engine.

Figure 2.2: EA71 engine

Source: www.allenginelist.com, retrieved 8 November 2012

2.2.2 Engine specification

EA71 engine can produce maximum output at 87 brake horse power at engine speed of 5600rpm and maximum torque is 120Nm of 3600 RPM. The brake effective pressure for EA71 engine is about 945.4 KPa and it can reach maximum top speed 150 Km/h. The EA71 engine specification is available in Table 2.1.

Table 2.1: EA71 Engine specification

Specs Item	Specification
Engine Type	EA71 Subaru Engine
Engine Manufacture	Subaru
Engine Variants	EA Engine Family
Displacement	1595cc
Transmission Type	5 Speed Manual Transmission (TM752RX3AA)
Compression Ratio	9 :1
Bore and Stroke (mm)	92mm x 60mm
Valve Per Cylinder	2 Valve
Valve System	Overhead Valve
Fuel System	Carburetor

Fuel Type	Gasoline
Maximum Engine Speed	5800 RPM
Horsepower	88.2 PS (87 bhp) (64.9 kW) at 5600 RPM
Torque	120Nm at 3600 RPM
Engine coolant	Water
Aspiration	Normal
Engine Installation	Front longitudinal
Maximum Top speed	150 Km/h
Brake Effective Pressure	945.4 KPa

Source: www.allenginelist.com, retrieved on 8 November 2012

2.3 GEAR TRANSMISSION SYSTEM

2.3.1 Development of Transmission System

In year 1894, three speed manual transmissions were invented by 2 French investors Louis-Rene Panhard and Emile Levassor. In early year of development of manual transmission, Panhanrd and Levassor use chain drive on their transmission. In year 1898, auto maker Louis Renault improves Panhanrd and Levassor transmission design by substituting a drive shaft for the drive shaft and added differential axle in the rear wheels to improve the performance of the manual transmission system (Yates, 2009).

In the beginning of the 20th century, most of the car manufactures using non-synchronized manual transmission based on the Renault design as a standard for all vehicles By the year 1928, Cadillac introduced the synchronized manual transmission. The synchronized manual transmission significantly reduces gear grinding and made shifting easier and smoother.

In year 1938, General Motor introduced a clutchless automatic transmission, Hydra-Matic which is used a torque converter in state of dry clutch and planetary gear set. Planetary gear uses to replace conversional gear set (Jefferson, McFarland, and Coy, 2008).

The evolution of transmission continued with the development of dual clutch transmission and the sequential manual transmission with the introduction of microprocessor in the 1980s. In year 1981, dual clutch transmission was introduced with prototypes built into the Ford Fiesta Mk1, Ford Ranger & Peugeot 205. Initially dual clutch transmission was designed for use in high performance car like the Porsche 911 and Audi Sport Quattro, until in the year 2003 where it uses in first road car Volkswagen golf Mk4 (www.volkwagen.com, retrieved on 8 November 2012)

2.3.2 Manual Transmission

. Manual transmission is a type of transmissions that give driver ability to choose it desire any forward gear ratio that are available. Manual transmission uses the dry clutch system to connect and disconnect power from the crankshaft, hence control the power flows from engine to transmission. This clutch engagement is controlled by the user using lever can cable system.

Dry clutches transmit torque from engine to manual transmission by use friction phenomenon that was generated when the friction pad mounted on the two sides clutch disk against the rotation of the flywheel and pressure pad. The maximum torque that can transmit by dry clutch is when the clutch is fully close (Francesco, Luigi, Adolfo, and, Maurizio 2008).

Figure 2.3: Manual Transmissions

2.3.3 Advantage of the Manual Transmission Compare to Automatic transmission

The transmission efficiency is becoming a very significant factor in the overall vehicle efficiency due to the increasing stringent emission target and the limits that had been achieved by an internal combustion engine (ICE). During the operation, transmission ratio is selected by the user in the passenger cabin for manual transmission or by a transmission control unit, as in stepper automatic transmission (AT) or continuous variable transmission (CVT). This transmission ratio is select depend on the vehicle driving conditions.

Manual transmissions have the advantage of having high mechanical efficiency, with the most of the lost come from the lubricant churning which is an undesirable friction that occurs between fluids. Automatic transmission l have lower mechanical efficiency compare to manual transmission because automatic transmission needs to constantly run the hydraulic pump to provide the power for clutch actuation, cooling, gear, and bearing lubrication. The Hydraulic pump is directly driven by the output from the internal combustion engine, and is rated to provide the required oil pressure and flow rate to enable clutch actuation (Andrew, Keith, Richard, and David, 2007).

2.3.4 Motorcycle Transmission

There are two types of transmission that mostly use in motorcycles to transfer engine rotational energy to the driving wheel; sequential manual transmission and continuous variable transmission. The sequential manual transmission mostly will be use in modern motorcycles except for scooter and ATV where they used continuously variable transmission as its transmission box (Abdo, 2002).

The sequential manual transmission, the gears only can be selected in order and direct access to specific gear is not allowed. On the sequential manual transmission gearbox, the gear shift lever operates a ratchet mechanism that converts the back and forth movement of the shift lever into a rotary motion. This rotary action will turn a selector drum which has three or four tracks machined around its circumference. Running on the tracks is the selector forks, either directly, or via selector rods. These tracks deviate around the circumference and as the drum rotates, the selector forks running on the tracks are moved to select the required gear (Valentina, 2010).

While for continuous variable transmission, it will consist of a drive pulley which is attached to the engine crankshaft and a driven pulley that's attached to a shaft which may also incorporate a centrifugal clutch. Driving and driven pulley are connected by a drive belt. As engine speed increases, centrifugal force pushes the weight rollers outward. This force pushes the movable face toward the fixed face, which in turn pushes the drive belt upward toward the top of the drive pulley. This reduces the drive ratio by forcing the drive belt to ride on a pulley of larger diameter. As the engine speed decreases, the belt is pulled back into the drive pulley, which increases the drive ratio by allowing the belt to ride on a pulley of smaller diameter (Abdo, 2002).

2.4 GEAR SHIFT AND FUEL CONSUMPTION

Based on the transmission gear ratio and engine data, it is important to get the harmonic gear shift position to optimize the vehicle performance and fuel consumption. Based on the analysis of the relation between driving behaviors and fuel consumption prove factor like gear selection, driving speed and acceleration or deceleration will give largest influence on the fuel consumption. These researches also show, the fuel consumption at the same average driving speed can be increased up to 20% only due to differences in the manner of gear shifting. The effect of the gear selection at the same speed and total fuel consumption can observe in Figure 2.3.

When taking fuel consumption in 5th gear at speed of 50km/h as a branch mark. At 50km/h, the results show that 3rd gear consume more fuel compare to when the drive's selected 5th gear when the speed is 50km/h. This can be concluded that significant saving in fuel consumption can be achieved by select suitable gear set which has both large economic and environmental significance (Ivan, Goran, Gradimir, Slobodan, and Vladimir, 2010).

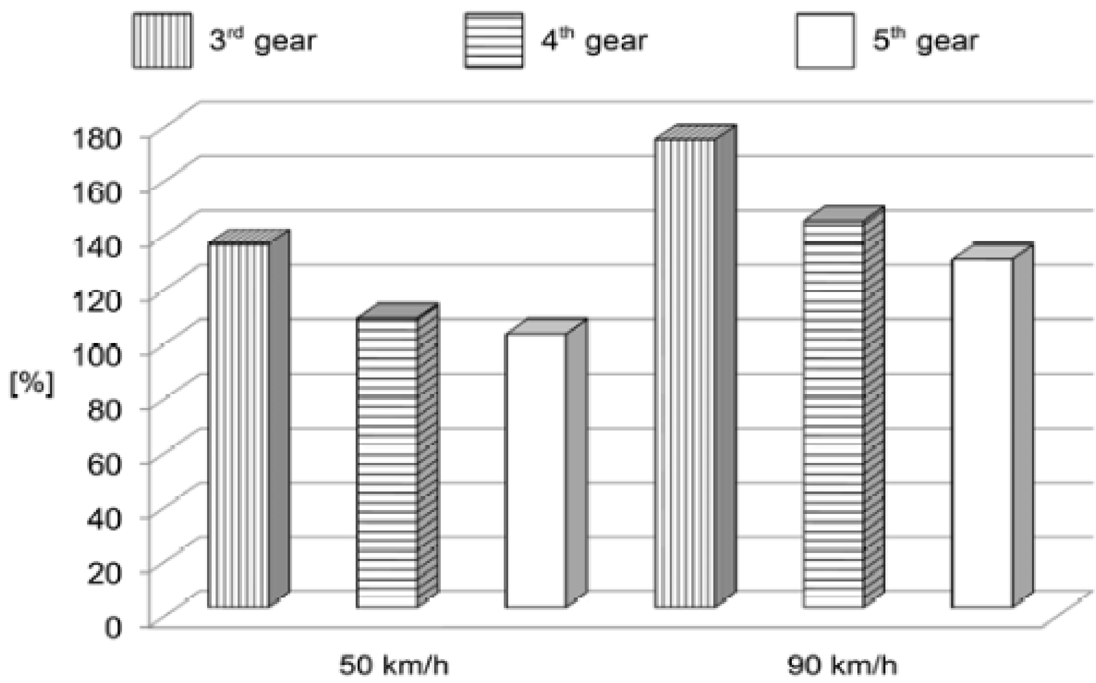


Figure 2.4: The percentage of fuel consumption at constant with difference gear selection

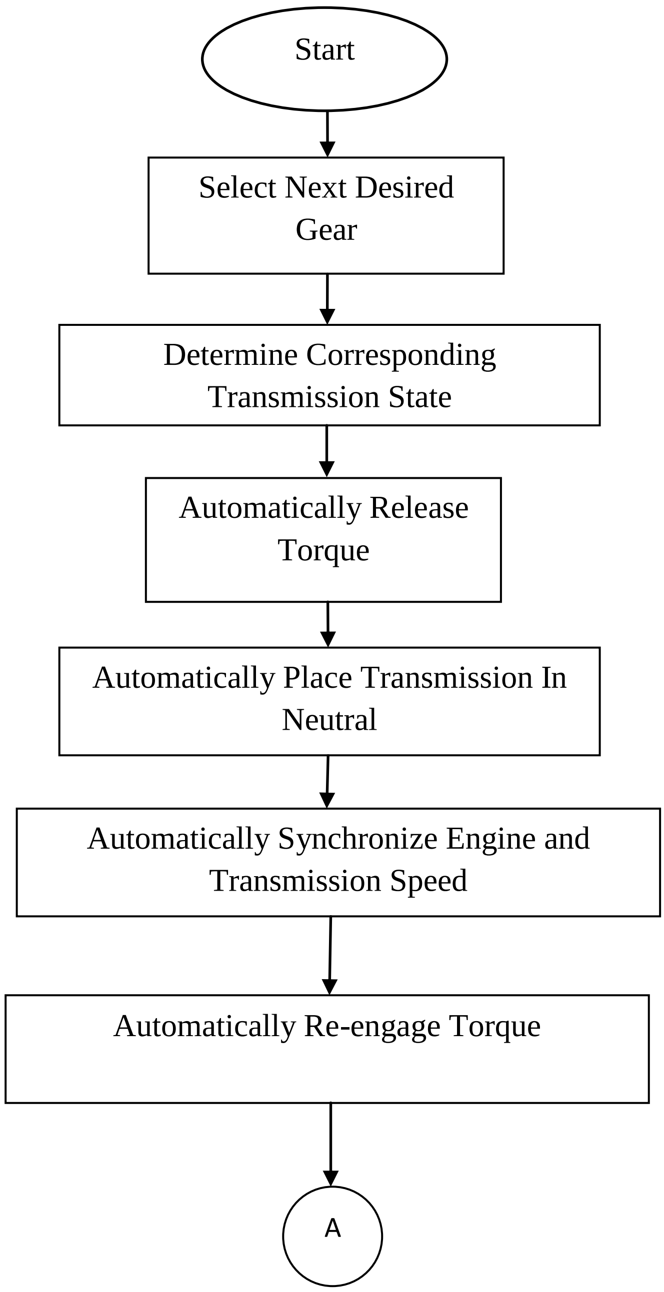
Source: Ivan, Goran, Gradimir, Slobodan, and Vladimir (2010)

2.5 SHIFTS BY WIRE SYSTEM

A shift by wire system is a system that uses electrical connection to replace a mechanical connection between the gearshift and transmission (via cable control or gearshift linkage). The electrical connection uses analog or digital signal to communicate with transmission.

Some of transmission manufacturer in the world will include the automation of clutch for shift by wire system. This kind of system will have an electronic transmission control unit (TCU) to control engine speed during a shift in order to synchronize the speed of an engine shaft and the transmission shaft. The driver just chooses a gear shift by moving shift lever, push or rotated switch to send electrical signal indicative of the desired change in gear (Huber, 1998).

There are many of advantages shift by wire system over conversational mechanical linkage system. Shift by wire system will provide optimal functional reliability and operating convenience due to less shifting force is required to shift gear. It also has flexible integration capabilities with the motorcycle body design (Matthias and Thomas, 2010). The shift by wire system to change gear flow chart will be displayed in Figure 2.5.



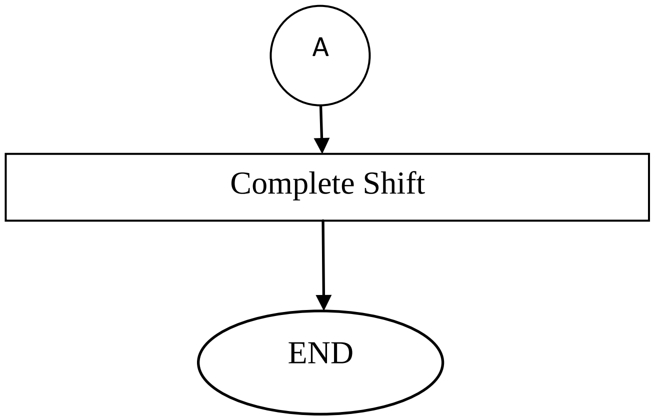


Figure 2.5: Shift by wire system to change gear flow chart

Source: Huber (1998)

2.5.1 Shift by Wire Shifting Mechanism

Shift by wire system shifting mechanism is different compare to conventional mechanical shifting process. For mechanical gear shifting system, the gear lever is attached to the transmission gear shift rail via mechanical linkage. While the shift-by-wire gear shifting system, there are no mechanical linkage between transmission and gear lever. In the shift-by-wire system, the transmission control unit (TCU) will receive electrical signals from the shift lever and send electrical signal to activate actuator that attach to the transmission gear shift rail (Haber, 1998).

The shift-by-wire actuators mainly consist of a combination between linear actuator and rotary actuator. Rotary actuator is directly connected to the linear actuator shaft, and used to move between gear shift rail while linear actuator for rail displacement. Hence, allows selection of all transmission gear ratios (Andrew, Keith, Richard, and David, 2007).

2.5.2 Shift by Wire Actuator

For shift by wire system, a high-force linear actuator is used to control the engagement of the gear. There are many types of linear actuator that available in the market. For example of linear actuator are electro-mechanical actuators. This actuator design is similar with a mechanical actuator but the mechanical linkage is replaced with an electric motor. The rotational motion of the electric motor is transferred to linear displacement of the cylinder. The electric motor will locate on the side of the actuator cylinder as separate cylinder.

Beside the electro-mechanical linear actuator, there are other types of linear actuator like hydraulic actuator, pneumatic actuator, and linear motor actuator. The advantage and disadvantage of each type actuator are shown in Table 2.2 (Sclater, 2007).

Table 2.2: Advantage and disadvantage of each type of actuator

Actuator type	Advantages	Disadvantages
Electro-mechanical	Cheap, repeatable, identical behavior, reliable, using DC motor, position feedback possible	Moving part have risk to wear
Hydraulic	Very high force	Leakage, external pump required.
Linear motor	Simple design due to minimum of moving part. High-speed.	Low thrust force
Pneumatic	Strong light, simple, and fast	Precise position control impossible except at full stops

Source: Sclater (2007)

2.5.3 Shifting Time and Force Require For Shift by Wire System

By using linear actuator, it is directly joined to the shaft of the gearshift rails and allows selection of all the transmission gear ratios. Based on the typical ‘ H-gate’ gate pattern, the target shift actuation times, and rail displacements from gear-to-gear and from rail to rail as shown in Figure 2.6 (Andrew, Keith, Richard, and David, 2007).

For typical manual transmission, the gear selector rail displacement range is about 16mm (±8mm for neutral stroke) and a peak force of up to 1KN is to applied to the selector rail during the gearshift time, which may take around 0.5-0.7 seconds from neutral to full gear engagement. Figure 2.7 shows a relationship of typical manual transmission from gear to gear shift event with the force on the selector rail, the speed of shafts that are being synchronized and the shift rail displacement (Andrew, Keith, Richard, and David, 2006).

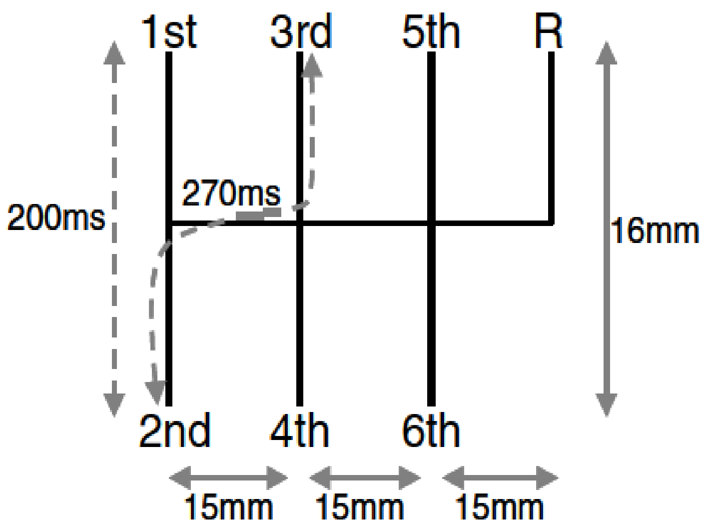


Figure 2.6: Rail transmission ‘H-gate’ shift pattern showing target displacements and time taken for actuation

Source: Andrew, Keith, Richard, and David (2007)

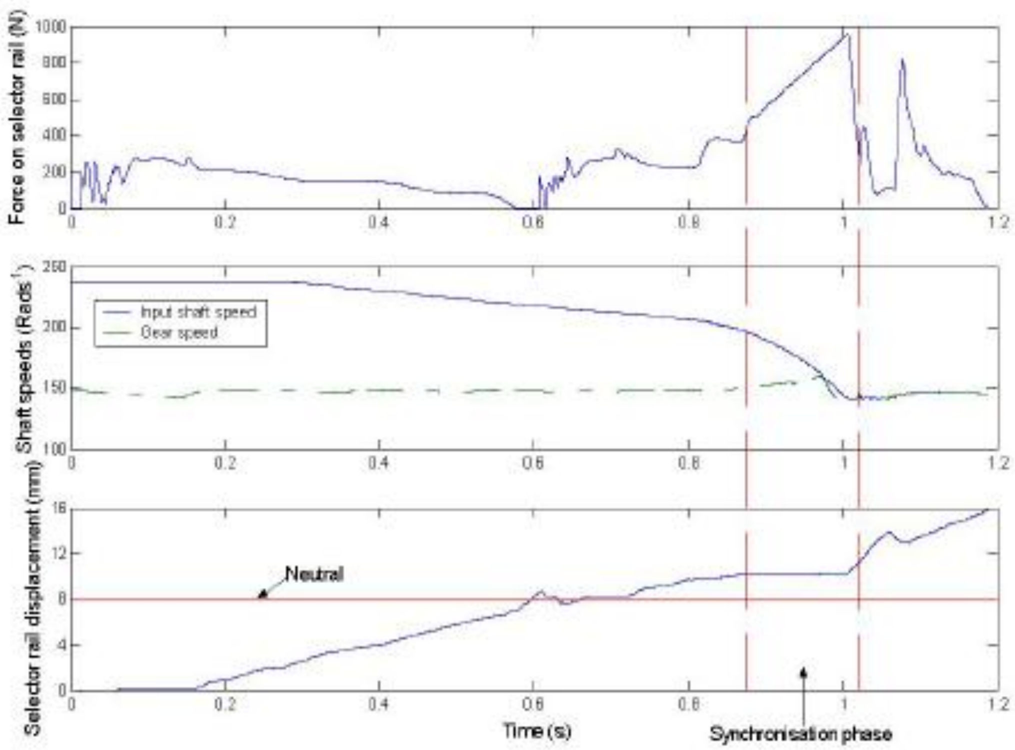


Figure 2.7: Manual transmission gear shifts event showing shift rail forces, shaft speeds and selector rail displacement.

Source: Andrew, Keith, Richard, and David (2006)

2.6 GEAR TRANSMISSION OUTPUT CONNECTION SYSTEM

2.6.1 Chain Drive System

Most of the motorcycles use the chain drive system because they are much more efficient compared to drive shaft or belt drive system. The chain drive system has a lot of advantages compared to other mechanical transmission method like, relatively inexpensive compare to other, length of chain is unlimited and many more. Besides that, chain drives have 95% to 99% for mechanical efficiency compared to the belt drives (www.Rexnord.com, retrieved 8-11-2012).

2.6.2 Type of Motorcycle Chain

Motorcycle roller chains usually come in a variety of sizes. The most important dimension of roller chain is the pitch of roller chain. Pitch dimension is the distance between pin centers. Normally the pitch of motorcycle chain varies from 3/8 inch to 3/4 inch. Table 2.3 summaries the key dimensions of chains used on motorcycles (Stuart and Chris, 2004).

Table 2.3: Typical motorcycle chain sizes

Chain code	Chain pitch (in)	Roller width (In)	Roller diameter (In)	Pin diameter (In)	Typical bike size (cc)
428	1/2	5/16	0.335	0.174	100
520	5/8	1/4	0.4	0.2	500
530	5/8	3/8	0.4	0.2	100
630	3/4	3/8	0.469	0.234	1300

Source: Stuart and Chris (2004)

2.6.3 Type of Motorcycle Sprocket

The motorcycle sprockets can be made with any number of teeth. But there are limitations on the minimum and maximum number of teeth that are possible due to the polygon effect.

According to the Figure 2.8, the roller chain will suffer a 4 percent change of speed when applied on the sprockets that have 11 teeth. If a 21-tooth sprocket is used, this imbalance will not exceed 1 %. From this figure also, it shows it is not suitable to use sprocket with less than 13 teeth even for low speed and loading.

Besides that, in the case of moderate speeds up to 6m/s, the chosen sprockets should have at least 17 teeth. For good running performance at mean speeds up to 15 m/s and have moderated loading, then sprockets with 21 to 25 teeth should be chosen and beyond.

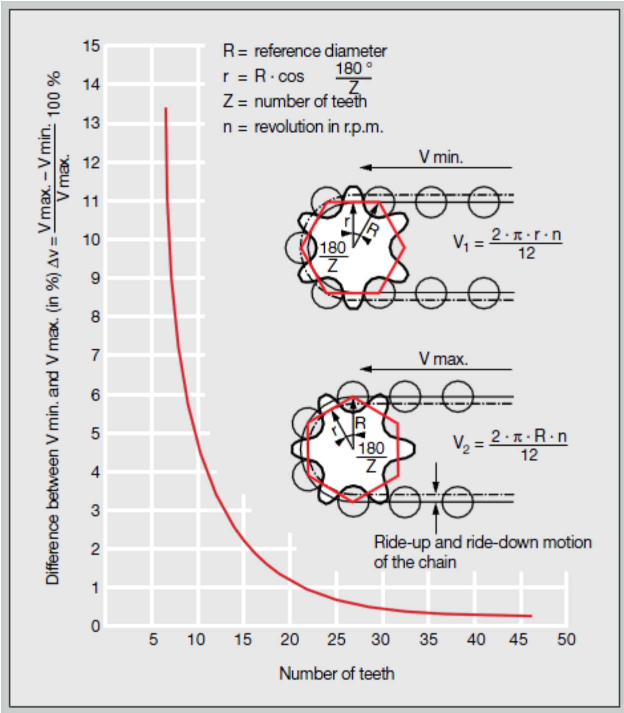


Figure 2.8: The number of teeth of the sprocket that need to choose based on the difference between V min and V max using polygon effect

Source: www.rexnord.com, retrieved on 8 November 2012

2.7 OPTIMIZATION OF CHAIN DRIVE SYSTEM

2.7.1 Optimization of the Sprocket

Because the chain transmission efficiency can be dropped when motorcycle reaches high speed, it is very important to choose the sprocket system that can give best transmission efficiency base on various conditions. Base on the experiment, 3 set of sprocket combination is that have similar gear ratio but difference sprocket size installs in the 600cc motorcycles.

From the Figure 2.9, it shows that by using larger sprocket teeth on the rear wheel will cause inertial tension when the speed is over 70miles/h, hence will make the chain consume more energy from the engine. For speed less that 70mile/h, the motorcycles with larger rear sprocket will have some advantage because increases in the sprocket mass and inertial would give better efficiency, smoother drive and longer chain and sprocket life (Stuart and Chris, 2004).

This shows that optimal sizes of the sprocket can be highly dependent on the motorcycle's speed.

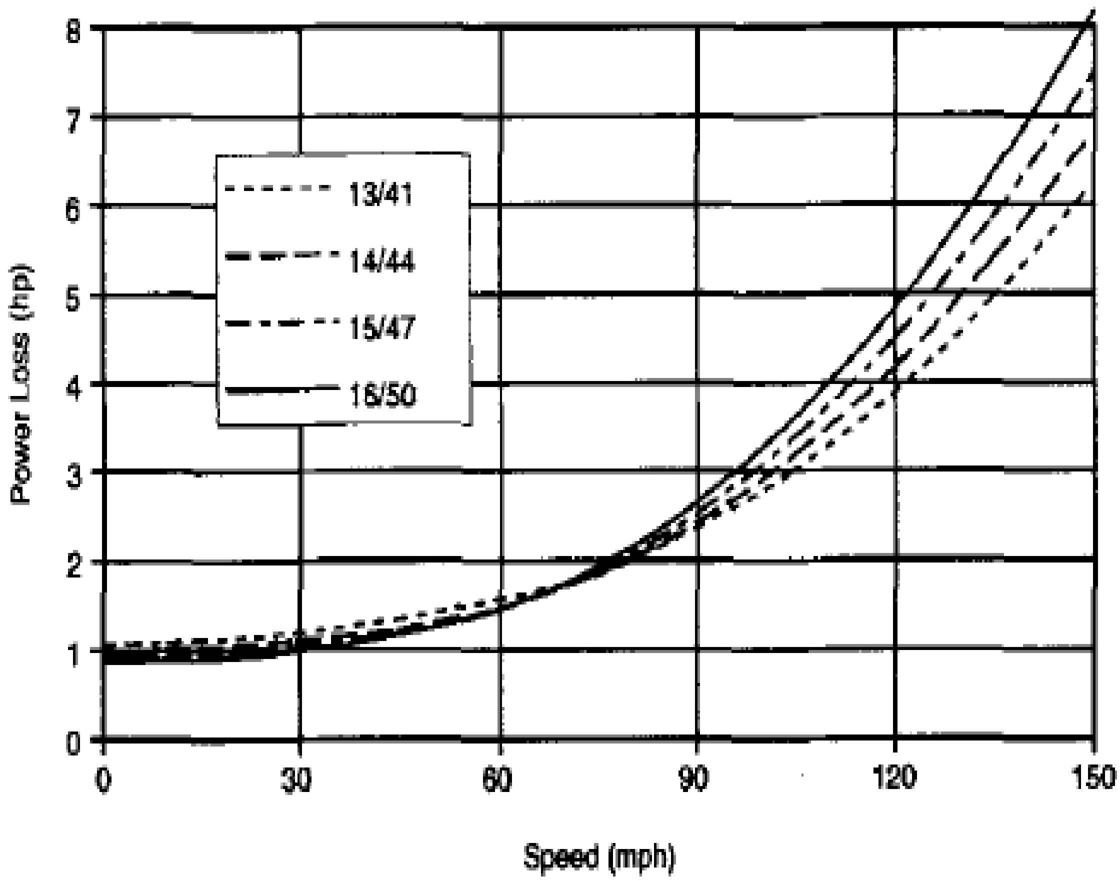


Figure 2.9: Power losses from 600cc motorcycles chain using different sprocket size with similar gear ratio

Source: Stuart and Chris (2004)

2.7.2 Optimization of the Chain

Optimization of the chain also plays an important key to increase the efficiency of the power transmission. Base the experiment, it shows that the most efficient chain drive transmission is use the chain with smallest bush internal diameter (Stuart and Chris, 2004).

2.8 GOVERNING EQUATION AND PARAMETER

Wheel circumference $W_c = 2\pi \; x \; r$ (2.1)

Where r is wheel radius

Angular velocity $\omega = \frac{2\pi \; x \; engine \;\; speed}{60}$ (2.2)

Angular velocity is defined as the rate of change of angular displacement and is a vector quantity (more precisely, a pseudo vector) which specifies the angular speed (rotational speed) of an object and the axis about which the object is rotating.

Final drive gear ratio $F_D = \frac{N_{output\ gear}}{N_{input\ gear}}$ (2.3)

Final gear ratio defined as the ratio of the angular velocity of the input gear (transmission) to the angular velocity of the output gear (wheel).

Motorcycles speed, $v = \frac{\omega \; x \; r}{i_P \;\; x \; I_{GB} \; x \; F_D}$ (2.4)

Where r is wheel radius

i_P is primary gear ratio

i_{GB} is transmission gear ratio

CHAPTER 3

METHODOLOGY

3.1 MECHANICAL POWER TRANSMISSION SYSTEM FOR AIR HYBRID FOUR WHEELS MOTORCYCLE

For the Mechanical Power Transmission System, 4 wheel air hybrids will be using the chain drive system to transfer torque and power from the transmission to the rear driving wheel. Chain drives were selected because it has high mechanical efficiency comparing to belt drive .Since the transmission box has 1 mechanical power output shaft on the both sides, one of the shaft will be used for driving the left rear wheel and another for right rear wheel.

The chain drive system consists of 2 sets of carbon steel chain sprocket with different number of teeth on each side of 4 wheel motorcycles. To increase the engine torque receive by driving wheel at the rear, under drive configuration is used. In this configuration, the sprocket with higher teeth numbers will be used on the rear wheel hub and smaller teeth number at transmission output shaft.

The external differential is not required due to the transmission already has built-in differential with a final drive ratio is 3.900. The gear ratio is controlled by changing the shift-by-wire sequential system. These systems replace the mechanical linkage with electrical connection. There are 2 electro-mechanical actuator connects the gear shifter lever that located at gear transmission box. This actuator will convert electrical signals to the 'H' patter movement to shift the gear. Below is the schematic diagram of mechanical power transmission system.

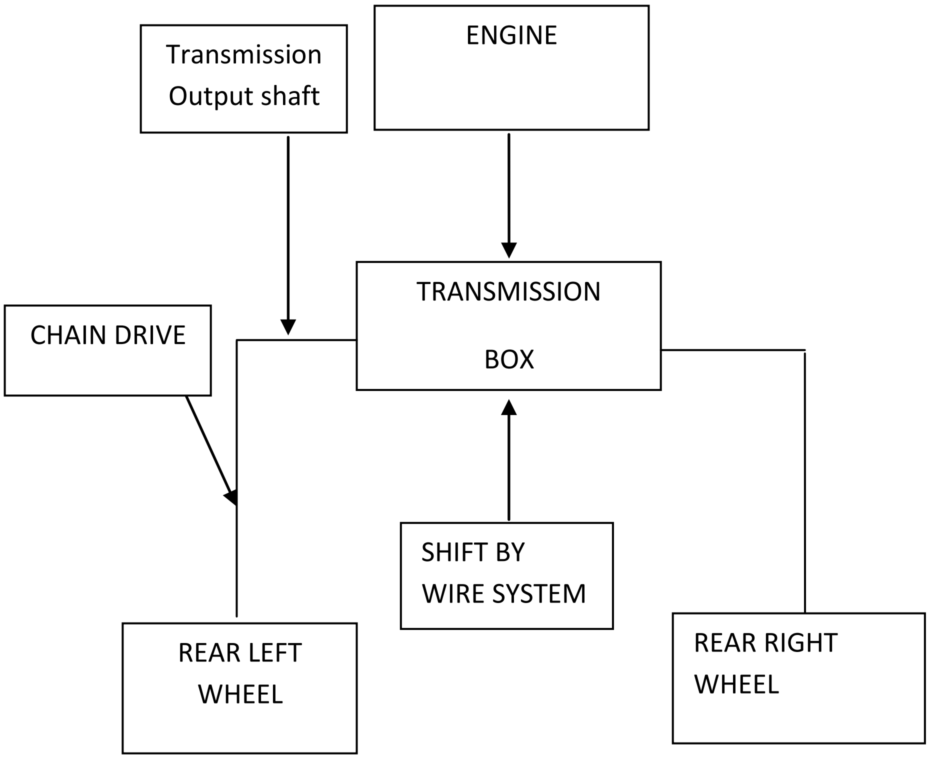


Figure 3.1: Schematic Diagram of Mechanical Power Transmission System

3.2 SEQUENTIAL SHIFT-BY-WIRE SYSTEM

In these 4 wheels air-hybrid motorcycle will use sequential shift-by-wire system to change the transmission gear ratio. By going sequential shift by wire system, the drive can change the transmission gear ratio without letting go handlebar while still driving. In this system, complexity of manual transmission 'H' patter gear shift is replaced by using push button which acts as gear selector.

Shift-by-wire systems give a high degree of integration with motorcycle chassis because it does not have any mechanical linkage to connect with gear shifter located on transmission box. This system only fully depends on the electro-mechanical actuator control by a control module. Below is the flowchart for the gear shifting process in manual transmission by using sequential shift-by-wire system in 4 wheel air hybrid motorcycle.

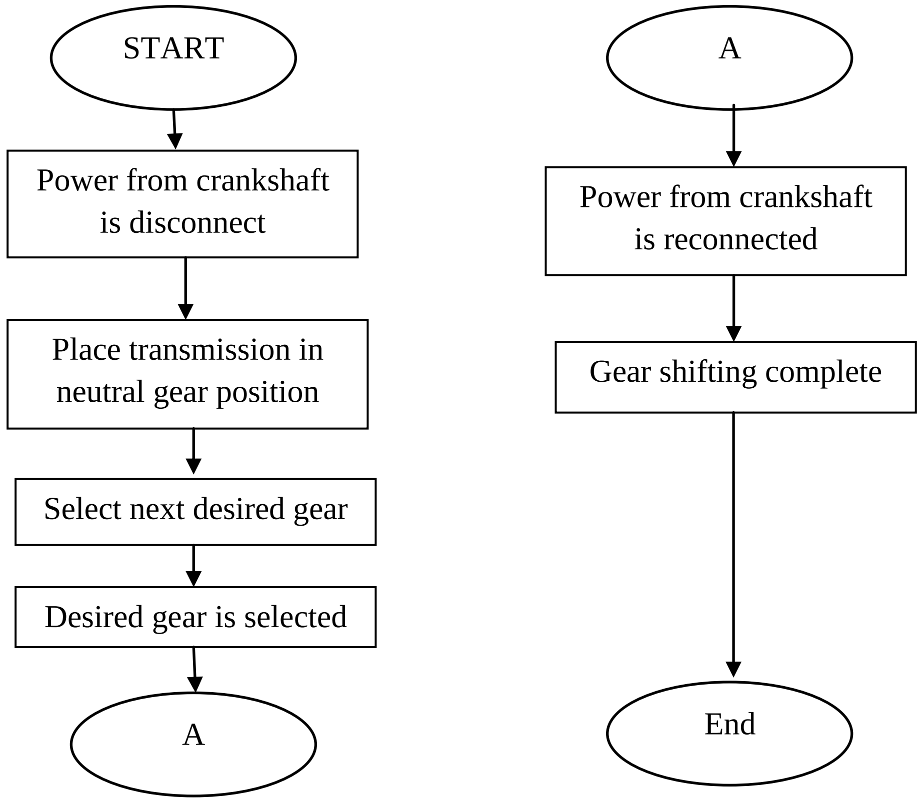


Figure 3.2: Flowcharts for the gear shifting process in manual transmission by using sequential shift-by-wire system.

3.3 SEQUENTIAL SHIFT-BY-WIRE SYSTEM DESIGN

3.3.1 Hardware

For sequential shift-by-wire system, a single unit of Peripheral Interface Controller (PIC Microcontroller) is used to control the gear shifting process. PIC Microcontroller is programmed to make gear shifts according to the user input. The user can give input to down shift or up shift gear by pressing push button (right side for up shift, left side of down shift) that located on the 4 wheel motorcycles handle.

2 units of electro-mechanical linear actuator is needed to control gear shifting in ‘H’ pattern. Each one of this actuator will use to control 1 axis. Electro-mechanical linear actuator ‘A’ is use to controlling X-axis while linear actuator ‘B’ to controlling Y-axis.

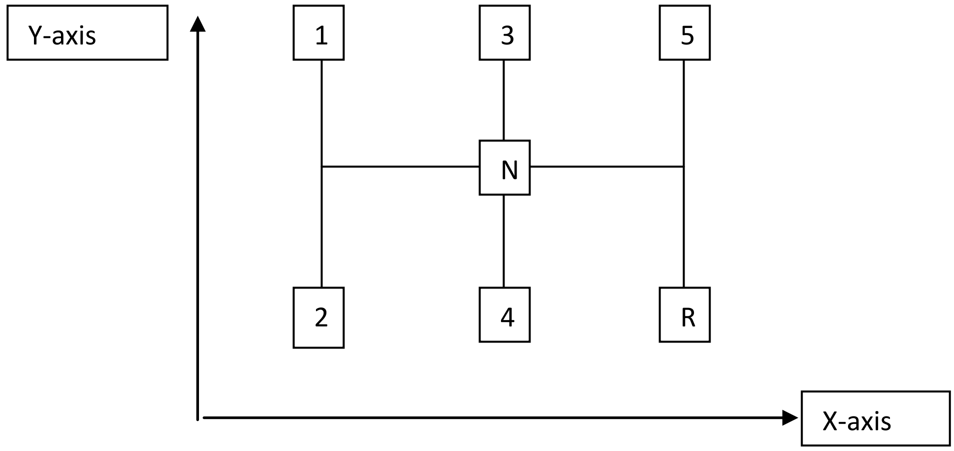


Figure 3.3: Typical 'H' patters for 5 speed manual transmissions

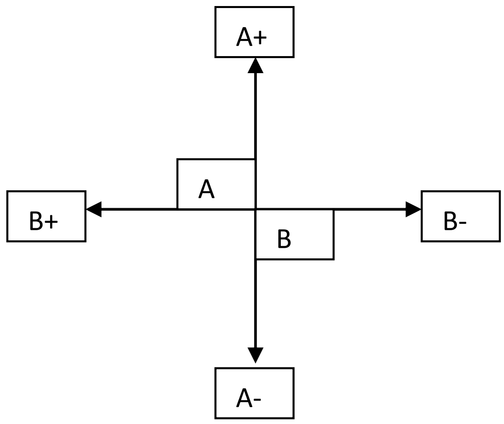


Figure 3.4: cylinder Position coding for electro-mechanical linear actuator

3.3.2 Software

Since the PIC microcontroller is used as the main controller for shift-by-wire system, it required a program or software that can change C programming language to become HEX code. Programming software like PIC Compiler, Mikro and MPLAB are suitable to be used as a PIC compiler to compile C programming language to HEX code. Graphical programming language like FlowCode also can be used to programming a PIC microcontroller.

For this project FlowCode graphical programming software was chosen to be used as programming software for the PIC microcontroller. FlowCode was chosen because it has ability to allow those with little programming experience to create complex programming for electronic systems. This is because FlowCode using flowchart instead of a textual programming likes MPLAB.

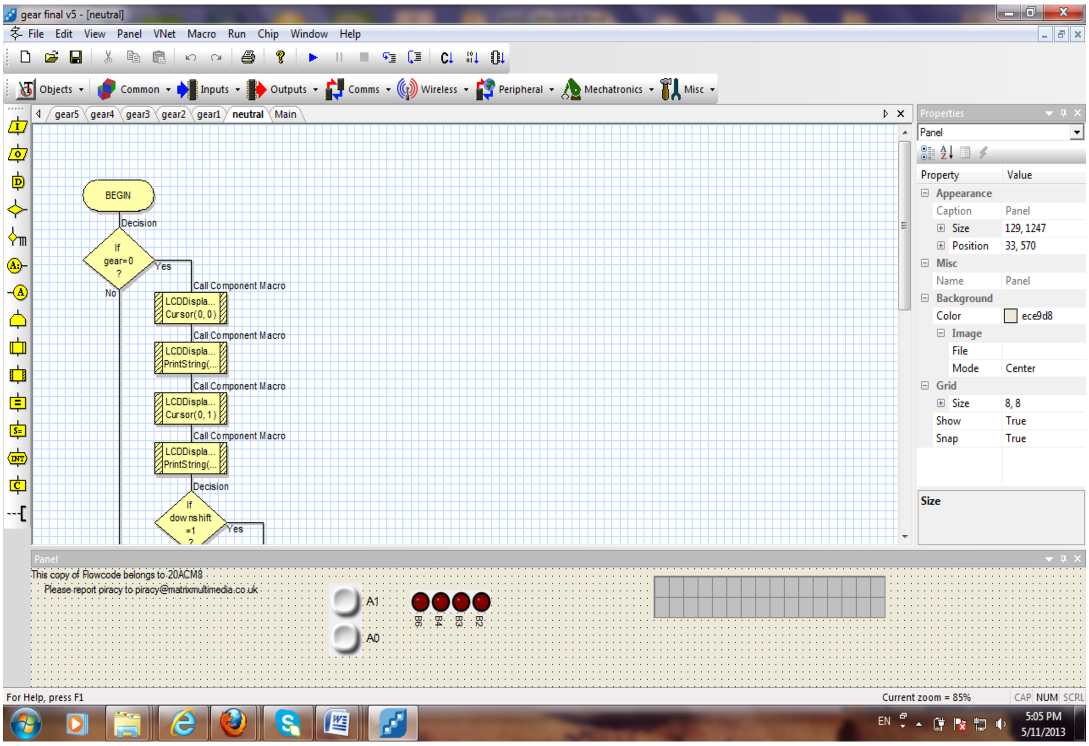


Figure 3.5: FlowCode user interfaces

3.4 ELECTRONIC BOARD CIRCUIT

For this sequential shift-by-wire system, there are basically three main stages of electronic board circuit design which are:

a. Digital Input Circuit: Sense 5v digital input from push switch

b. Microcontroller Circuit: Power up the microcontroller and process the input signal to send output signal.

c. Output Circuit : Send output voltage to SPDT relay

3.4.1 Digital Input Circuit

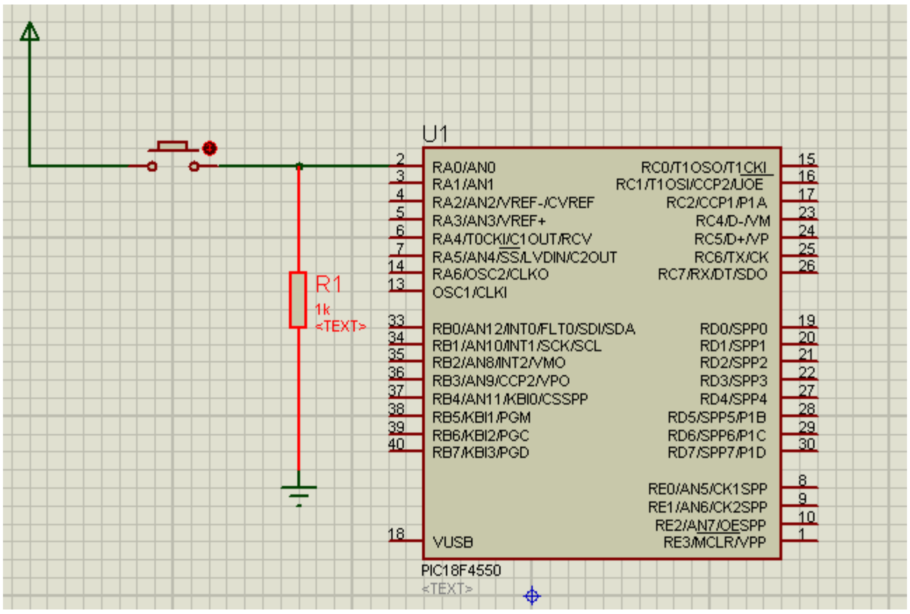


Figure 3.6: Digital input circuit

This circuit design is to give a 5v digital input to the microcontroller. When the push button is pressed, a 5v direct current is flowing to the microcontroller input port. After the push switch is released, the 1k resistor will pull the current and force the current to be grounded. This flow change will make microcontroller to sense high logic '1' when push button is pressed and low logic '0' when push button is released.

3.4.2 Microcontroller Circuit

As already mentioned, PIC microcontroller PIC18F4550 is used to control predefined sequence program that had been stored in PIC memory for opening and closing SPDT relay that will act as H-bridge to actuate the electro-mechanical linear actuator. The figure below is showing the basic circuit design that must have in order to operate a microcontroller.

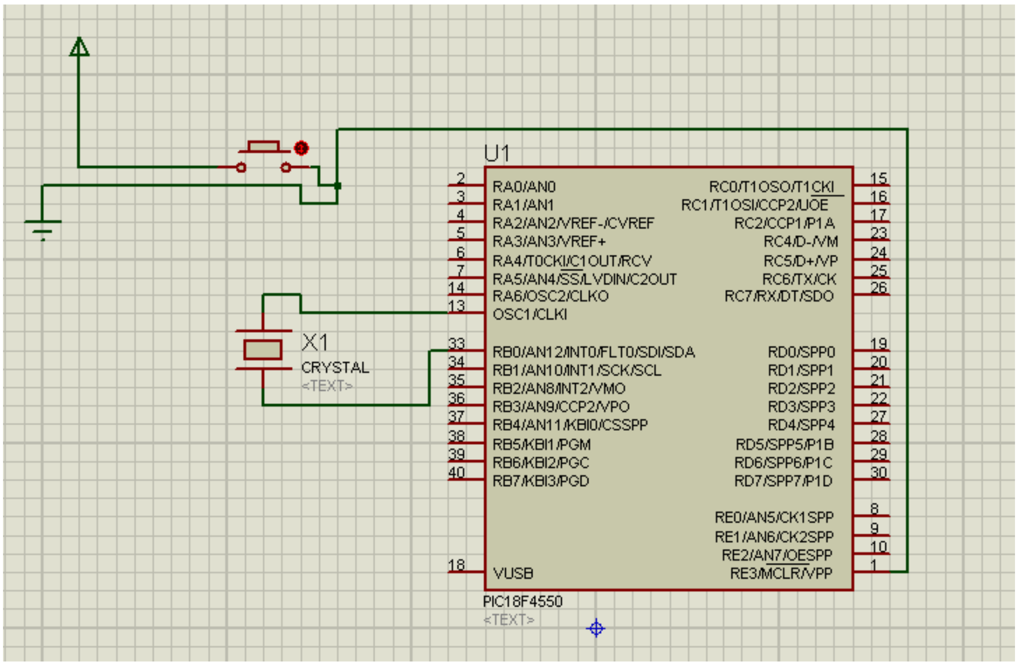


Figure 3.7: Microcontroller circuit

For PIC18F4550, it have 5 input/output port knows as Port A, Port B, Port C, Port D and the last one is Port E. For sequential shift-by-wire, only Port A and Port B are used, while Port D was reserve for LCD displays. Generally, Port A will use to sense input signal from push switch and Port B is used to send digital signals to output circuit to actuate electro-mechanical linear motor actuator.

But all of this circuit design for microcontroller circuit already simplifies by using a SK40C PIC starter kit which is specially designed for PIC 18F4550. By using the SK40C PIC starter kit, main circuits that need to operate a microcontroller are already included inside SK40C circuit. In order to use PIC microcontroller, the user just needs plug-in PIC microcontroller on the Sk40C starter kit.

3.4.3 Output Circuit

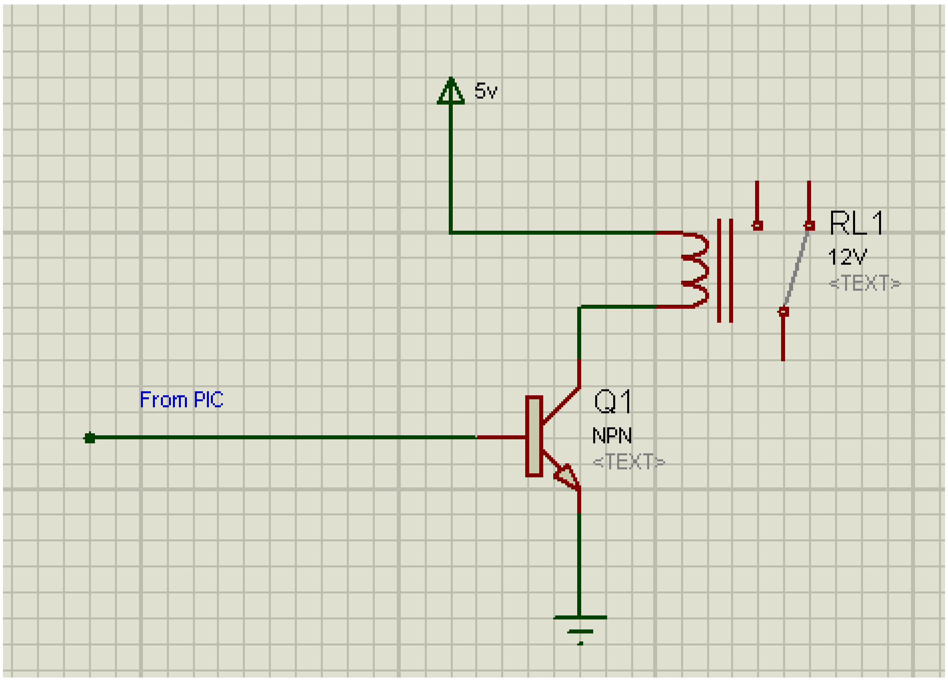


Figure 3.8: Output circuit

PIC 18F4550 Microcontroller specification shown rated output ampere is about 25mA. This output ampere is not enough to trigger a relay that required 71mA of current. Therefore, output circuit above is designed to trigger the relay at low current output signal. By using this circuit, the relay will be activated when microcontroller sending digital signals.

3.5 Analysis Parameter

There are few data that need to collect when doing performance testing on the 4 wheel air hybrid motorcycles drivetrain system. Data like engine and motorcycle speed, engine torque and horsepower are important because it can be used to draw the drivetrain performance graph and calculate the right speed to change the gear ratio.

The torque that available on the rear wheel of reach gear can be calculated by using the following formula:

Motorcycles rear wheel torque $T_{wheel} = T \ x \ i_P \ x \ i_{GB} \ x \ F_D$ (3.1)

Where T is engine torque at a particular engine speed

i_P is primary gear ratio

i_{GB} is transmission gear ratio

F_D is final drive ratio

3.6 MECHANICAL COMPONENTS

3.6.1 5 Speed Manual Transmission (TM752RX3AA)

Figure 3.9: TM752RX3AA 5 speed manual transmissions

Figure 3.9 shows manual transmission that will be used in a 4 wheel air hybrid motorcycles. Manual transmission is chosen because it has high mechanical efficiency compare to automatic transmission to distribute air engine power and torque to driving wheel. Besides that, this manual transmission is suitable to be used with the EA71 engine model.

This manual transmission comes with 2 over drive gear which is located on 4th gear and 5th gear and final drive ratio 3.900. It has 2 constant velocity shaft output on the both sides on transmission with is connected to the internal differential inside the transmission housing. The gear ratio for this manual transmission is available in Table 3.1.

Table 3.1 Gear ratio for TM752RX3AA 5 speed manual transmissions

Gear	Gear ration
1st	3.636
2nd	1.950
3rd	1.344
4th	0.972
5th	0.780
Reverse	3.583
Final drive	3.900

Source: www.Subaru.com, retrieved on 1 December 2012

3.6.2 Sprocket

To transfer power and torque from air engine to driving wheel, chain drive system is used. In chain drives system, it have 2 main part; sprocket and roller chain. To make a complete chain drive system, there are at least need to have 1 set of sprocket. Normally, driven sprockets have more teeth compare to drive sprocket. The propose using this kind of configuration because to increase the engine torque. For build material, most of the sprocket using steel, aluminium alloy and titanium.

For this project, 4 wheel air hybrid motorcycles are using two rear wheel drive system (2WD) with under drive configuration. So two set of chain drive is required for each side of motorcycles to drive it.

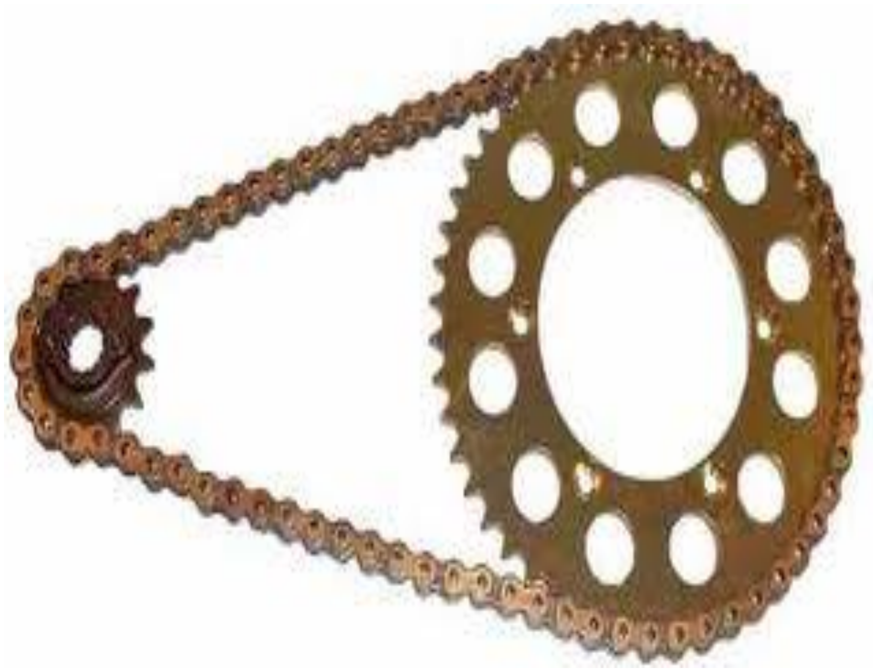


Figure 3.10: Sprocket set with roller chain

Source: www.rexnord.com, retrieved on 8 November 2012

3.6.3 Roller Chain

Roller chain is use to connect drive sprocket with driven sprocket. Roller chain consists of two types of link; roller link and pin link. Most of the roller chains are made from hardened high carbon steel.

428 roller chains is most suitable to be used in 4 wheel air hybrid motorcycles, this is because it have smaller pitch dimension compare to other roller chain. By having smaller pitch dimension will reduce the power loss and increase transmission efficiency.

Figure 3.11: Roller chain

Source: www.rexnord.com, retrieved on 8 November 2012

3.7 ELECTRICAL COMPONENT

3.7.1 Electro-Mechanical Actuator

Figure 3.12: Electro-mechanical linear actuator

Source: www.cytron.com, retrieved on 8 November 2012

There are many types of linear actuator that available already in the market like actuator like hydraulic actuator, pneumatic actuator, and linear motor actuator. For 4 wheel air hybrid motorcycles application, electro-mechanical linear actuator is the most able linear actuator to be used.

The electromechanical linear actuator is chosen because it is cheap compared to the other type of actuator and it uses a DC as power supply which is suitable use in the 4 wheel air hybrid motorcycles. By using electro-mechanical linear actuator also will give more advantage to precisely control the position compared to pneumatic linear actuator.

The specification that required by for electro-mechanical linear actuator is having thrust about 1KN has actuation speed about 20mm/s and can run on 24VDC power supply.

3.7.2 Relay Switch

To control the movement electro-mechanical linear actuator, a relay must be used. The relay is a type of electromagnetic switch by using electric current flow to do on and off function. When the electric signal send to the relay, relay coil will become magnetic and complete the circuit between 24V battery supplies to the electro-mechanical linear actuator.

By only using ‘ON-OFF’ function in the relay, the flow direction of electrical current can be controlled hence control the movement of actuator cylinder. Based on the schematic diagram for shift-by-wire sequential manual system, at least 16 relay with 24V must be used to complete the system.

.

Figure 3.13: Relay

3.7.3 PIC Controller 18F4550

In this project, the PICF4550 microcontroller has been chosen to be used to control the electro-mechanical linear actuation so that the sequential shift-by-wire system can actuate according to the preset program. This PICF4550 microcontroller use 5 volt low supply to operate. Compare to other PIC, it has more number of input/output port, so it can provide enough input and output for sequential shift-by-wire system. Furthermore, it can support frequency as high as 20MHZ.

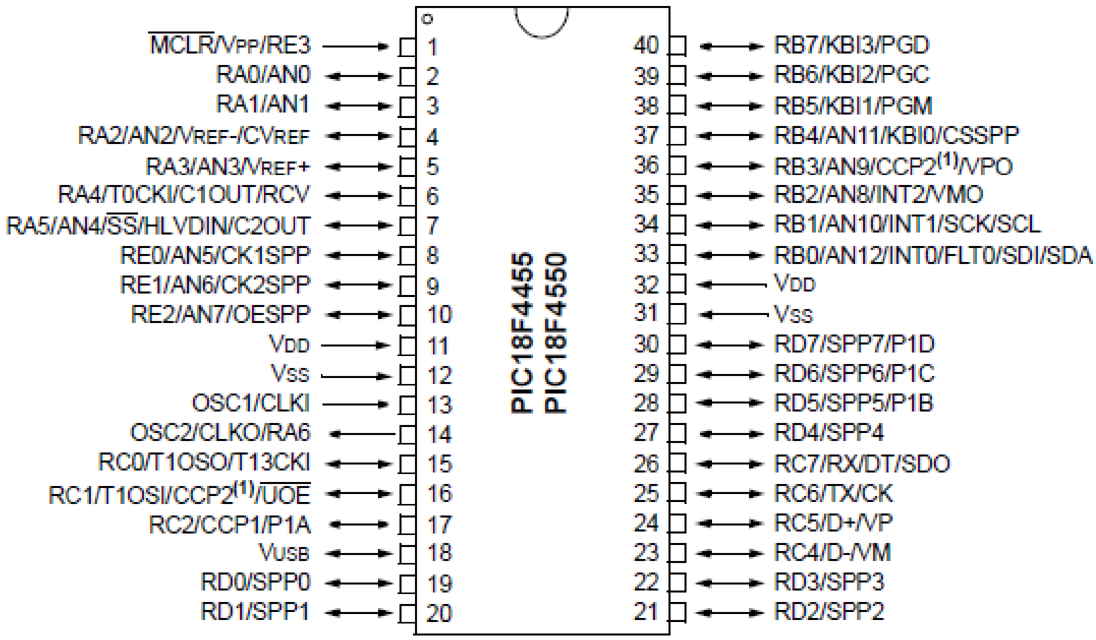


Figure 3.14: PIC 18F4550 diagram

Source: www.cytron.com, retrieved on 8 November 2012

3.7.4 SK40C PIC Starter Kit

The SK40C Starter kit is specially designed to be used with PIC 18F4550. It is enhanced version compare to SK40B. SK40 is designed to give an easy to start boarding for new PIC micro controller user that's not very familiar with PIC circuit wiring. But all interfaces and program need to be designed and developed by user itself. It offers plug and use features so user just plug in PIC micro controller and start programming job. By using SK40 it can save development and soldering time.

SK40 comes with 33 I/O pin that nicely label to avoid miss-connection by user and 20 MHz high speed crystal oscillator. It is also designed with UIC00A/B connector for fast and simple method to load programs into PIC controller.

Figure 3.15: SK40C

Source: www.cytron.com, retrieved on 8 November 2012

3.7.5 NPN Transistor

In this project, the NPN type transistor is used. The amount of current and voltage that provide by the microcontroller is not sufficient to trigger the relay. Because of that, existence transistor is acquired to make sure there has enough current and voltage flow hence trigger on the SPDT relay.

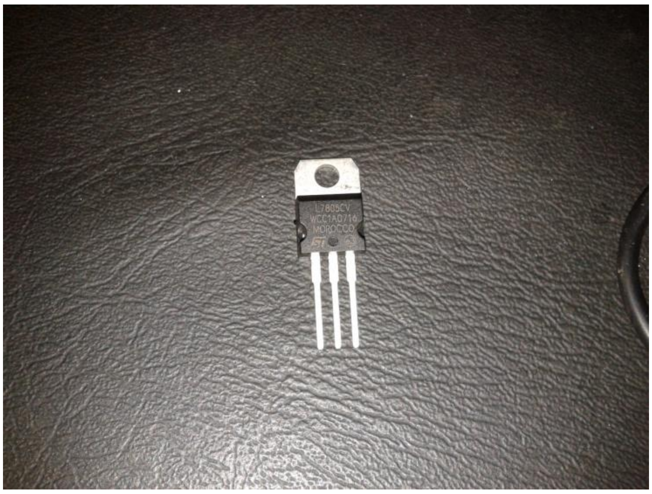


Figure 3.16: NPN Transistor

3.7.6 Diode

In order to avoid high external DC power supply from battery that might harm low voltage microcontroller, diode is used. This diode will only allow current and voltage to flow in one direction and it prevents voltage goes into the microcontroller. In this project, IN4007 general diode is used.

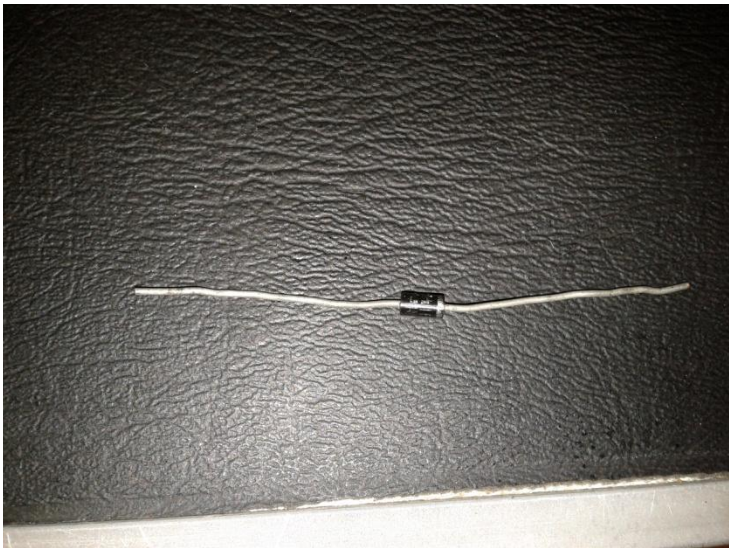


Figure 3.17: 1N 4007 diode

3.8 FABRICATION

The fabrication process began after all the selected components and material were completely obtained. First of all, the sequential shift-by-wire system testing rigs need to design and fabricate. The purpose of fabricate testing rig is to test the system before it install in the 4 wheel motorcycles. The design of test rig must be according to the 4-wheel motorcycles chassis transmission compartment, so it can fit into the chassis after all testing done on the test rig.

3.8.1 Test Rig design for Sequential shift-by-wire system

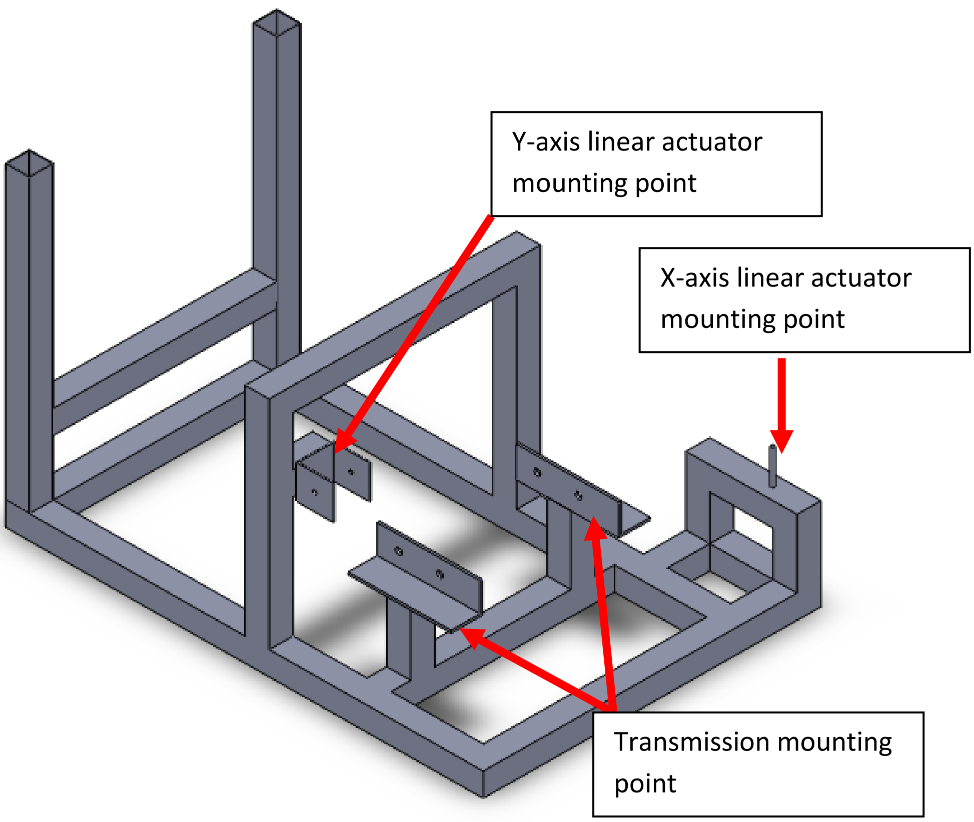


Figure 3.18: Test rig design for testing sequential shift-by-wire system in hybrid-air 4 wheels motorcycle

Figure 3.18 shows a solid work design for sequential shift-by-wire system testing rig. The main function of this testing rig is to test the sequential shift-by-wire system before the system install on hybrid-air 4 wheel motorcycles. Because of this purpose, this testing rig is needed to specially design so it can match perfectly with the TM752RX3AA 5 speed manual. On this testing rig also, will have two mounting point electro-mechanical actuator.

The dimension of this testing rig is 757mm long times 430mm width with maximum height above 470mm. The materials that will use to fabricate this test rig is 1.5inch hollow square mild steel with 2mm thickness.

3.9 SCHEMATIC CIRCUIT DESIGN AND INTEGRATIONS OF SHIFT-BY-WIRE SYSTEM

3.9.1 Schematic Circuit Design for actuator control module

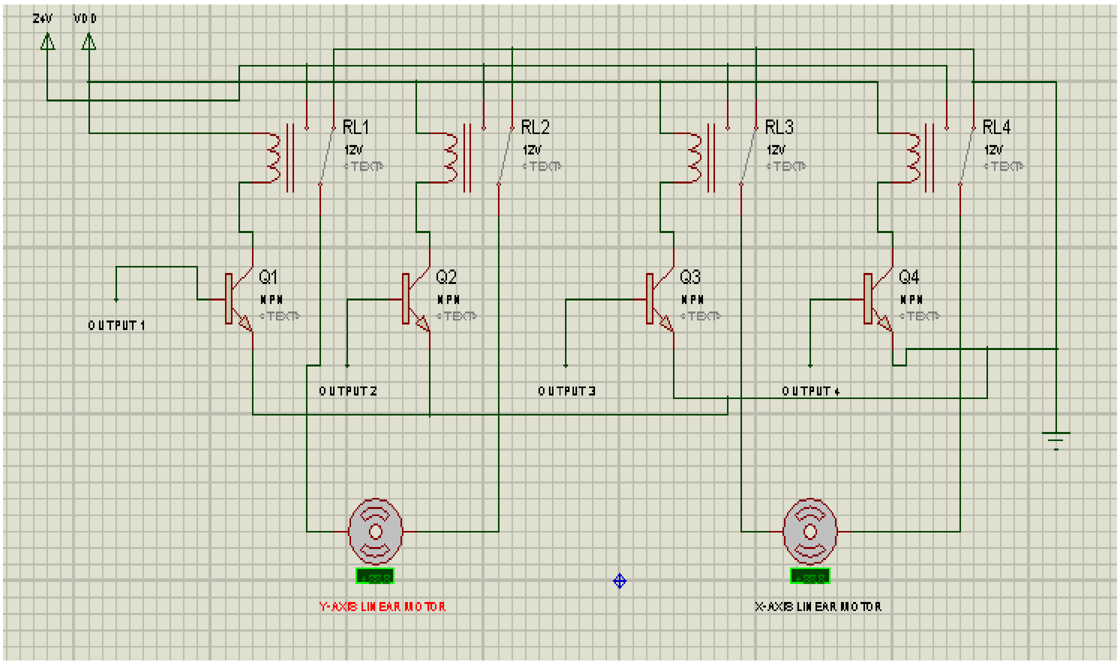


Figure 3.19: Actuator control module for shift-by-wire system

Figure 3.19 shows the actuator control module schematic circuit design in shift-by-wire system. This circuit will include few electronic components like NPN transistor and SPDT relay. The main purpose of this circuit is to act as H -bridge to allow electro-mechanical linear motors actuator to run forwards and backwards according to the output signal from PIC microcontroller

.

The function of NPN transistor and SPDT relay in this control module will be further discussed in the integrations of the sequential shift-by-wire system electrical circuit design.

3.9.2 Integration of the Sequential Shift-by-Wire System Electrical Circuit Design

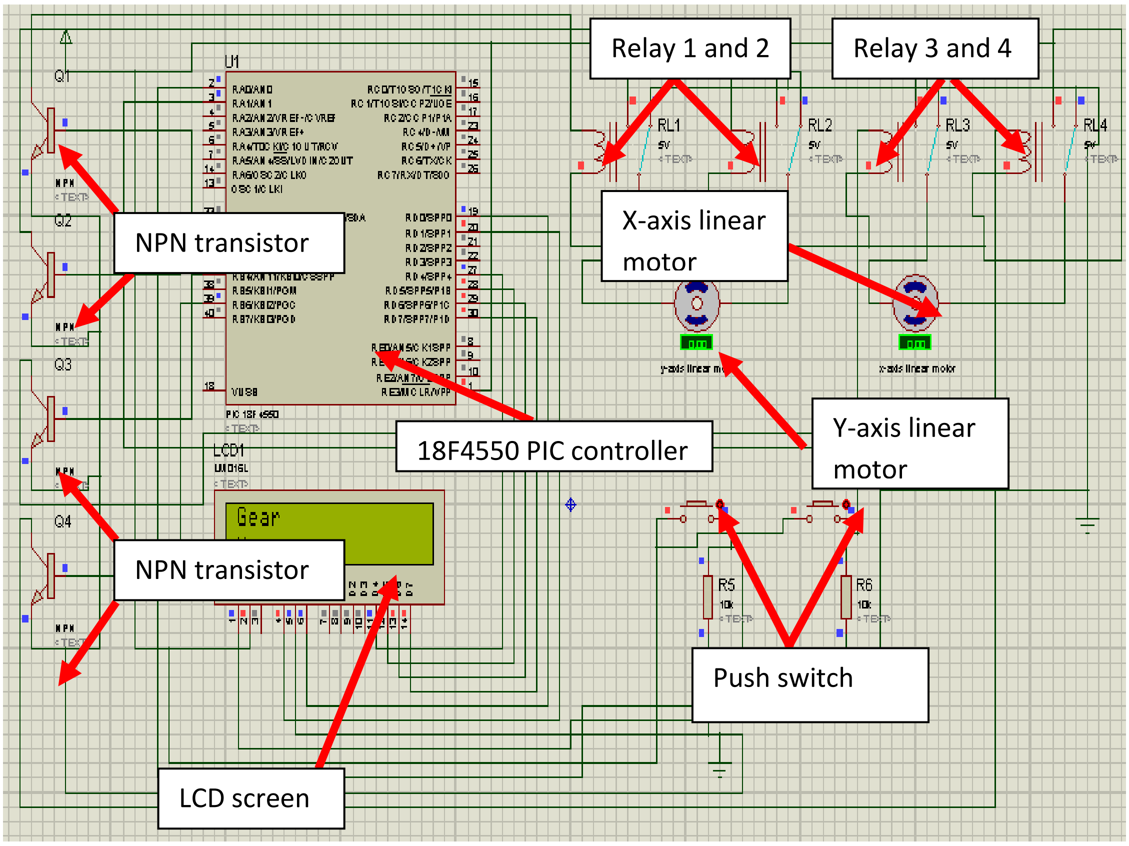


Figure 3.20: Complete shift-by-wire system circuit design and it's component using ISIS simulator

Figure 3.20 shows schematic circuit design for sequential shift-by-wire-system that already integrated with actuator control module. This system will be used in air-hybrid 4 wheel motorcycles for gear shifting operation. In designing sequential shift-by-wire system, there are few important electric and electronic components that need to use to make sure the system run perfectly. The main electric and electronic that use in this sequential system are 18F4550 PIC microcontroller, NPN transistor, SPDT relay, push switch and linear motor.

In this sequential shift-by-wire system, 18F4550 PIC controller use to control gear shifting process. Its main function is to receive digital input from user and process it before sending output to actuator control module according to the program that already install in it's memory. It has 4 output channels that connect to the actuator control module. Output channel 1 and channel 2 are used to control electro-mechanical linear actuator that located at y-axis. While output channel 3 and channel 4 are used to control another electro-mechanical linear actuator that located at x-axis.

After output signal out from PIC microcontroller, it need to amplify first before it can be used to trigger 5V SPDT relay. This is because, the digital signals from PIC microcontroller have lower voltage and compare to the current minimum value that can be used to trigger 5v SPDT relay. To amplify the output signal, NPN transistor can be used. The NPN transistor 'Base' terminal is connected to an output signal from PIC microcontroller. While the NPN transistor 'Emitter' terminal is connected to circuit common ground. Finally the SPDT relay coil is connected to NPN transistor 'collector' terminal.

In this sequential shift-by-wire system, the SPDT relay will act as H-bridge to allow electro-mechanical linear motors actuator to run forwards and backwards. For example, when output channel 1 is active, it will trigger SPDT relay 1 and complete the circuit for electro-mechanical linear motor actuator to move forward from its initial position. It occurs because when SPDT relay 1 active while relay 2 inactive, it will allow a positive voltage be applied across the motor and vice versa if output 2 is active.

For the LCD screen, it uses to display the current gear position. This LCD screen has 16 pins and 8 pins from it are for data transfer usages. But in this circuit design, only 4 pins will be used for data transfer compare to 8 pins due to using 8bits program. Below table is showing the wire connection for LCD screens.

Table 3.2 shows the wire connection for LCD display for sequential shift-by-wire system.

Table 3.2: Wire connection for LCD display

LCD Pins number	LCD Pins Label	Connect to
1	GRD	Ground
2	VDD	VDD
3	VO	-
4	RS	PIC RD1
5	RW	Ground
6	E	PIC RD0
7	DB0	-
8	DB1	-
9	DB2	-
10	DB3	-
11	DB4	PIC RD4
12	DB5	PIC RD5
13	DB6	PIC RD6
14	DB7	PIC RD7
15	BLA	VDD
16	BLK	Ground

3.10 ALGORITHM DESIGN SEQUENTIAL SHIFT-BY-WIRE SYSTEM PROGRAMMING (FLOWCODE)

As mention above, sequential shift-by-wire system program is using FlowCode software which is graphical programming software. In FlowCode, the programs need to be will be in term of algorithm of the system.

3.10.1 Algorithm Design for Sequential shift-by-wire system

For sequential shift-by-wire system, each of the flowcharts will have its own particular purpose. Only one flowchart will be used by at one time depend on the gear selecting and condition. There are total 7 separate flowcharts that use in FlowCode to design shift-by-wire program.

The flowchart in graphical programming software FlowCode will command the PIC controller to send 4 outputs I/O port. This 4 output port will be defined as A+, A-, B+, and B-. By using these 4 outputs ports, the movement of 2 unit electro-mechanical actuator in axis and x-axis can be controlled. The figure below will show the function of 4 outputs ports on that PIC controller in order to control electro-mechanical actuator.

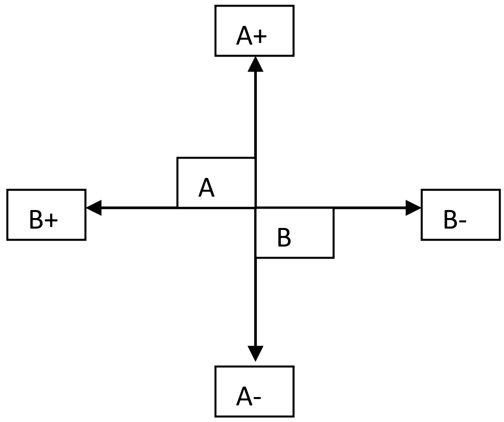


Figure 3.21: Position coding for electro-mechanical linear actuator cylinder

3.10.2 Algorithm design for Gear Position (Neutral)

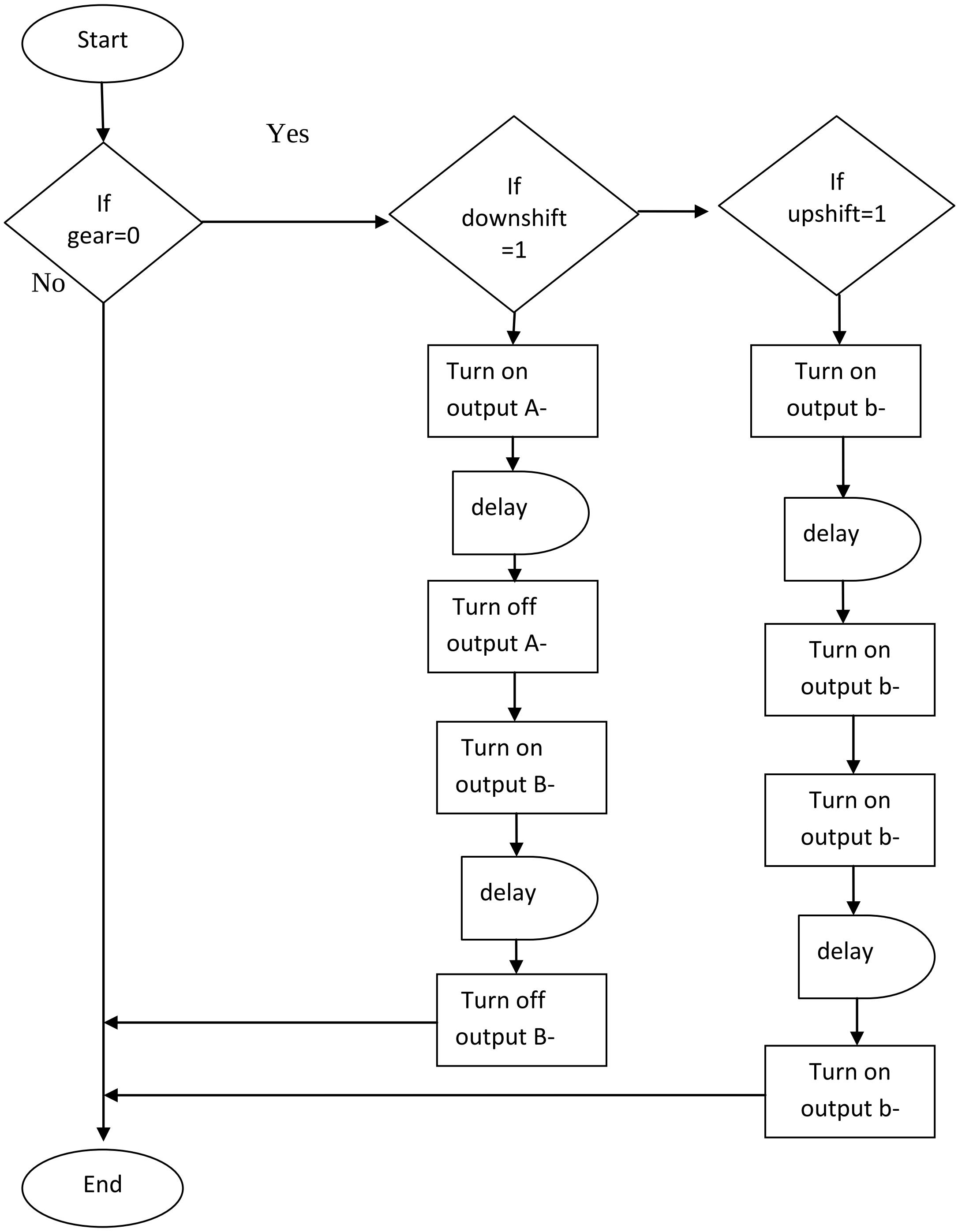


Figure 3.22: Algorithm design for neutral gear

Based on Figure 3.22, when the downshift or up shift push button is pressed, a 5v digital input will send to the PIC controller via its input ports. After PIC controllers receive the 5v digital signal for push button, it will send digital outputs through its output port based on the programming algorithm.

In gear downshift process (from 1st gear), PIC controller will send a 5v signal through the A+ output port. This output signal will send to actuator control module that and make y-axis electro-mechanical actuator to retard. The actuator control module will receive signals from output port A+ until its move 10mm from it original position.

After y-axis move 10mm from initial position, PIC controller will send out 5v digital signal to actuator control module via output port B-. This action will make x-axis electro-mechanical actuator to retard 5mm and complete the gear shifting process.

For gear up shift process (from reverser gear), PIC controller will send 5v signal through output port A+ to actuator control module. This action will make electro-mechanical actuator to advance 10mm in the y-axis. After y-axis actuator move 10mm, PIC will deactivate y-axis actuator and activate the x-axis actuator by sending out 5v digital signal to actuator control module via output B+. This action will make x-axis electro-mechanical actuator to advance 5mm in x-axis to complete gear shifting process.

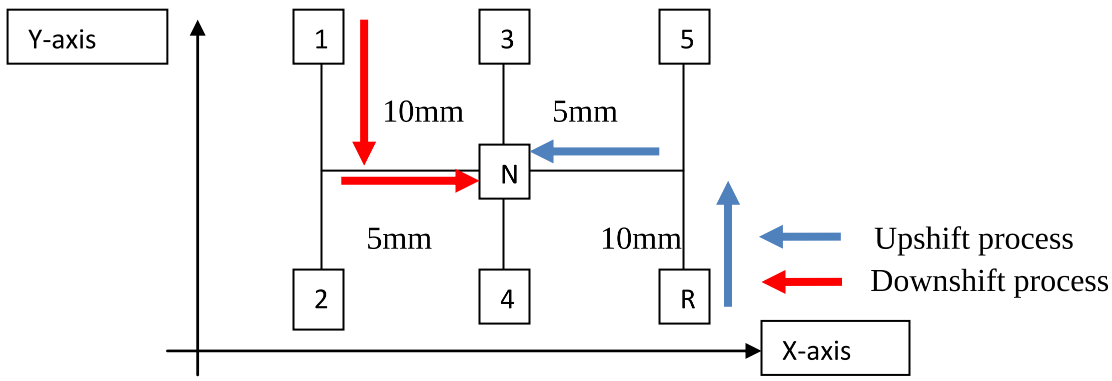


Figure3.23: Actuator movement process for neutral gear

3.10.3 Algorithm design for Gear Position (1st gear)

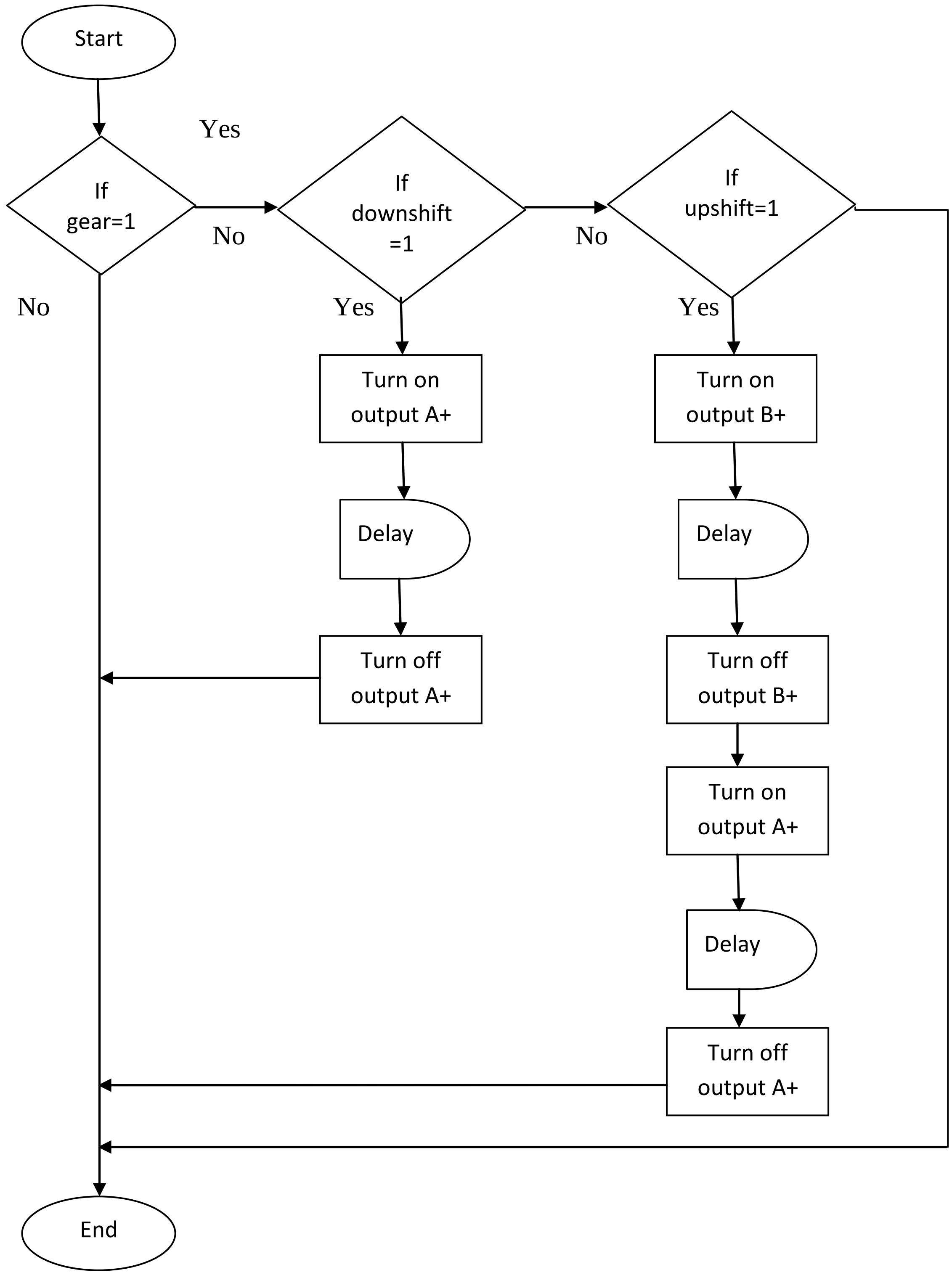


Figure 3.24: Algorithm design for first gear

Based on Figure 3.24, when up shift push button is pressed, gear up shift process will occur (from neutral gear to 1st gear); the PIC controller will send out a 5v digital signal through B+ output port to actuator control module. This action will activate the x-axis electro-mechanical actuator to advance from its initial position. The actuator control module will receive signals from output port B+ until x-axis actuator move advance 5mm.

After x-axis actuator, PIC controller will send out another 5v digital signal to actuator control module via output port A+. This action will make y-axis electro-mechanical actuator to advance 10mm from its initial position and complete the gear shifting process.

When downshift push button is pressed, gear down shift process will start (from 2nd gear to 1st gear); the PIC controller will send out a 5v digital signal through output port A+ to actuator control module until y-axis actuator advance 20mm from its initial and complete the downshift process.

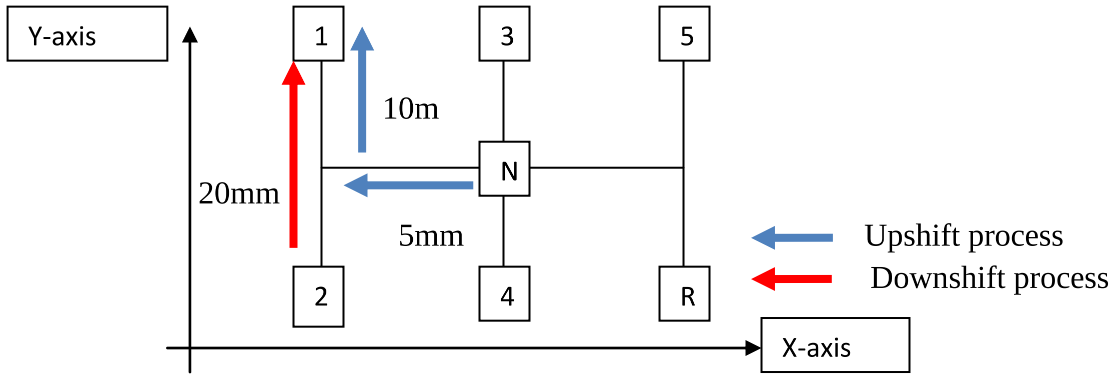


Figure 3.25: actuator movement process for 1st gear

3.10.4 Algorithm Design for Gear Position (2nd gear and 4th gear)

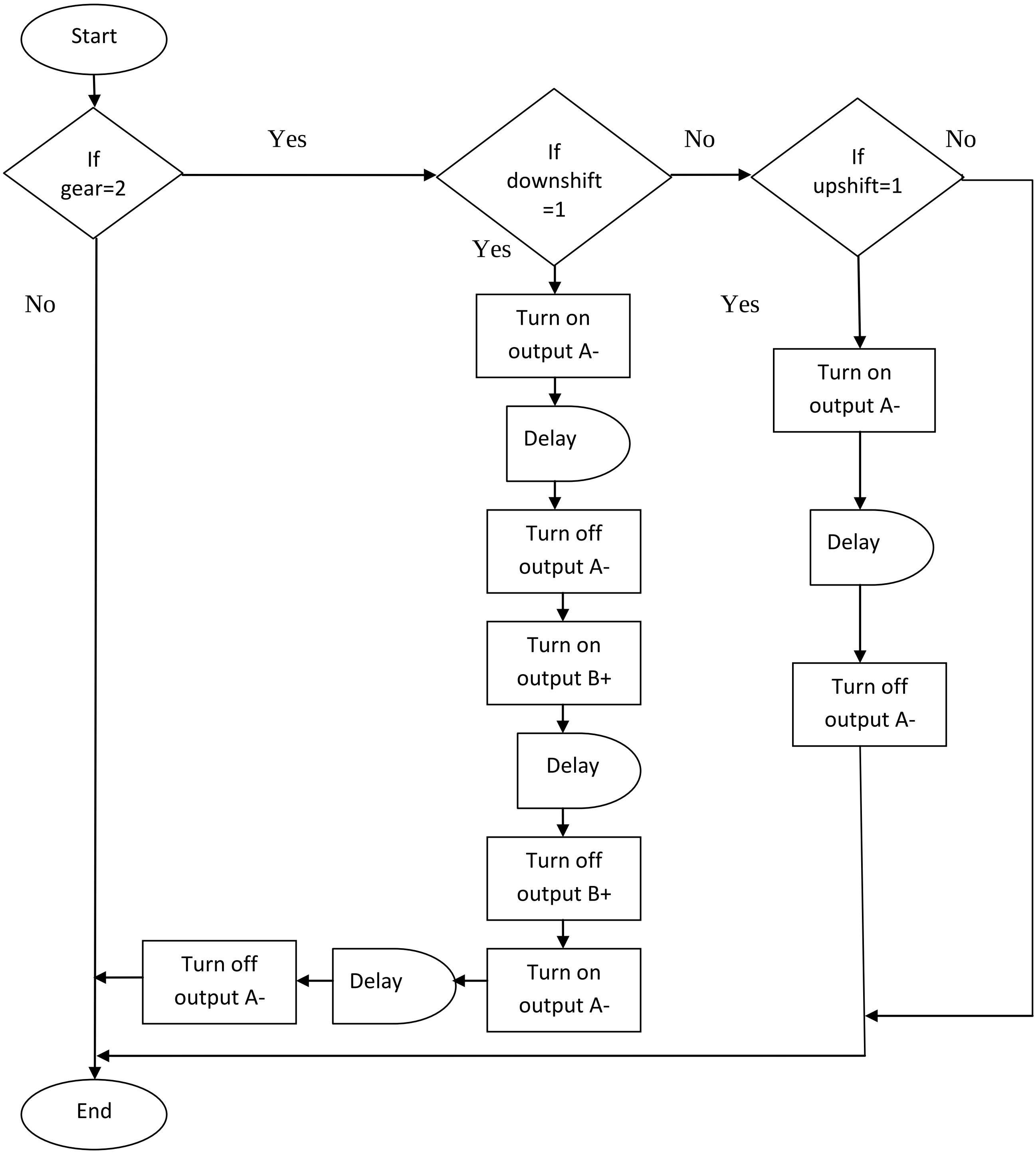


Figure 3.26: Algorithm design for second and forth gear

For Figure 3.26, this algorithm design will be for second and forth gear. When the up shift push button is pressed, gear up shift process will start (from 1st gear to 2nd gear or 3rd gear to 4th gear); the PIC controller will send out a 5v digital signal through output port A- to actuator control module. This action will make electro-mechanical actuator to retard 20mm in y-axis from its initial position, hence make the complete the gear up shift process.

If down shift push button is pressed, gear down shift process will start (from 3rd gear to 2nd gear or 5th gear to 4th gear); the PIC controller will send out a 5v digital signal through A- output port to actuator control module. This action will activate the y-axis electro-mechanical actuator to retard from its initial position. The actuator control module will receive signals from output port A- until y-axis electro-mechanical actuator retard 10mm.

After y-axis electro-mechanical actuator retard 10mm, PIC controller will send out another 5v digital signal to actuator control module via output port B+. The actuator control module will receive signals from output port B+ and make x-axis electro-mechanical actuator to advance 5mm from its initial position.

Finally after x-axis electro-mechanical actuator move 5mm from its initial position, PIC controller will turn off signal from output port B+ and activate outputs port A- by sending 5v digital signal to actuator control module and make y-axis electro-mechanical actuator start to retard again for another10mm. After y-axis linear actuator retard 10mm in y-axis, the gear downshift process complete.

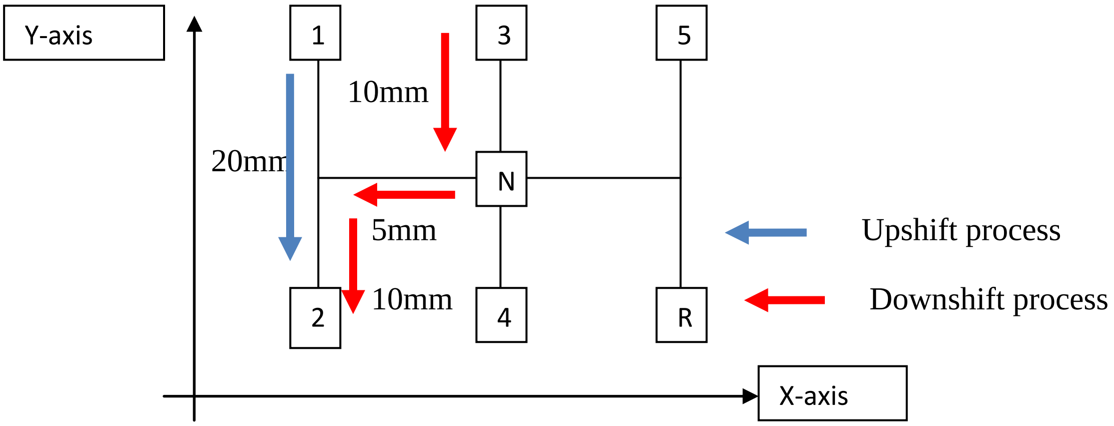


Figure 3.27: Actuator movement process 2nd gear

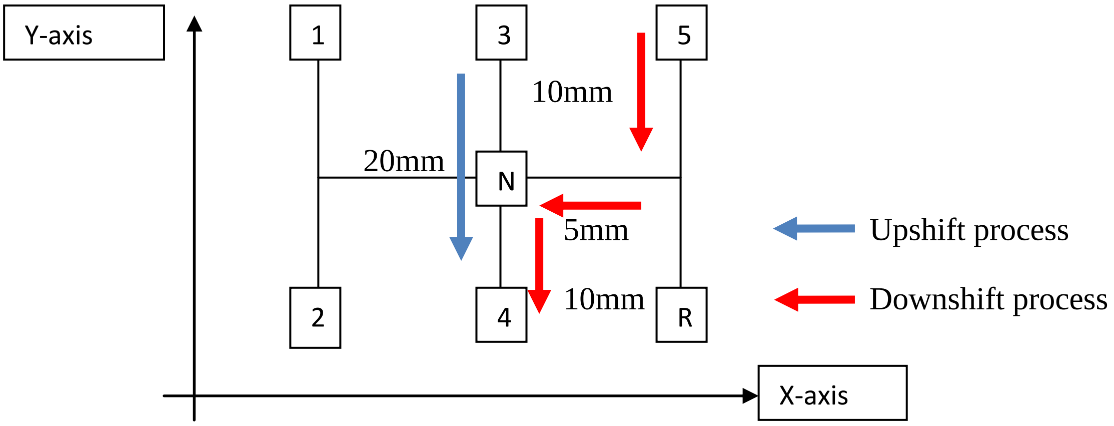


Figure 3.28: Actuator movement process for 4th gear

3.10.5 Algorithm design for Gear Position (3rd gear)

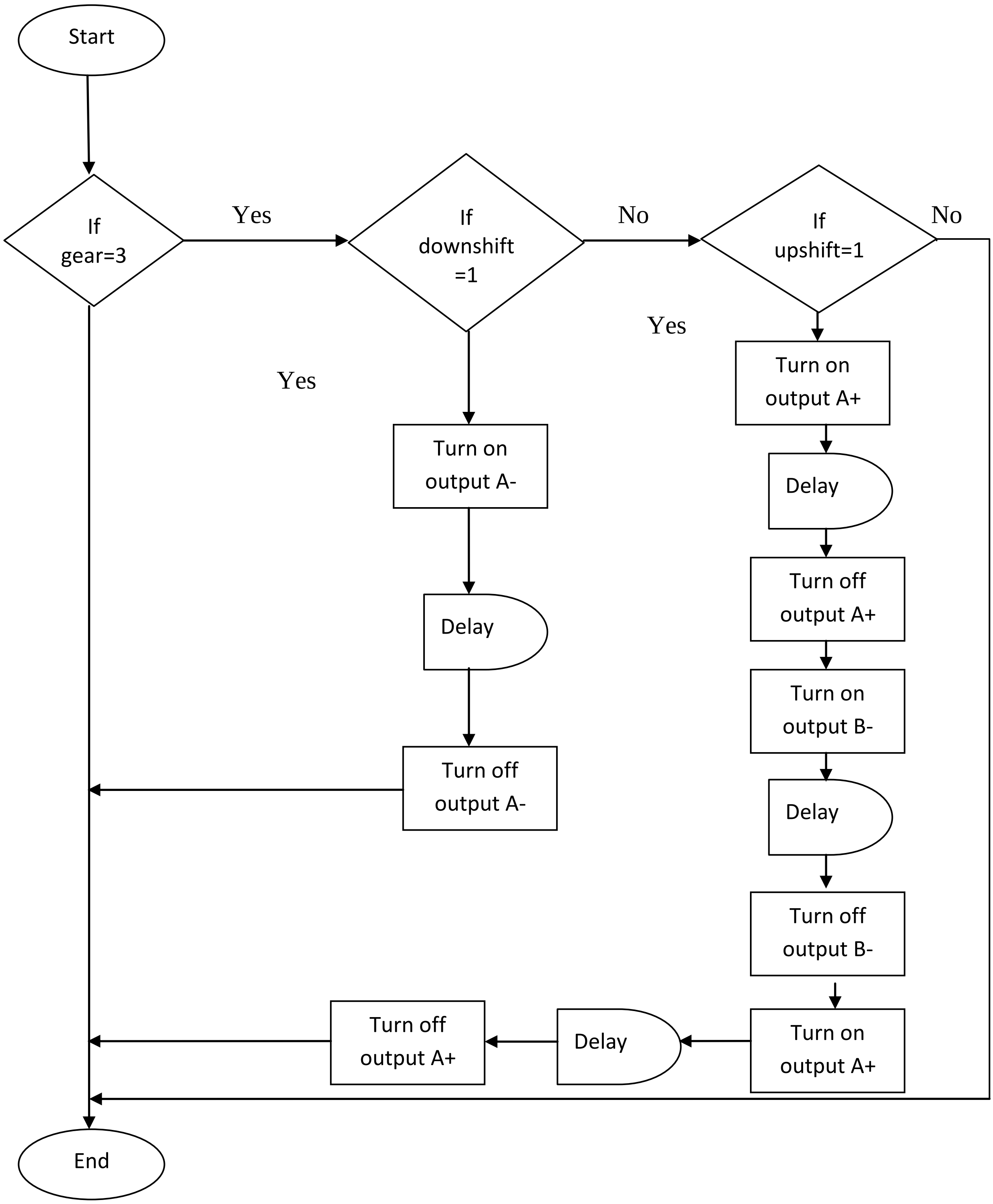


Figure 3.29: Algorithm design for third gear

Based on Figure 2.29, when the downshift push button is pressed, gear down shift process will start (from 2nd gear to 3rd gear); the PIC controller will send out a 5v digital signal through output port A+ to actuator control module and make the electro-mechanical actuator to advance 20mm in y-axis from its initial position hence complete the gear down shift process

If up shift push button is pressed, gear up shift process will activate (from 2nd gear to 3rd gear); the PIC controller will send out a 5v digital signal through A+ output port to actuator control module. This action will activate the y-axis electro-mechanical actuator to advance from its initial position. Signal from PIC will make y-axis electro-mechanical actuator to advance for 10mm in the y-axis.

After linear actuator move 10mm, PIC controller will send out another 5v digital signal to actuator control module via output port B-. The actuator control module will receive signals from output port B- and make x-axis electro-mechanical actuator to retard 5mm from its initial position.

Finally after x-axis actuator retard 5mm from its initial position, PIC controller will turn off signal from output port B- and activate outputs port A+ by sending out a 5v digital signal to actuator control module to make y-axis electro-mechanical actuator start to advance again for another10mm. After y-axis actuator will advance another 10mm from its gear down shift process complete.

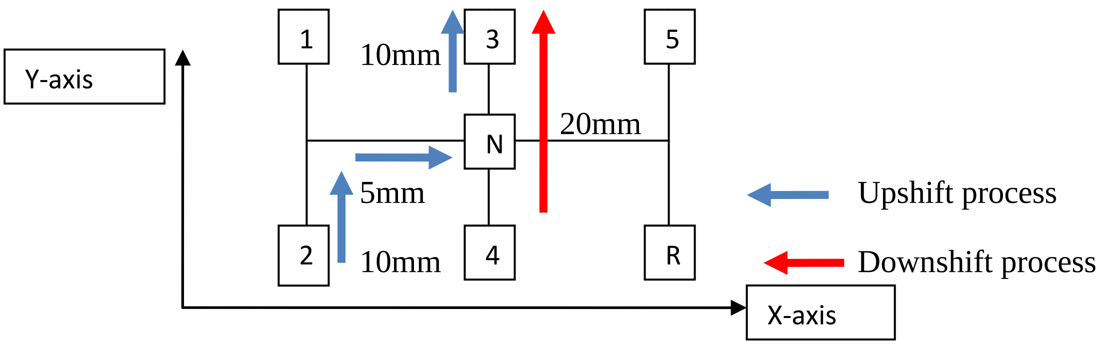


Figure 3.30: Actuator movement process for 3rd gear

3.10.6 Algorithm design for Gear Position (5th gear)

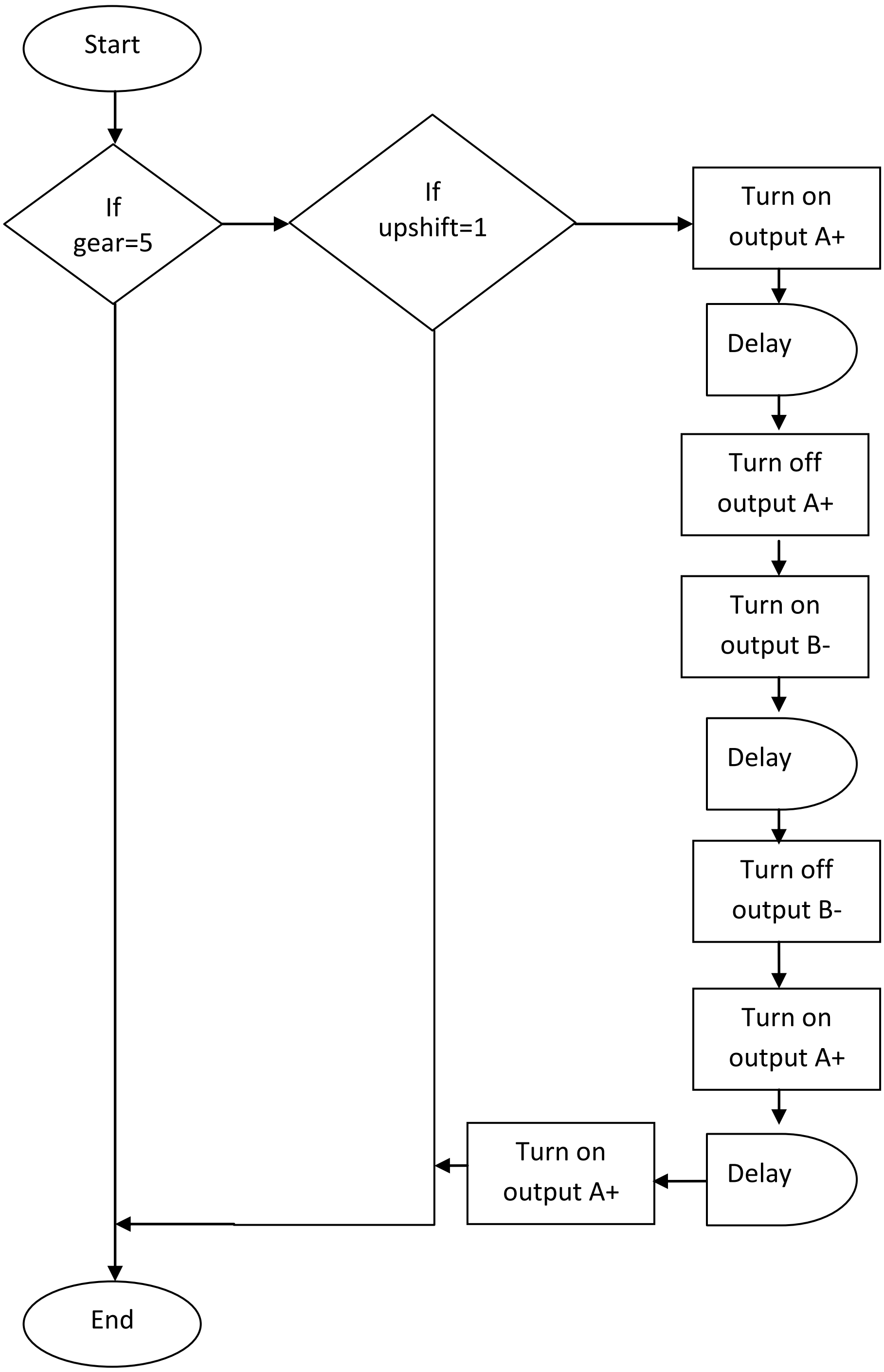


Figure 3.31: Algorithm design for fifth gear

From Figure 3.31, if a final gear is selected, PIC controller will send out a 5v digital signal through A+ output port to actuator control module. This action will activate the y-axis electro-mechanical actuator to advance from its initial position. The actuator control module will receive signals from output port A- and make y-axis actuator to advance for 10mm in the y-axis.

After y-axis actuator to advance for 10mm in the y-axis, PIC controller will send out another 5v digital signal to actuator control module via output port B-. The actuator control module will receive signals from output port B- and order x-axis electro-mechanical actuator to retard 5mm from its initial position.

Finally after x-axis electro-mechanical actuator move 5mm, PIC controller will turn off signal from output port B- and activate outputs port A+ by sending out 5v digital signal to actuator control module to y-axis electro-mechanical actuator and make its advance again for another10mm. After y-axis actuator advance another 10mm from its initial position make the gear down shift process complete.

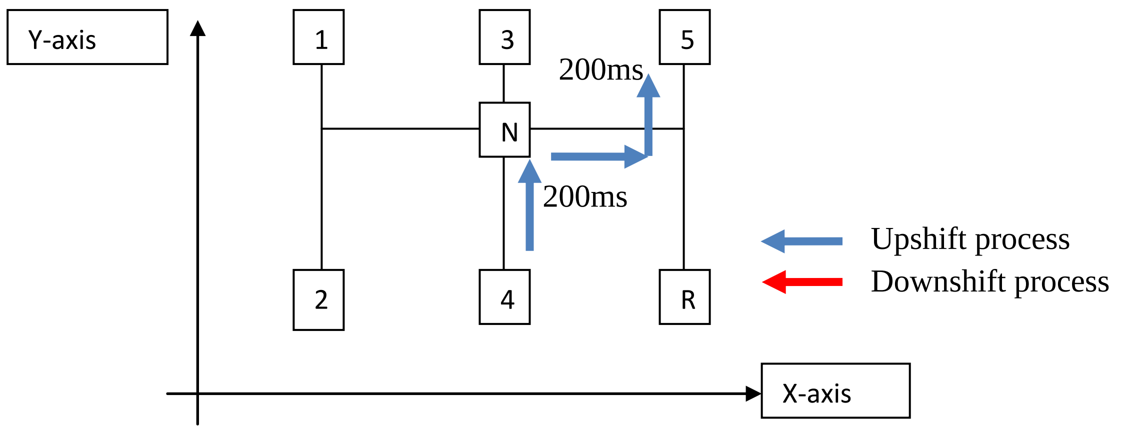


Figure 3.32: Actuator movement process for 5th gear of final gear

3.10.7 Algorithm design for Gear Position (Reverse gear)

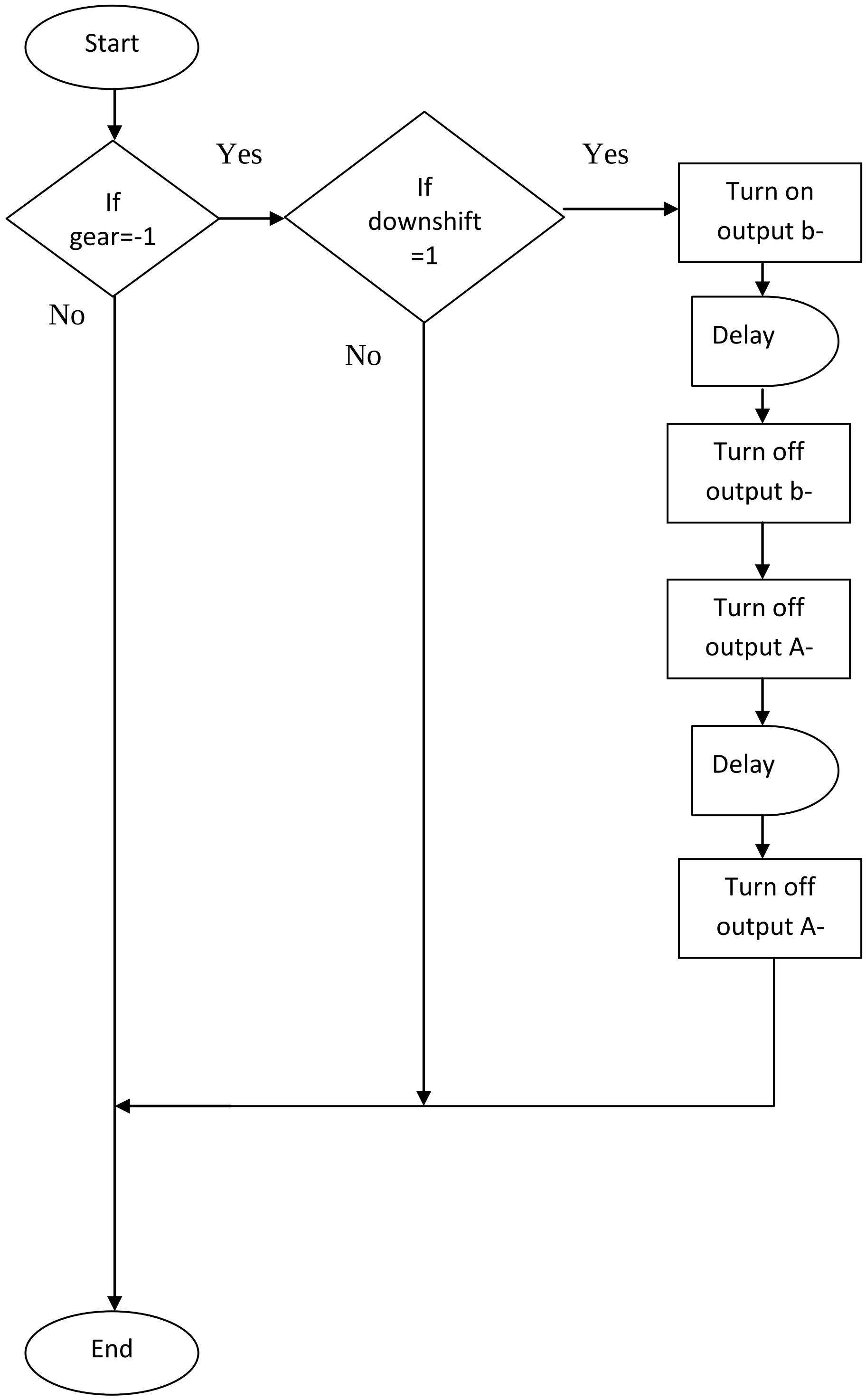


Figure 3.33: Algorithm design for reverse gear

Based on Figure 3.33, reverse gear only can be activated if the transmission in neutral gear condition (N). When in neutral position, by pressing downshift button that's located on the 4-wheel motorcycle bar handle, PIC controller will send out 5v signal through output port B- to actuator control module. This action will make electro-mechanical actuator to retard 5mm in x-axis.

After x-axis electro-mechanical actuator move 5mm, PIC will deactivate x-axis actuator and activate the y-axis actuator by sending out 5v digital signal to actuator control module via output A-. This action will make x-axis electro-mechanical actuator to retard 10mm in y-axis to complete gear shifting process for reverse gear.

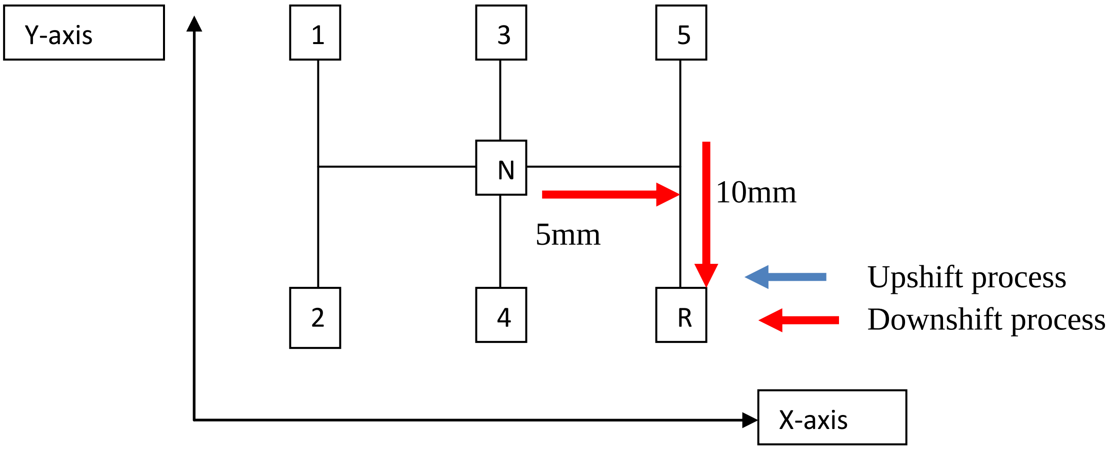


Figure 3.34: Actuator movement process for reverse gear

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESULT OF FABRICATION

The fabrication is the most important part in the development; it also is a crucial stage for the real time testing of the system. The fabrication of testing rig and sequential shift-by-wire control module are according to the initial requirement unless there have some obstacles that prevent it to be so. The complete fabrication of sequential shift-by-wire control module and testing rig is shown in the Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4.

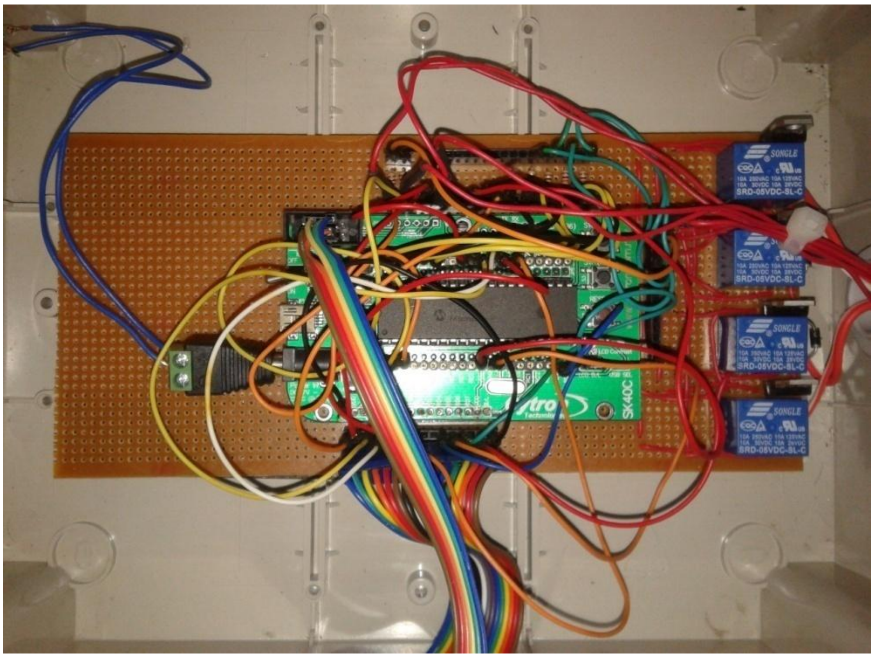


Figure 4.1: Control system circuit module

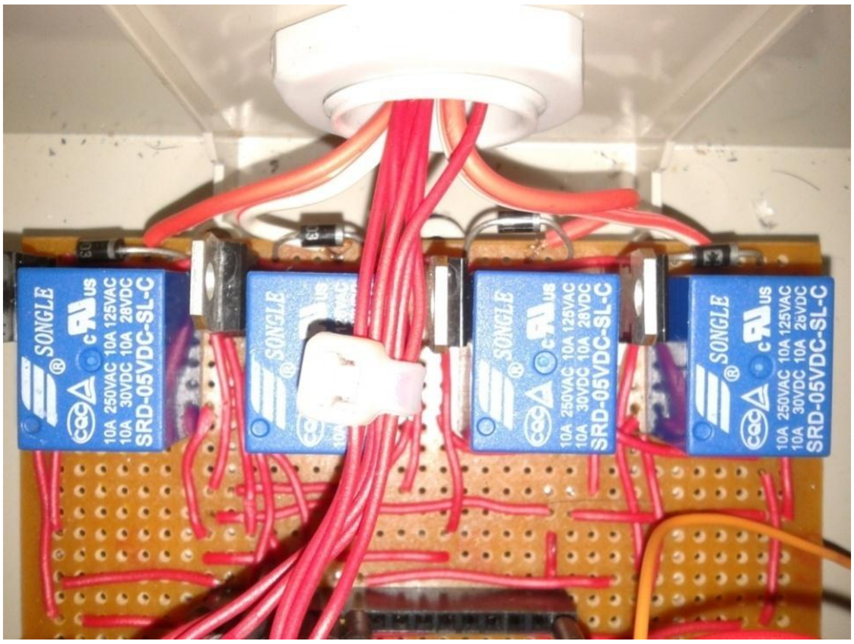


Figure 4.2: Actuator control module

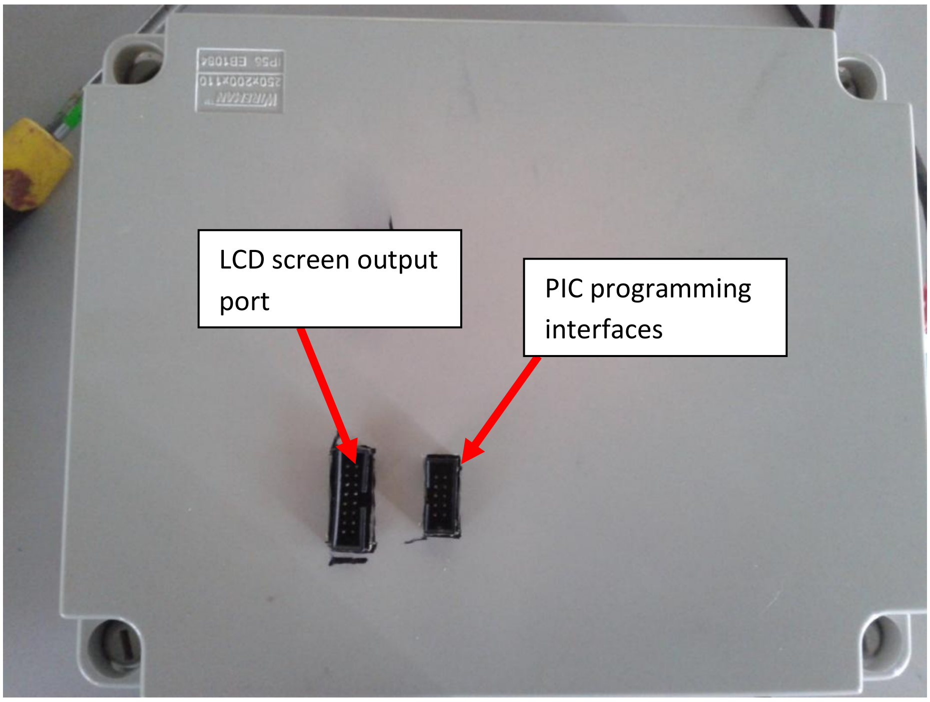


Figure 4.3: Sequential shift-by-wire system protection cases with 2 interface port

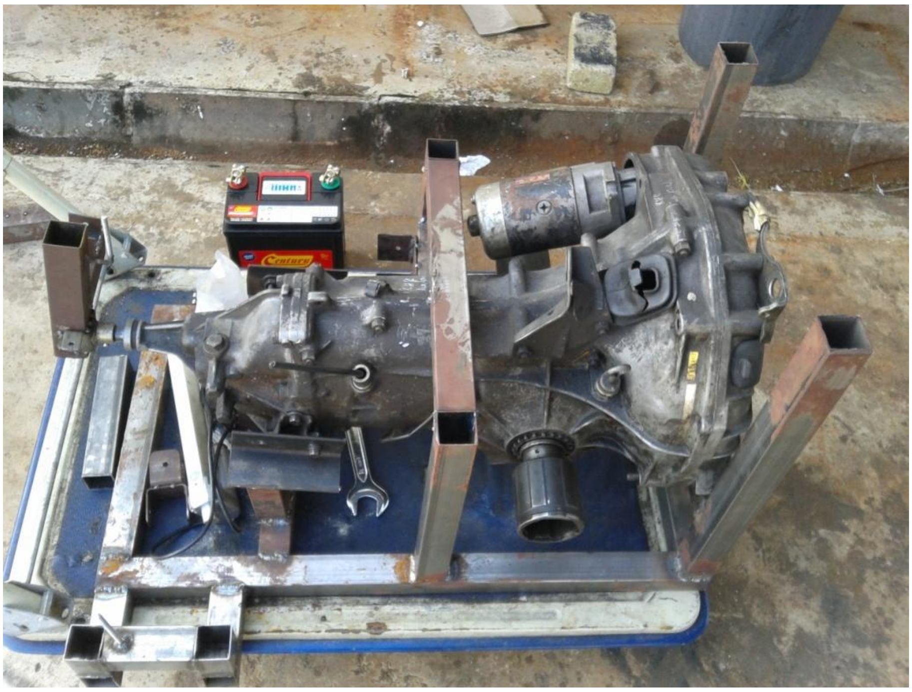


Figure 4.4: completed test rig fabrication

4.3 REAL TIME TESTING

The real time testing was a major step taken in the development of this project. In this part sequential shift-by-wire system was tested in order to know the performance and reliability of this system. Figure 4.5 shows the complete test setup for sequential shift-by-wire system real time testing. The direct current power supply is used to power up the control module and electro-mechanical linear motor actuator. This power will simulate the battery in the air-hybrid 4 wheel motorcycles. It will supply 12V to the sequential control module and 24V to linear actuator.

The computer is use to flash the program for the sequential shift-by-wire system via USB ICSP PIC Programmer. By using this method, the sequential shift-by-wire system programming parameter like actuator timing can easily alter without need to open control module protection cases.

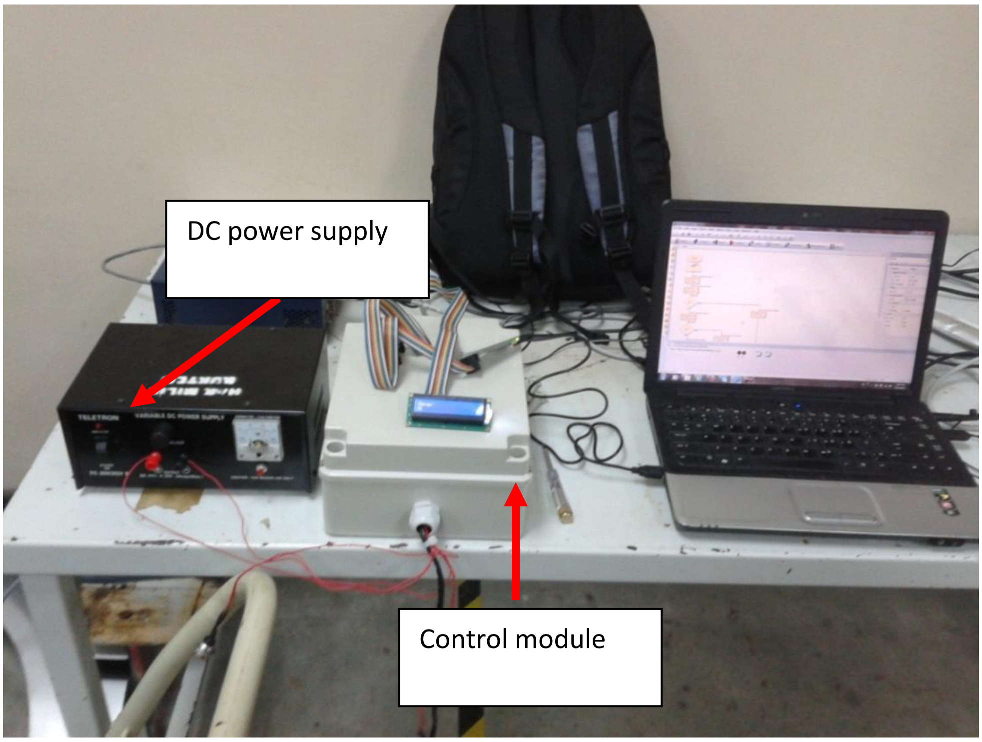


Figure 4.5: The complete test setup for sequential shift-by-wire system

Figure 4.6 until 4.9 was showing the movement of sequential shift-by-wire linear actuator in order to make gear shifting from 3rd gear to 4th gear. The sequential figure was shown in order.

Figure 4.6: LCD screen showing transmission in 3rd gear position

Figure 4.7: A figure showing on actuator start to advance from its initial position

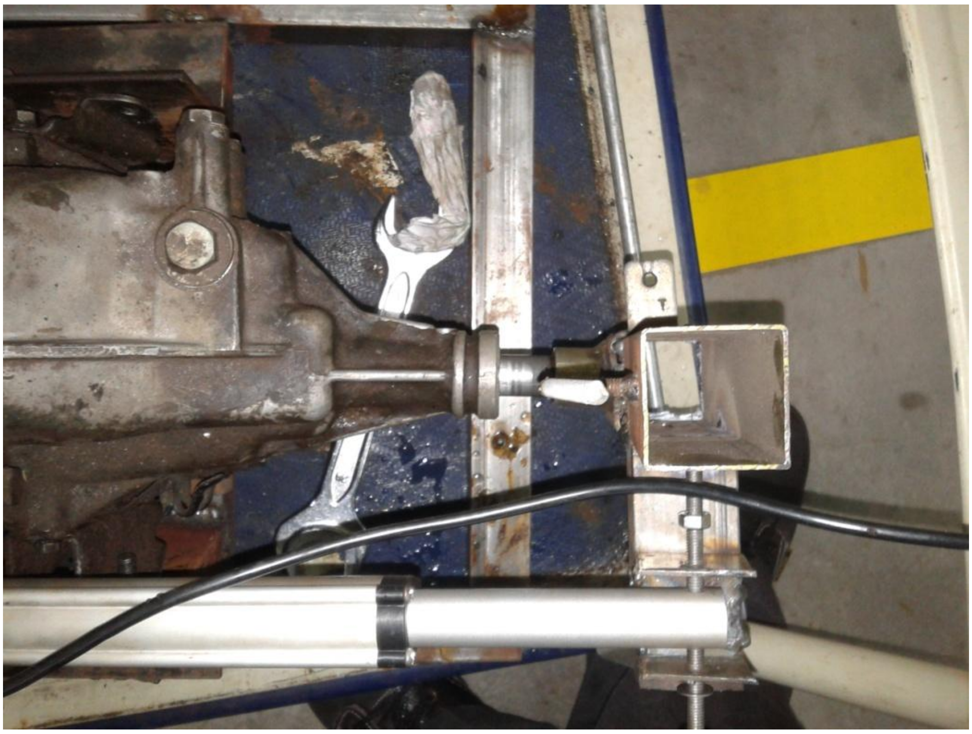


Figure 4.8: A figure showing actuator stop advance and complete gear shifting from 3rd gear to 4th gear

Figure 4.9: After shifting process complete, the LCD screen will show ‘Gear 4’

4.4 TIMES REQUIRED FOR EACH GEAR SHIFTING BETWEEN THEORETICAL AND EXPERIMENT

Table 4.1: Times required for Each Gear Shifting (Theoretical)

Gear Position		Time(s)		
From	To	X-axis	Y-axis	Total
N	1st	0.25	0.5	0.75
1st	2nd	-	1	1
2nd	3rd	0.25	1	1.25
3rd	4th	-	1	1
4th	5th	0.25	1	1.25

Table 4.2: Times required for Each Gear Shifting (Experiment)

Gear Position		Time(s)		
From	To	X-axis	Y-axis	Total
N	1^{st}	0.27	0.7	0.97
1^{st}	2^{nd}	-	1.1	1.10
2^{nd}	3^{rd}	0.28	1.3	1.50
3^{rd}	4^{th}	-	1.18	1.18
4^{th}	5^{th}	0.27	1.23	1.26

By comparing the times taken to make a complete gear shift between Table 4.1 and Table 4.2, there are a slightly different between theoretical or calculation and experiment result. From the table, its shown that experiment takes longer time to complete gear shifting compare to the time taken based on the calculation.

These conditions happen because there are few factors that are not considered when the calculation was made. Factor like relay response time, friction between the gear rail, and the gap between the shifting linkages will make the shifting time longer than expected.

Beside that, factors like unstable voltage for DC power supply also may affect the speed of the linear actuator. Based on the linear actuator specification, the linear actuator speed is about 20mm/s when it 24VDC is supplied to actuator. If the supply voltage is lower that 24V, the linear actuator speed will be decreased hence make the gear shifting time longer than usual.

4.5 REAR WHEEL TORQUE ANALYSIS

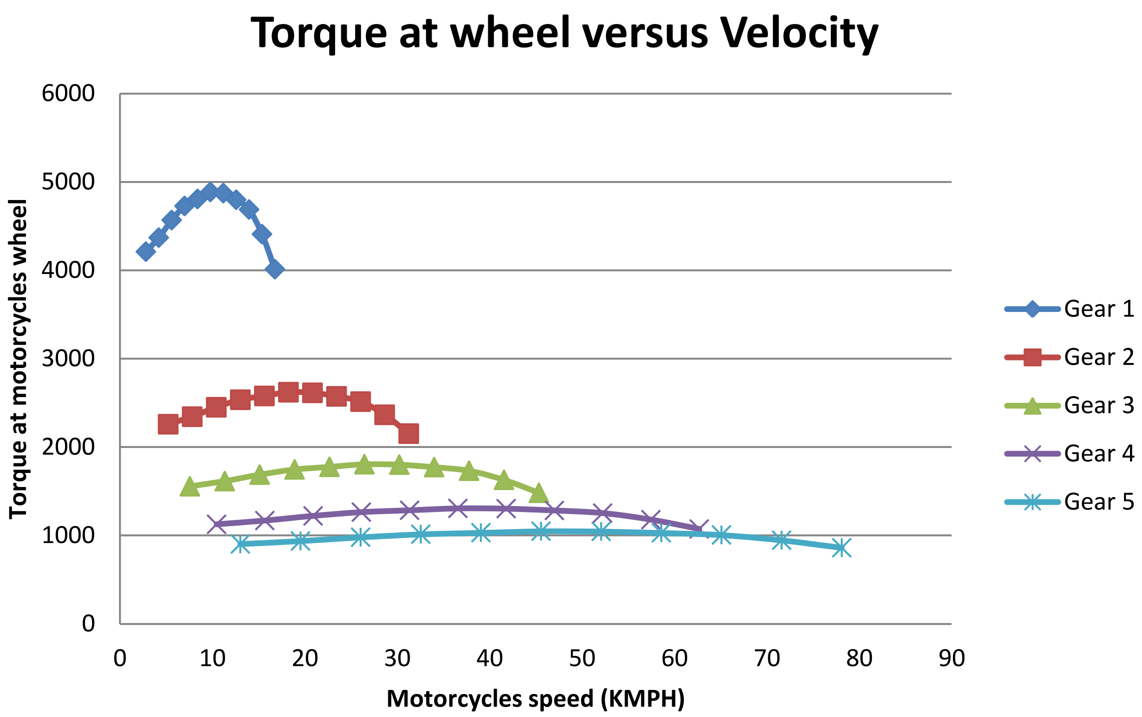


Figure 4.10: Graph of torque at motorcycle wheel versus motorcycle velocity

Figure 4.10 shows the graph of 4 wheel motorcycle rear wheel torque again the motorcycle velocity. From the graph, it's shown that 4 wheel motorcycle rear wheel will have maximum torque around 4885.718 Nm when it is in 1st gear and minimum torque around 860.63 Nm when it in fifth gear.

From this analysis also it indicates that 1st gear is used as starting gear to move the 4-wheel motorcycles form statics condition due to it can provide maximum torque which is important for vehicle to take off. For the 2nd and 3rd gear ratio, its mainly use for the overtaking another vehicle. This is because 2nd and 3rd gear ratio can provide enough torque to overtaking vehicle at higher speed.

4th and 5th gear also knows as overdrive gear because the gear ratio is lower than 1.0. These conditions allow the 4 wheel motorcycles to cruise at high speed at lower engine speed. But it is no suitable use in overtaking condition due to its low torque value.

4.6 VEHICLE SPEED ANALYSIS

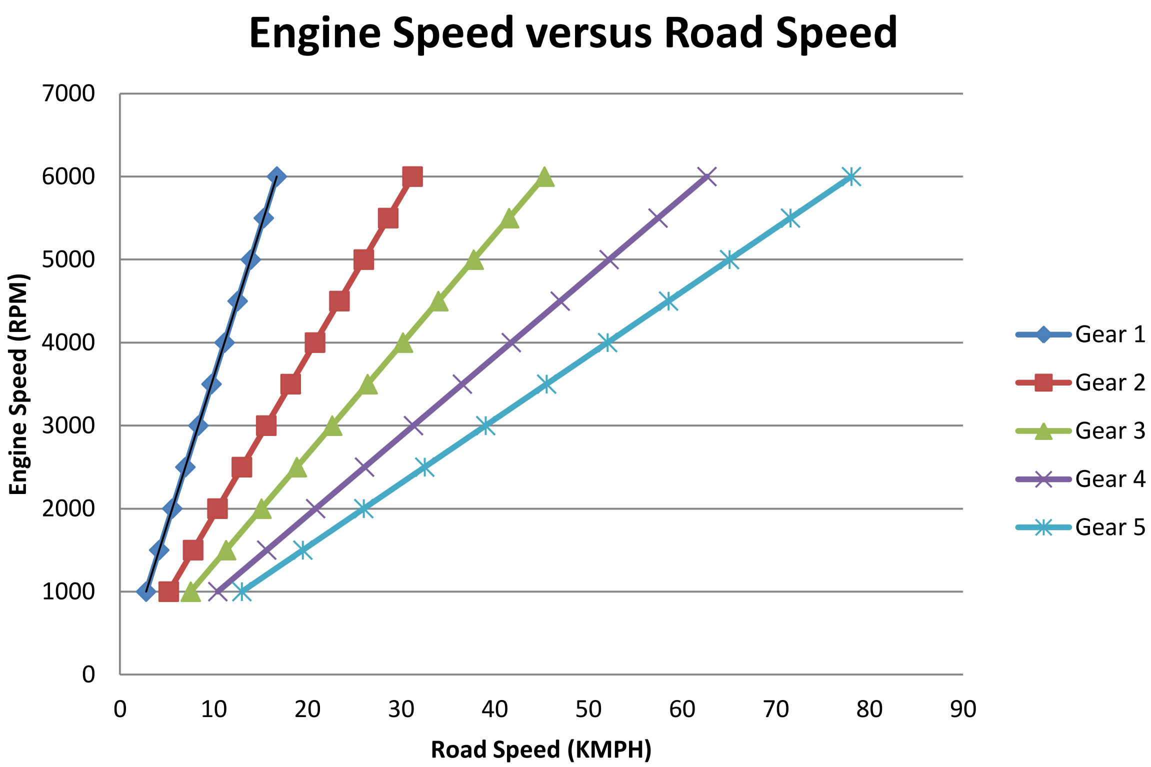


Figure 4.11: Graph of engine speed versus road speed

The Figure 4.11 shows the graph for the engine speed again 4-wheel motorcycle's speed. From the graph, it is shown that 4-wheel motorcycles will have a maximum speed around 78.1 Kmph or 21.96 m/s when the engine at 6000 RPM. This relatively low top speed of 4-wheels motorcycles compare to another vehicle is because 4-wheel motorcycles has a high final drive ratio around 11.14 which excellent for city drive or stop go condition.

The prediction of engine speed for next gear ratio also can be done by using this graph. For example, by assuming the gear ratio only will be change after engine speed reach 6000 RPM; the engine speed drop to 3200 RPM at 2nd gear, 4300 RPM in 3rd gear, 4500 RPM in 4th gear and 4900 RPM for final gear.

This is shown that 4-wheel motorcycle transmission has a wide - ratio for the starting gear and closer-ratio for 4th and 5th gear. This is because the wide gap between 1st gear and 2nd gear will allow a good take off from static condition. While the more narrow gap between 4th and 5th gear will allow 4 wheel motorcycles to increase acceleration and its top speed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion, this development project can consider as successful although there are few parts of the development need to extend for the future work. For the implementation drivetrain system on the air-hybrid 4 wheel motorcycles need to be extended for future due to a few problems that prevent it to be done.

The entire objective of the project was successfully achieved. In this project sequential shift-by-wire system was fully developed. By using a microcontroller to control electro-mechanical linear actuator and transmission is the integration between mechanical and electrical component. Real time testing had proven that the sequential shift-by-wire system can successfully perform complete gear shifting movement based on the user input.

For the power transfer linkage unit, the functionality of the system was tested on the transmission test rig. But for the system implementation on air-hybrid 4 wheel motorcycles need to be extended as future work due to few major problems that need to solve first before it can be done.

5.2 DESIGN LIMITATION

In this project, there a few limitations of the drivetrain design and sequential shift-by-wire system. These limitations of the design due to few factors like lack of knowledge in PIC microcontroller programming, PIC circuit design and etc.

One of the limitations in this drivetrain system is the gear shifting process. Where the user need to shift the gear in the ascending order for gear up shift and descending order for gear down shift. This limitation is very inconvenient if the 4-wheel motorcycles equip with this system stop at traffic light. User needs slowly shift down the gear to neutral by press down shift push button. For example, if a user wants to down shift the gear from 3rd gear to 1st gear, user need first down shift to 2nd gear before he can down shift again to 1st gear. This condition will be very disadvantage in city drive or stop go traffic condition.

Beside that, only 24VDC can use to power up this sequential shift-by-wire system. This is because all programming parameters are based on the 24V power supply. If the power supply is lower than 24v, it will cause the system to malfunction and may be even worst will damage the electro-mechanical actuator. Because of this requirement, the curb weight of air-hybrid 4 wheel motorcycles will be more heavy compare to the original design.

5.3 RECOMMENDATION

Toward perfecting the project, there are a few recommendations for the future work. One of the recommendations is using sensor to sense the position and movement of the actuator. There are some sensors that suitable for this application like infrared sensor and proximity sensor. By using sensors, the position of the actuator can be accurately determined compared to the timing based programming.

Using sensor also can eliminate the gear shifting problem when the power supply to linear actuator is not stable. This is because the timing base programming is heavy affect by the voltage of power supply to linear actuator. Besides that, using sensor also can prevent actuator to damage due to wrong shifting.

Another recommendation is to create external casing for the LCD screen in order to protect it from the environment element. Element like dust, and water can damage the LCD screen. The external casing must be watertight to prevent water get into the LCD screen and damage the screen. Material like acrylic glass is suitable for this application because acrylic glass is transparent that will allow user see the information shown by LCD screen.

REFERENCES

Abdo, E. Clutches,Transmissions,and Drives.

Andrew Tumer, Keith Ramsay, Richard Clark, David Howe. 2006. Direct-Drive Electromechanical Linear Actuator for Shift-by-Wire Control of an Automated Transmission. 1-2.

Andrew Turner, Keith Ramsay, Richard Clark, David Howe. 2007. Direct-Drive Rotary-Linear Electromechanical Actuation System for Control of Gearshifts in Automated Transmissions. 267-268.

Celli, C. A. 2011. The Fuel Efficiency Improvement through a Six Speed Manual Transmission Application in Passengers Vehicles with Low Displacement Engines. 2149-2151.

Erjavec, J. 2011. Automotive Technology A Systems Approach. DELMAR.

Francesco Vasca, Luigi Iannelli, Adolfo Senatore, Maurizio Taglialatela Scafati. 2008. Modeling Torque Transmissibility for Automotive Dry Clutch Engagement. 306.

Francesco Vasca, MemberFrancesco Vasca, Luigi Iannelli, Adolfo Senatore, and Gabriella Reale. 2010. Torque Transmissibility Assessment for Automotive Dry-Clutch Engagement. 564-566.

Huber, J. M. 1998. Shift By Wire transmission System. *United States Patent*, 2.

Ivan A, Goran. S, Gradimir S. (n.d.). ENERGY EFFICIENCY IMPROVEMENT BY GEAR SHIFTING OPTIMIZATION. 2-3.

Luigi Glielmo, Luigi Iannelli, Vladimiro Vacca, Francesco Vasca. 2004. Speed Control for Automated Manual Transmission with Dry Clutch. 1709-1710.

Matthias Lindner,Thomas Tille. (2010). Design of Highly Integrated Mechatronic Gear Selector Levers for Automotive Shift-by-Wire Systems. 916.

Stuart Burgess, Chris Lodge. 2004. Optimisation of the chain drive system on sports motorcycles. 65-72.

Yao, C.-H. 2008. Automotive Transmissions: Efficiently Transferring Power from Engine to Wheels. *ProQuest*, 4.

APPENDIX A

	SCOPES	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
FYP1	Design Shif-by-Wire System															
	Material Selection															
	Solidwork drawing															
	Simulation															
	PSM1 Report Preparation															
FYP2	Build Shift-by-Wire System															
	drivetrain linkage Fabrication															
	Components Assembly															
	Preliminary Testing															
	Final Report Preparation															