COMPARISON MANUAL AND CVT TRANSMISSION FOR A CAR UNDER 1 LITER ENGINE

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COMPARISON MANUAL AND CVT TRANSMISSION FOR A CAR UNDER 1 LITER ENGINE

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Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering.

Faculty of Mechanical Engineering
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DECEMBER 2010

SUPERVISOR'S DECLARATION

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

Signature ---------------------------------

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Date: 6 DECEMBER 2010

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 concurrently submitted for award of other degree.

Signature ....
Name: MOHAMMAD AZLAN BIN ABDUL AZIZ
ID Number: MH07067
Date: 6 DECEMBER 2010

Dedicated,

encouragements and always be there during hard times,

my beloved family.

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ABSTRACT

This thesis presented about comparison manual and CVT transmission. This thesis deals with analysis on performance of transmission for a car under 1 liter engine. The objective of this thesis is to compare the performance of transmission between manual transmission and CVT transmission. Besides that, the purpose of this thesis is to analyze the performance of the Manual Transmission and the CVT Transmission for a car under 1 liter engine. This thesis also purposes to study the suitability using CVT for a car under 1 liter engine. Manual transmission and CVT transmission have their own advantages and one of that is better in their performance. In performance, there are many category that compared consist of power available, tractive force, fuel consumption and many more. The data used for the analysis is obtained through calculation using specification data that has got from brochure which is downloaded from Toyota's official web because this model only market at Europe. This model fulfilled this project because it had two types of transmission which is CVT transmission and Manual Transmission. The post-processing method was performed using manual calculation with certain engineering formula and graph is plotted by using assistance software such as Microsoft Excel. The post-processing method to analyze the performance of transmission was performed using the SAE definition. From the results, it is observed that the performance of CVT is better than manual transmission. It is also observed that Manual Transmission is better than CVT in term of fuel consumption for a car under 1 liter engine. Besides that, CVT are suitable to use for a car under 1 liter engine because it gives more power and ride comfort ability. Future work, this comparison between manual transmission and CVT must do in experimental or simulation since CVT technology just begun to blossom to Malaysia. There are many factors that required to do research by experimental especially in transmission's performance and driveability.

ABSTRAK

Tesis ini membentangkan perbandingan tentang penghantaran manual dan penghantaran CVT. Tesis ini berkaitan dengan analisis terhadap prestasi penghantaran untuk kereta berenjin di bawah 1 liter. Tujuan dari tesis ini adalah untuk membandingkan prestasi penghantaran antara transmisi manual dan transmisi CVT. Selain itu, tujuan dari tesis ini adalah untuk menganalisis prestasi penghantan Manual dan penghantaran CVT untuk kereta berenjin di bawah 1 liter. Tesis ini juga bertujuan untuk mempelajari kesesuaian menggunakan CVT untuk kereta berenjin di bawah 1 liter. Penghantaran manual dan penghantaran CVT memiliki kelebihan mereka sendiri dan salah satu yang lebih baik dalam prestasi mereka. Dalam prestasi, ada banyak kategori yang dibandingkan terdiri daripada kuasa, gaya traksi, penggunaan bahan bakar dan banyak lagi. Data yang digunakan untuk analisis diperolehi melalui perhitungan dengan menggunakan data spesifikasi yang telah didapati dari brosur yang dimuat turun dari Laman web rasmi Toyota kerana model in hanya berada di pasaran Eropah. Model ini memenuhi projek ini kerana mempunyai dua jenis penghantaran iaitu CVT penghantaran dan Transmisi Manual. Kaedah pemprosesan dilakukan menggunakan perhitungan manual dengan rumus tertentu dan graf diplot dengan menggunakan software bantuan seperti Microsoft Excel. Kaedah yang digunakan untuk menganalisis prestasi penghantaran dilakukan dengan menggunakan definisi SAE. Dari hasil, diperhatikan bahawa prestasi CVT lebih baik daripada penghantaran manual. Hal ini juga didapati bahawa Transmisi Manual lebih baik dari CVT dalam hal penggunaan bahan bakar untuk kereta berenjin di bawah 1 liter. Selain itu, CVT sesuai digunakan untuk kereta berenjin di bawah 1 liter kerana memberikan kekuatan lebih dan keselesaan semasa pemanduan. Pada masa datang, perbandingan antara penghantaran manual dan CVT harus dilakukan dalam eksperimen atau simulasi kerana teknologi CVT baru sahaja mula berkembang di Malaysia. Ada banyak faktor yang diperlukan untuk dilakukan kajian secara eksperimen terutama dalam prestasi penghantaran dan kebolehan pemanduan.

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Comparison Manual and CVT Transmission for a Car Under 1 Liter Engine "is written by Mohammad Azlan bin Abdul Aziz. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality 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.

Tuan Haji Amirruddin Bin Abdul Kadir

Examiner Signature

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LIST OF SYMBOLS

A	Cross-section area
C_d	Aerodynamic drag coefficient
g	Gravitational force
G	Overall drive ratio
G_{fd}	Final gear ratio
m	Mass of vehicle
N_e	Engine speed
P	Power available
P_{req}	Power required
R_a	Aerodynamic drag resistance
R_r	Rolling resistance
R_g	Gravitational resistance
R_i	Acceleration resistance
r	The radius of the tyre
T_e	Engine Torque
T_w	External torque
TF_w	Tractive effort
v	vehicle speed
$\dot{v}$	Acceleration in the direction of motion of the vehicle
ρ	Air density
θ	Road slope
η	Efficiency

LIST OF ABBREVIATIONS

CVT	Continuously Variable Transmission
FYP	Final Year Project
IC	Internal combustion
RPM	Revolution per Minute
RWS	Road wheel speed
SAE	Society of Automotive Engineers
VDP	Variable-Diameter Pulley

CHAPTER 1

INTRODUCTION OF THE PROJECT

1.1 INTRODUCTION

Transmission is one of part that is important after engine part. It can assume as the heart of the drivetrain. It is because gasoline engines develop their torque over a very narrow speed range, several gears are needed to reach useful road speeds. A manual transmission is a type of transmission uses a driver operated clutch, typical operated by a pedal or lever, for regulating torque transfer from internal combustion and gear shift, either operated by hand. The CVT is a transmission which can change steplessly through an infinite number of effective gear ratios between maximum and minimum values.

There has been a clear trend in the automotive industry in recent years toward increased ride comfort and fuel efficiency. As power transmission unit, transmission plays an important role in vehicle performance and fuel economy (Lechner, 1999). Manual transmission have an overall efficiency of 96.2 percents, this is the highest efficiency value for any type of transmission. Current production automatics have been improved to provide an efficiency of not more than 86.3 percents and CVT's have an overall efficiency of 84.6 percents. However, the major advantage of CVT is that it allows the engine to operate in the most fuel-efficient manner (Klunger, 1999).

In order to seek the best performances, a research will be carried out to the car under 1 liter engine. Toyota iQ 1000cc is selected in this study because only this model which have manual and continuously variable transmission for a car under 1 liter engine. A calculation was required to estimate which one have better performance especially in performance characteristic. The best method to calculate the performance is by manual calculation with certain formula and graph is plotted by using assistance software such as Microsoft Excel.

1.2 PROBLEM STATEMENT.

The performance of the vehicles depends on so many factors and one of it is the type of transmission. Nowadays, there are three types of transmission being used all around the world that effect the engine and each of it has their own advantages and disadvantages. But the best or ideal transmission for the vehicle still not exist and there are too many space for improvement for researcher to find the perfect one and to make sure the performance of the vehicle at the high level.

Manual transmission is familiar and widely used in passenger car at this age. CVT have become increasingly popular in the automotive marketplace in the past decade. Normally, the CVT is used in heavy vehicles such as trucks, buses and etc. This is because the CVT can provide high power and torque to facilitate in controlling of heavy vehicles. So, Manual and CVT transmission have their own advantages and of one of their advantage is better in performances. But, the question is which transmission provides better performance?

1.3 OBJECTIVES

The objectives of this project are as follows:

i. To compare the performance of transmission between Manual Transmission and CVT transmission based on Toyota iQ 1.0 liter.
ii. To analyze the performance of the Manual Transmission and the CVT Transmission for a car under 1 liter engine
iii. To study the suitability using CVT for a car under1 liter engine.

1.4 PROJECT SCOPES.

This project is focusing on comparing between CVT Transmission and Manual Transmission in terms of performance. To complete this project, the following actions are required:

i. Study of manual transmission and CVT transmission based on technical specification of Toyota iQ 1.0 liter on the plane road.
ii. Study of the CVT Transmission mechanism.
iii. Study of the Manual Transmission mechanism.
iv. Study of vehicle dynamics.
v. Compare the CVT Transmission and Manual Transmission performance by using the graph

1.5 METHODOLOGY AND FLOW CHART.

Methodology is one of the most important things to be considered to ensure that the project will run smoothly and will get the expected result. It will be discuss on the process of the project due to the flow chart or more specifically due to the Gantt chart. In this methodology, there are several steps that must followed in order to ensure that the objective of the project can be achieved starting from the literature finding until submitting the report. Below are the steps of the project which briefly being shortlisted into the flow chart.

FLOW CHART

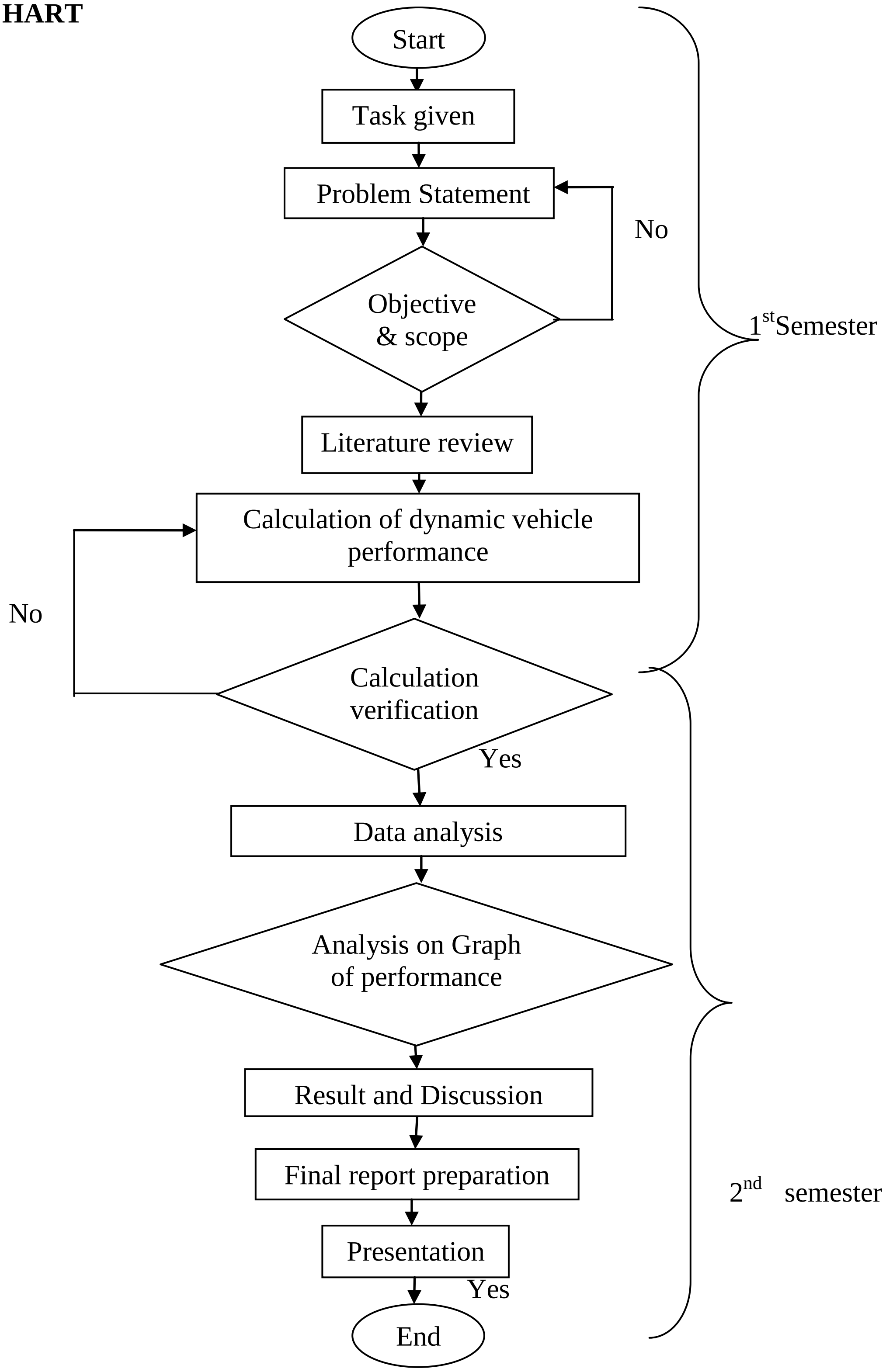


Figure 1.1: Flow Chart of Project

1.6 STRUCTURE OF THESIS.

This thesis purposes to study comparison between Manual transmission and CVT Transmission. Besides that, this thesis also aims to analyze the performance of the Manual Transmission and the CVT Transmission for a car under 1 liter engine. This thesis consists of five (5) chapters.

First chapter describes overall framework of basic information of this project such as introduction, problem statement, objective of the project, project scope and structure of thesis was verified. The main ideas of this project were stated in introduction.

In second chapter, various reviews on theoretical topics which are required as a background study were present. Every important information and theoretical study related to this project is stated in this chapter. Brief explanations about transmission, history, types, and advantages and disadvantages of transmission to achieve the project objectives are reviewed. Some of the explanations give extra information which is useful in conducting this project.

In third chapter, all the method used when conducting the project was described including explanation. The overall methodology sequence are mentioned and explained in detail.

Otherwise, chapter four is about result and discussion about project. This chapter explains the result and analysis that got from the graph.

The conclusion of overall project, recommendation and future works are stated in fifth chapter of the thesis. The conclusion made based from result obtained, the encountered problem lead to recommendation to troubleshot the predicaments. The area o f improvement will be the source of future projects.

Finally, the references of this project were listed and follow by appendices. The related tables are included in appendices for general review.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY AND DEVELOPMENT OF DRIVETRAIN.

A car receives power from the engine but it is the transmission that helps utilize engine power efficiently. The gearbox in a car brings variety to driving and a very responsive transmission can make a big difference in ride quality for the occupants. Most cars today come installed with good transmissions.

The earliest transmissions were all of manual type. Manual transmissions still continue to be just as popular as they used to be for the sole reason that they give the driver a sense of thrill through the ability to shift gears up or down at any desired moment. In 1894, the modern transmission was introduced by a pair of Frenchmen who are Louis-Rene Panhard and Emile Levassor (Bohen, 2006). By 1904, the new transmissions were on most cars. The basic concept survives today, with many improvements, of course, and one major change. Introduced by Cadillac in 1928, it's called a synchromesh transmission. It synchronizes gear speeds before shifts so the gears mesh smoothly and shifting is easier for drivers (Bohen, 2006).

The automatic transmission that resembles what's on today's cars got its start in 1948 as Buick's two-speed Dynaflow. Detroit's Big Three and other carmakers soon had versions on all sorts of models. Chevy had the Powerglide, Ford the three-speed Fordomatic and Merc-O-Matic (made by Borg-Warner), Chrysler the M-6 Torque Converter Automatic. As the last name indicates, the innovation was a torque converter, which replaced the fluid coupling (Bohen, 2006).

Though similar to its predecessor, with both eliminating the need for mechanical clutches, the torque converter also multiplied torque at low engine speeds, increasing acceleration. An interesting fact about both fluid couplings and torque converters is that they get power to the wheels even though the only direct connection between the engine and the transmission is through the transmission fluid (Bohen, 2006).

By the 1960s, three-speed torque-converter automatics dominated. They gave way in the 80's to overdrive transmissions with four forward speeds and a lockup feature that increased fuel efficiency. Starting in the late 80's, engine computers or separate transmission chips took greater control of transmissions, improving shift quality, dropping shift times and making semi-automatic shifting without clutches possible (Bohen, 2006).

To say that the CVT is nothing new would be a gross understatement: Leonardo da Vinci sketched his idea for CVT in 1940 (Birch, 2000). In automotive applications, CVT's have been around nearly as long as car themselves, and certainly as long as conventional automatics. General Motors actually developed a fully toroidal CVT in the early 1930s and conducted extensive testing before eventually deciding to implement a conventional, stepped-gear automatic due to production (Yamaguchi, 2000). British manufacturer Austin used a CVT for several years in one of its smaller cars, but "it was dropped due to its high cost, poor reliability, and inadequate torque transmission" (Yamaguchi, 2000). Many early CVTs used a simple rubber band and cone system, like the one developed by Dutch firm DAF in 1958 (Birch, 2000). However, the DAF CVT could only handle a 0.6L engine, and problems with noise and rough starts hurt its reputation (Yamaguchi, 2000). Uninspired by these early failures, automakers have largely avoided CVTs until very recently.

2.2 CONTINUOUSLY VARIABLE TRANSMISSION

2.2.1 Introduction of CVT

In the last decades, a growing attention has been focused on the environmental question. Governments are forced to define standards and to adopt actions in order to reduce the polluting emissions and the green-house gasses. To reduce vehicles' gas emissions in relatively short times, a great deal of research has been devoted to find new technical solutions, which may improve the emission performances of nowadays internal combustion (IC) engine vehicles. A very good solution may be that of using a CVT which is able to provide an infinite number of gear ratios between two finite limits. CVT transmissions are even potentially able to improve the performances of classical IC engine vehicles, by maintaining the engine operation point closer to its optimal efficiency line. Several studies have shown, indeed, that CVTs may improve the fuel savings and reduce the vehicle polluting emissions. For instance, a mid class CVT car may achieve fuel savings of about 10% in comparison to the traditional manual stepped transmission (Brace et al., 1997; Brace et al., 1999; Mangialardi et al., 2002; Carbone et al., 2004).

A CVT (see Figure 2.1) is a transmission which can gradually shift to any effective gear ratios between a set upper and lower limit. In contrast, most transmissions equipped on production cars have only 4-6 specific gear ratios that can be selected. The almost infinite variability of a CVT allows the engine to maintain a constant speed while the vehicle increases in velocity. This can result in better vehicle performance if the CVT is shifted such that the engine is held at the RPM that it runs most efficiently at and/or produces the most power (Gibbs, 2009)

.

Physical limitations of strength and friction have in the past restricted the CVT transmission torque handling capabilities to light-duty applications such as lawn mowers, ATVs, and snowmobiles. There was very little desire to develop them to their full potential. However, a renewed public outcry for improved vehicle efficiency combined with advancements in lubricants and materials have sparked new interests in

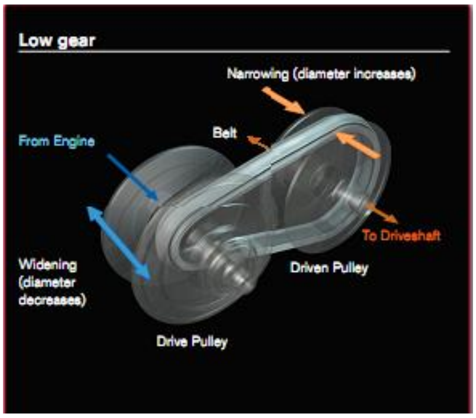
CVTs. They have now been proven to support the torque requirements for production vehicles, buses, heavy trucks, and earth-moving equipment (Gibbs, 2009).

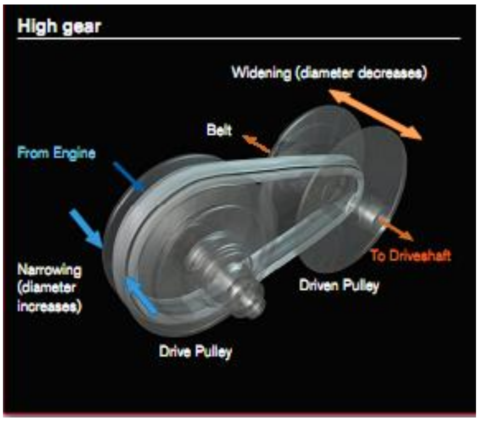
Figure 2.1: CVT Transmission

Source**:** Takahashi, M. et al. (1999)

2.2.2 CVT's Basic Principle.

The CVT is an automatic transmission that uses two pulleys with a steel belt running between them. To continuously vary its gear ratios, the CVT simultaneously adjusts the diameter of the "drive pulley" that transmits torque from the engine and the "driven pulley" that transfers torque to the wheels. From Figure 2.2 (a), the diameter of driven pulley increase but the diameter for drive pulley decrease. It is occurred because the power transmitted from engine to driveshaft. It is vice versa for diameter driven pulley and drive pulley for Figure 2.2 (b) which is in high gear condition. Besides that, because it is continuously variable, the CVT not only avoids the shift-shock and peaks and dips in torque transmission associated with a conventional AT, but also maintains optimum torque for any given power demand. This makes the CVT an exceptional transmission solution that delivers smooth and powerful driving performance together with excellent fuel economy (Nissan Motor, 2008).





(a) Principle for Low Gear (b) Principle for High Gear

Figure 2.2: CVT's Basic Principle.

Source: Nissan Motor (2008).

2.2.3 Types of CVT

2.2.3.1 Friction CVTs

The most common types of CVTs are based on friction between two or more rotating components in which the radius for the point of contact can be varied. This is typically archived with a VDP (refer Figure 2.3) also known as a Reeves drive. In this system there are two V-belt pulleys comprised of a stationary and movable sheave separated perpendicular to their axes of rotation, with a V-belt running between them. The effective gear ratio is changed by moving the sheaves of one pulley closer together while farther separating the other. Due to the V-shaped cross section of the belt, it will be forced to ride the pulleys at a different radius than before, thus the effective diameters of the pulleys changes. Since the center of rotation for each pulley and length of the belt doesn't change in the process, the movable sheaves of both pulleys must adjust simultaneously in opposite directions in order to maintain the proper belt tension (Gibbs, 2009).

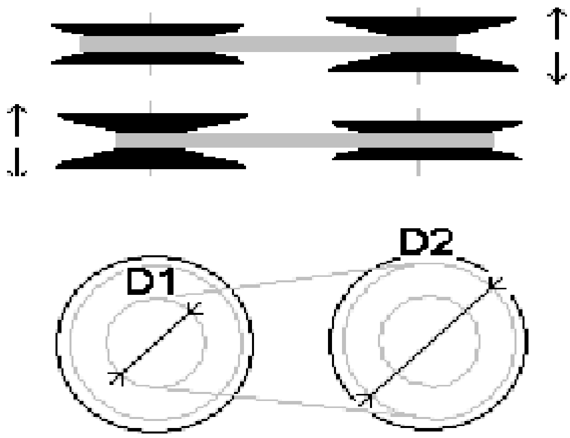


Figure 2.3: Variable- Diameter Pulley CVT

Source: Gibbs, J. H. (2009)

2.2.3.2 Torodial Traction Drive.

These transmissions use the high shear strength of fluids to transmit torque between input torus and an output torus. As seen in Figure 2.4, the moveable slides linearly, the angle of a roller changes relative to shaft position. This results in a change in gear ratio (Fussner, 1997)

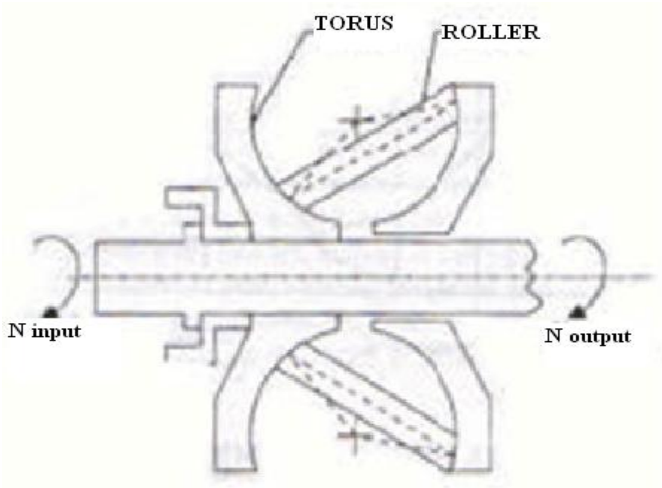


Figure 2.4: Torodial CVT

Source: Fussner (1997)

2.2.3.3 Ratcheting CVT.

The ratcheting CVT (refer Figure 2.5) is based on a set of elements that repeatable engages and disengage based on the variable stroke of a reciprocating component connected to a one-way clutch or ratchet. The ratchet only allows the work to be transmitted in the forward motion when it is locked into static friction such that the driving and driven surfaces momentarily move together without slipping. The effective gear ratio is adjusted by changing linkage geometry of the oscillating elements (Gibbs, 2009).

Ratcheting CVTs can transfer lots of torque because they are based on static friction which increases relative to the transmitted torque as shown in Figure 2.5. In a properly designed system slippage is impossible. Efficiency is generally higher than friction CVTs, such as VDP, which are based on dynamic friction that wastes energy through slippage of twisting surfaces. The major drawbacks to ratcheting CVTs are their complexity and the vibration caused by the oscillating elements (Gibbs, 2009).

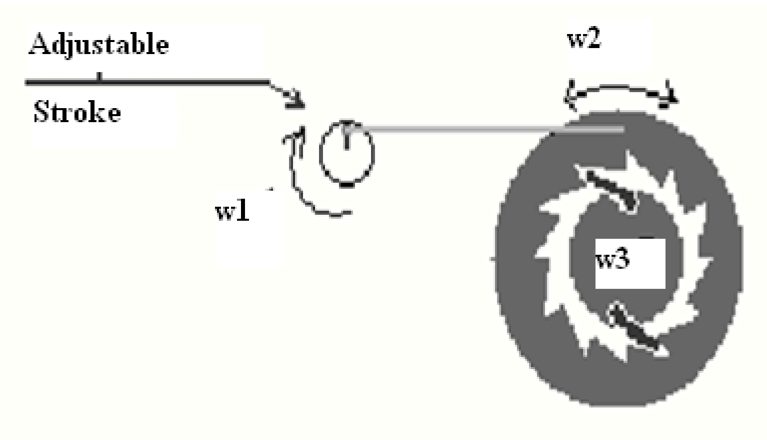


Figure 2.5: Ratcheting CVT

Source: Gibbs, J. H. (2009)

2.2.3.4 Hydrostatic CVTs

Hydrostatic CVTs (refer Figure 2.6) use a variable displacement pump to vary the fluid flow into a hydrostatic flow. These types can generally transmit more torque since hydraulic fluid is not limited by tensile strength, but can be sensitive to contamination. Typically the hydraulic motor(s) are mounted directly to the wheel hub. Doing this eliminates the efficiency losses from friction in the drive train components. No additional gear boxes are required after this transmission to archive a reverse gear since flow to the hydraulic motors can easily be reversed using valves. Do to the heat generated by the flowing hydraulic fluid, hydrostatic CVTs are generally not used for extended duration high torque applications (Gibbs, 2009).

Slow moving agriculture equipment is atypical application for hydrostatic CVT such as tractors, combines, and foragers. They can be commonly found in many riding lawn mowers and garden tractors designed to pull equipment like a reverse tine tiller or bladed plow. There is even a variety of heavy earth-moving equipment manufactured by Caterpillar Inc. which currently uses hydrostatic CVT transmissions (Gibbs, 2009).

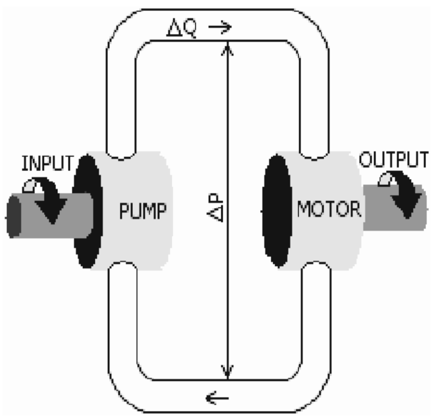


Figure 2.6: Hydrostatic Transmission

Source: Gibbs, J. H. (2009)

2.2.4 Epicyclic Gear Train Construction and Description.

Drive in both forward and reverse direction is obtained by a single epicyclic gear train controlled by a forward multiple clutch and reverse multiplate clutch and reverse multiplate brake, both which are of the wet type (immersed in oil). The forward clutch is not only used for engagement of drive but also to provide an initial power take-up when driving away from test (Heisler, 2002).

The epicyclic gear train consist of an input planetary gear carrier, which supports three sets of double planetary gears, and the input forward clutch plate. Surrounding the planetary gear is an internally toothed annulus gear which also supports the rotating reverse brake plates. In the centre of the planetary gears is sun gear which is attached to primary pulley drive shaft (Heisler, 2002).

2.2.4.1 Neutral or park (N or P position)

When neutral or park position is selected, both the multiple clutch and brake are disengaged. This means that the annulus gear and the planetary carrier are free to revolve around the sun gear without transmitting any power to the primary pulley shaft (Heisler, 2002).

The only additional feature when park position is selected is that a locking pawl is made to engage a ring gear on the secondary pulley shaft, thereby preventing it from rotating and causing the car creep forward (Heisler, 2002).

2.2.4.2 Forward drive (D or L position)

Selecting the D or L drive energizes the forward clutch so that torque is transmitted from the input engine drive to the right and left hand planetary carriers and planetary carries and planet pins, through the forward clutch clamped drive and driven multiplates. Finally it is transferred by the clutch outer casing to the primary pulley shaft. The forward gear drive is a direct drive causing the planetary gear set to revolve bodily at the engine speed no relative rotational movement of the gears themselves (Heisler, 2002).

2.2.4.3 Reverse drive (R position)

Selecting reverse gear disengages the forward clutch and energizes the reverse multiple brake. As a result, the annular gear is held stationary and the input from the engine rotates the planetary carrier. The forward clockwise rotation of the carrier causes the outer planet gears to rotate on their own axes as they are compelled to roll round the inside of internally toothed annular gear in an anticlockwise direction (Heisler, 2002).

Motion is transferred from the outer planet gear to the sun gear via the inner planet gears. Because they are forced to rotate clockwise, the meshing sun gear is directionally moved in the opposite sense anticlockwise, which is in the reverse direction to the input drive from the engine (Heisler, 2002).

2.2.5 Advantages and disadvantages of the CVT

CVT are becoming more popular for good reason. It boasts several advantages that make it appealing both to drivers and to environmentalists. Engines do not develop constant power at all speeds and they have specific speeds where torque (pulling power), horsepower (speed power) or fuel efficiency is at their highest levels. It is because the CVT allows an engine to run at this most efficient point virtually independent of vehicle speed, a CVT equipped vehicle yields fuel economy benefits when compared to a conventional transmission. Moreover, CVTs offer improved efficiency and performance. This yields an average efficiency of 86%, compared to a typical manual transmission with 97% efficiency. These CVTs each offer improved efficiency over conventional automatic transmissions, and their efficiency depends less on driving habit than manual transmissions (Fussner and Klunger, 1997). Testing by ZF Getriebe GmbH several years ago found that “the CVT uses at least 10% less fuel than a 4-speed automatic transmission” for U.S. Environmental Protection Agency city and highway cycles.Moreover, the CVT was more than one second faster in 0-60 mph acceleration tests (Boos and Mozer, 1997)

Because there are no steps between effective gear ratios, CVTs operate smoothly with no sudden jerks commonly experienced when a typical transmission is shifted to a different gear. This apparent advantage has ironically been one of the major factors to why they haven't been used more in production vehicles today. Since drivers expect a car to jerk or the engine sound to change as they press the accelerator pedal further, it is very confusing for them when the car smoothly accelerates without the engine reviving faster. Drivers have unfortunately perceived this as the car lacking power which is causing a marketing problem for the transmissions. (Gibbs, 2000)

CVT development has progressed slowly for a variety of reasons, but much of the delay in development can be attributed to a lack of demand: conventional manual and automatic transmissions have long offered sufficient performance and fuel economy. Thus, problems encountered in CVT development usually stopped said progress (Lang, 2000). Designers have unsuccessfully tried to develop [a CVT] that can match the torque capacity, efficiency, size, weight, and manufacturing cost of step-ratio transmissions (Broge, 1999).

One of the major complaints with previous CVTs has been slippage in the drive belt or rollers. This is caused by the lack of discrete gear teeth, which form a rigid mechanical connection between to gears; friction drives are inherently prone to slip, especially at high torque. With early CVTs of the 1950s and 1960s, engines equipped with CVTs would run at excessively high RPM trying to "catch up" to the slipping belt. This would occur any time the vehicle was accelerated from a stop at peak torque (Lang, 2000). For compressive belts, in the process of transmitting torque, micro slip occurs between the elements and the pulleys. This micro slip tends to increase sharply once the transmitted torque exceeds a certain value (Kobayashi et al., 1998).

For many years, the simple solution to this problem has been to use CVTs only in cars with relatively low-torque engines. Another solution is to employ a torque converter (such as those used in conventional automatics), but this reduces the CVT's efficiency Perhaps more than anything else, CVT development has been hindered by cost. Low volume and a lacks of infrastructure have driven up manufacturing costs, which inevitably yield higher transmission prices. With increased development, most of these problems can be addressed simply by improvements in manufacturing techniques and materials processing. For example, Nissan's Extroid "is derived from a century-old concept, perfected by modern technology, metallurgy, chemistry, electronics, engineering, and precision manufacturing (Yamaguchi, 2000).

2.3 MANUAL TRANSMISSION

2.3.1 Introduction of Manual Transmission.

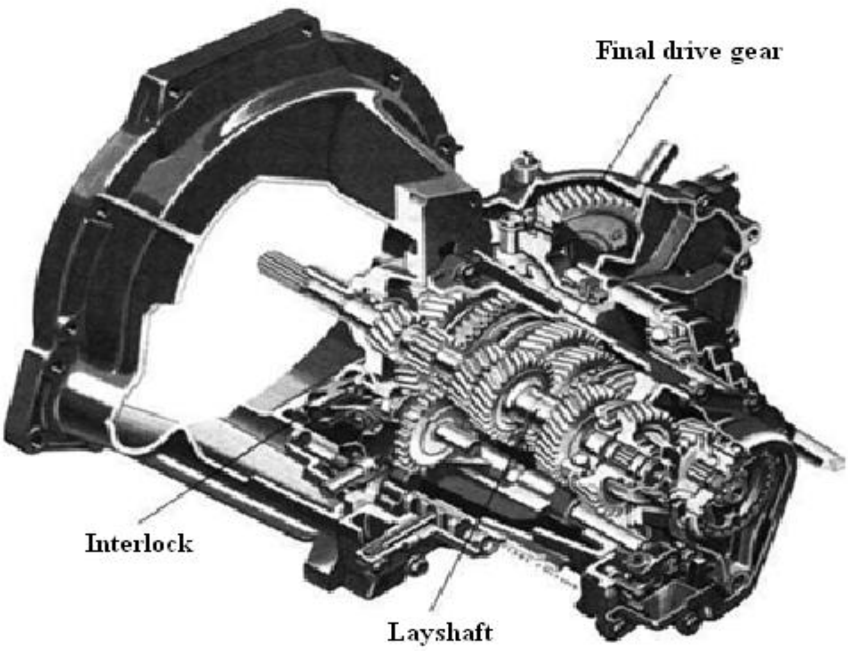


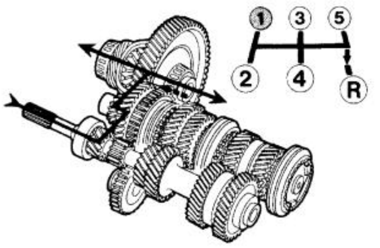
Figure 2.7: Manual Transmission.

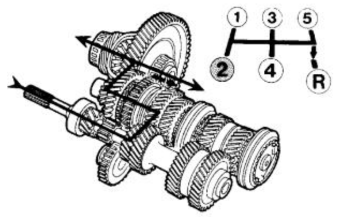
Source: Denton, T. (2000)

A manual transmission (Figure 2.7) is a type of transmission used in motor vehicle applications which uses a driver operated clutch, typical operated by a pedal or lever, for regulating torque transfer from internal combustion and gear shift, either operated by hand and it also known as a manual gear box or standard transmission.

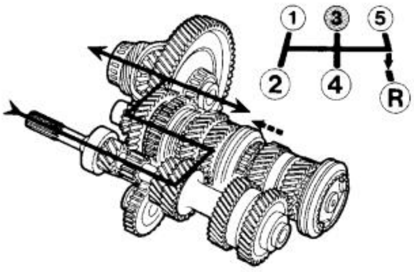
Manual transmissions are characterized by gear ratios that are selectable by locking selected gear pairs to the output shaft inside the transmission. Contemporary automobile manual transmissions typically use between four to six forward gears and one reverse gear, although automobile manual transmissions have been built with as few as two and as many as eight gears. Transmission for heavy trucks and other heavy equipment usually have at least 9 gears so the transmission can offer both a wide range of gears and close gear ratios to keep the engine running in the power band. Some heavy vehicle transmissions have dozens of gears, but many are duplicates, introduced as an accident of combining gear sets, or introduced to simplify shifting. Some manuals are referred to by the number of forward gears they offer as a way of distinguishing between automatic or other available manual transmissions.

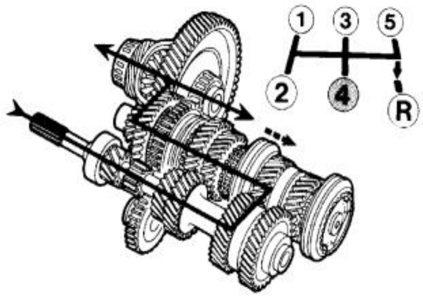
2.3.2 Manual Transmission's Principle.



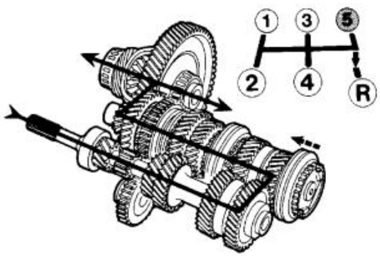


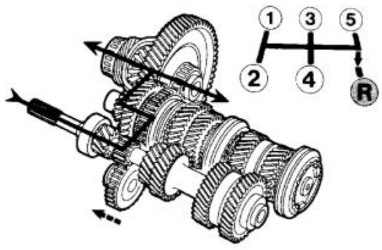
(A) First gear (B) Second gear





(C) Third Gear (D) Fourth Gear





(D) Fifth Gear (F) Reverse Gear

Figure 2.8: Manual Transmission's Operation

Source: Denton, T., (2000)

2.3.2.1 First gear.

To shift into first, depress the clutch pedal to disengage the clutch. Move the gearshift lever into the first position. This causes linkage in the transmission to select the first-reverse synchronizer and move its sleeve to the right. The sleeve locks to the first-speed gear. Since the synchronizer and sleeve assembly are locked to the output shaft, the first-speed gear drives the output shaft when the clutch is engaged (Crouse, 1993).

Figure 2.8 (A) shows mechanism that occurred in first gear. In first gear, there id torque multiplication and speed reduction through the transmission. The main-drive gear is smaller than the counter gear it drives. This provides gear reduction. There is more gear reduction as the small counter gear drives the large first-speed gear. The gear reduction can vary. A typical first gear ratio is about 4:1. The crankshaft turns four times to turn output shaft once. There is further gear reduction through the final drive in the rear drive axle (Crouse, 1993).

2.3.2.2 Second Gear

Figure 2.8 (B) shows mechanism that occurred in second gear. To shift into second, the first-second synchronizer sleeves moves to the left. The sleeve moves through its center or neutral position, un-locking the first-speed gear and locking the second –speed gear to output shaft. The second-speed gear, driven by counter gear second gear, now drives the output shaft through the synchronizer sleeve. There is less gear reduction than the first gear because there is less difference in the size of the gear. A typical gear ratio for second is about 2.4:1. The input shaft turns 2.4 times to turn the output shaft once (Crouse, 1993).

2.3.2.3 Third Gear

Figure 2.8 (C) shows mechanism that occurred in third gear. In third, the first-second synchronizer sleeve moves to its neutral position. The third-fourth synchronizer sleeve moves to the right so that it meshes with the third-speed gear. The counter gear third gear now drives the third speed-gear and the output shaft through the synchronizer. A typical gear reduction in third is about 1.5:1 (Crouse, 1993).

2.3.2.4 Fourth Gear or Direct Drive.

Figure 2.8 (D) shows mechanism that occurred in fourth gear. In fourth, the third-fourth synchronizer sleeves moves to the left, so that it meshes with the main-drive gear on the end of the input shaft. The output shaft is now driven by the main-drive gear through the synchronizer. This is direct drives and the gear ratio is 1:1 (Crouse, 1993).

2.3.2.5 Fifth Gear or Overdrive.

Figure 2.8 (E) shows mechanism that occurred in fifth gear. In fifth, both the first-second synchronizer and the third-fourth synchronizer move to neutral. The sleeve on the fifth synchronizer moves forward. This locks the fifth-speed gear to the counter gear. The fifth-speed gear now turns fifth gear which is splined to the output shaft. Overdrive is provided because the fifth-speed gear is larger than the gear it drives. A typical overdrive gear ratio is 0.8:1. The output shaft turns one complete revolution while counter gear turns only 0.8 (a little more than three-quarters) revolution (Crouse, 1993).

2.3.2.6 Reverse Gear.

Figure 2.8 (F) shows mechanism that occurred in reverse gear. In reverse, all synchronizer are equal in neutral. The reverse-idler gear slides into mesh with reverse gear on the counter gear and the gear teeth on the first-second synchronizer sleeve. This serves as the reverse gear on the output shaft. The countergear drives the reverse-idler gear and it drives the output shaft through the synchronizer sleeve. The output shaft turns in the reverse direction because of the reverse idler gear. A typical reverse gear ratio is about 3.5:1 (Crouse, 1993).

2.3.3 Advantages and Disadvantages of Manual Transmission.

Manual transmissions generally offer better fuel economy than automatic torque converter transmissions and however the disparity has been somewhat offset with the introduction of locking torque converters on automatic transmissions. Fuel consumption increased when operated manual transmission vehicle because the fuel consumption is depending on driving conditions and style of driving. Manual transmissions do not require active cooling and generally weigh less than comparable automatics. The manual transmission couples the engine to the transmission with a rigid clutch instead of a torque converter which slips by nature. Manual transmissions also lack the parasitic power consumption of the automatic transmission's hydraulic pump.

Manual transmissions also generally offer a higher selection of gear ratios. Many vehicles offer a 5-speed or 6-speed manual, whereas the automatic option would be a 4-speed all the way up to 8-speed. The higher selection of gears allowed for more uses of the engine's power band, allowing for higher fuel economy and power output. This is generally due to the space available inside of a manual transmission versus an automatic since the latter requires extra components for self-shifting, such as torque converters and pumps.

Manual transmissions are more efficient in term of handling than automatics transmission and CVT. The driver has more direct control over the car with a manual than with an automatic, which can be employed by an experienced, knowledgeable driver who knows the correct procedure for executing a driving maneuver, and wants the vehicle to realize his or her intentions exactly and instantly. An engine coupled with a manual transmission can often be started by the method of push starting. This is particularly useful if the starter is inoperable or defunct. Recently only fully manual transmissions allow the driver to fully exploit the engine power at low to medium engine speeds. This is due to the fact that even automatic transmissions which provide some manual mode which use a throttle kick down switch, which forces a downshift on full throttle and causes the gearbox to ignore a user command to upshift on full throttle. This is especially notable on uphill road; where cars with automatic transmission need to slow down to avoid downshifts, whereas cars with manual transmission and identical or lower engine power are still able to maintain their speed.

Manual transmission also has disadvantages. The smoothness and correct timing of gear shifts are wholly dependent on the driver's experience and skill because the driver selects each gears, it is also possible to select the wrong gear. Attempting to select reverse while the vehicle is moving forward causes severe gear wear and choosing a low gear with the car moving at speed can over speed and damage the engine.

Manual transmissions place slightly more workload on the driver in heavy traffic situations, when the driver must often operate the clutch pedal. In comparison, automatic transmissions merely require moving the foot from the accelerator pedal to the brake pedal, and vice versa. Manual transmissions require the driver to remove one hand periodically from the steering wheel while the vehicle is in motion.

2.4 GENERAL OF TOYOTA IQ 1.0 VVT-I

Figure 2.9: Toyota iQ 1.0 liter.

Source: Toyota Motor Europe. (2008).

The 1.0 VVT-i petrol engine, vehicle that full criteria to do this project which was awarded ‘Engine of the Year’ in 2008 in the sub-1.0 liter class, achieves top-level power output of 50 kW and delivers 91Nm of torque at 4,800rpm (Toyota Motor Europe, 2008). This model full fills this project because it has two types of transmission which is CVT transmission and Manual Transmission. Combined with a high ratio 5-speed manual transmission, the 3-cylinder lightweight inline unit delivers a fuel economy of 4.3 l/100 km and CO_2 emissions of just 99g/km. This allows the iQ to remain under the 100 g/km taxation threshold in major European markets, resulting in a yearly tax saving of around 0 - 1000 Euro, depending on the country (Toyota Motor Europe, 2008).

This power unit can also be specified with the new CVT transmission, with emissions of 110g/km. iQ’s innovative CVT transmission, Toyota’s latest CVT technology, delivers an incredibly smooth ‘shift feel’ while optimizing the balance of fuel economy and performance. It continuously monitors and selects the most appropriate gear ratio and shifting speed, automatically eliminating ‘shift shock’ or jumps while changing gear. It maximizes available engine torque without unnecessary acceleration, as well as smoothing gear ratio changes. For example, limiting uphill shifts and executing downhill shifts to achieve optimum engine brake force. CVT delivers the city-friendly characteristics of an automatic transmission (Toyota Motor Europe, 2008).

2.5 SUMMARY

The main contribution of this chapter is knowledge about the transmission. From this chapter, the advantages and disadvantages of each transmission which is manual transmission and CVT transmission have been known. Otherwise, knowledge about mechanism and types of manual transmission and CVT transmission also can help to be more understand about transmission. Besides that, the general about the car will be use in this project which is Toyota iQ 1.0 liter engine is analysed from technical data for guiding to find performance of manual transmission and CVT transmission.

CHAPTER 3

VEHICLE DYNAMIC PERFORMANCE

3.1 INTRODUCTION

This chapter will further describe the study about this research which is study of performance of vehicle. This begins with the necessity of understanding the process to be calculating which is very important in study of performance of transmission. A mathematical model pertinent can be very useful in achieving this understanding, and can also be used as a cost-effective test bed for controller development, especially in the absence of a real physical system (Smith, 1998; Law, 2001). This chapter describes the study of performance for each transmission based on a 1.0 liter car. The calculations of performance of transmission are based on the vehicle dynamics that capture the pertinent dynamic behaviour related to performance of transmission. Simplification and assumptions are made throughout, and will be described and justified accordingly (Ariyono, 2008).

3.2 VEHICLE RESISTANCE AND ROAD DISTURBANCE

There are many resistance need to consider for finding performance of vehicle. Figure 3.1 shows the forces acting on a vehicle with mass, *m*, and speed, v. By applying Newton's second law in the longitudinal direction, the friction force (R_w) is described by (Gillespie, 1992):

$$R_w = R_a + R_r + R_g + R_i \tag{3.1}$$

where,

R_a : the aerodynamic drag resistance
R_r : rolling resistance
R_g : gravitational resistance
R_i : acceleration resistance,

The external torque could be modelled as

$$T_w = R_w \times r \tag{3.2}$$

where,

r : the radius of the tyre (m)

the radius of tyre, r can calculate based on this equation

$$r = \frac{2\,((\text{aspect ratio x tyre width}) + (\text{wheel's diameter x } 0.0254\,))}{2} \tag{3.3}$$

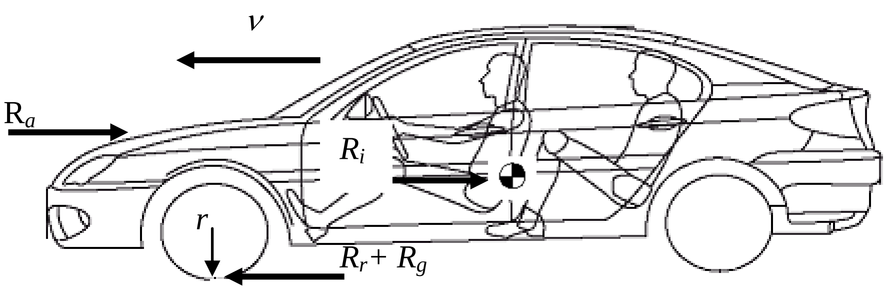


Figure 3.1: Force acting on a vehicle

Source: Ariyono, S. (2008)

3.2.1 Aerodynamics Resistance

On modern cars and trucks, the road load is dependent on the aerodynamic factor. The aerodynamic forces of a vehicle arise from two source-forms, drag and viscous friction (Ariyono, 2008). Since airflow over a vehicle is so complex, it is necessary to use semi-empirical model to represent the effect (Gillespie, 1992). Thus the aerodynamic drag, R_a, is characterised by equation:

$$R_a = \tfrac{1}{2} \rho C_d \; A v^2 \qquad (3.4)$$

where,

ρ : the air density (kg/m^3)
C_d : the aerodynamic drag coefficient
A : the maximum vehicle cross-section area (m^2)
v : vehicle speed (m/sec).

3.2.2 Rolling Resistance

The other major resistance on level ground is the rolling resistance of the tires. At low speed on hard pavement, the rolling resistance is the primary motion resistance force. Aerodynamic resistance becomes equal to the rolling resistance only at the speed of 80 – 100 km/h (Gillespie, 1992). There are several factors affecting rolling resistance such as tyre temperature, tire inflation pressure, vehicle velocity, and type of tyre. The coefficient is proportional to the speed but the effect is small at moderate and low speeds and is often assumed to be constant. The influence of speed becomes more pronounced when coupled with lower inflation pressure. Because of the complexity of factors affecting rolling resistance, it is necessary to simplify the equation and the rolling resistance, R_r, and approximated as

$$R_r = (c_a + c_b\, v)mg \tag{3.5}$$

where,

c_a : constant (0.013) (Gillespie, 1992)

c_b : constant (0.00004) (Gillespie, 1992)

m : mass of vehicle (kg)

g : gravitational force (m/sec^2).

3.2.3 Gravitational Resistance

When a vehicle climbs an inclined road, force due to gravity needs to be considered. This extra force due to inclined road has to be overcome by the engine. When the road slope is declining the engine should be able to provide engine break by increasing its transmission ratio (Ariyono, 2008).

Gravitational force, R_g, is approximated by

$$R_g = mg \sin \theta \tag{3.6}$$

where,

θ : the road slope (%)

3.2.4 Acceleration Resistance

For acceleration resistance, assume the mass is fixed. So the acceleration resistance (R_i) is equal to

$$R_i = m\frac{dv}{dt} = m\dot{v} \tag{3.7}$$

Where,

$\dot{v}$: Acceleration in the direction of motion of the vehicle.

3.3 PERFORMANCE OF TRANSMISSION

3.3.1 Tractive Effort- Speed.

The tractive force generated by the engine or power train is the effort available to overcome road load forces and accelerate the vehicle (Gillespie, 1992).

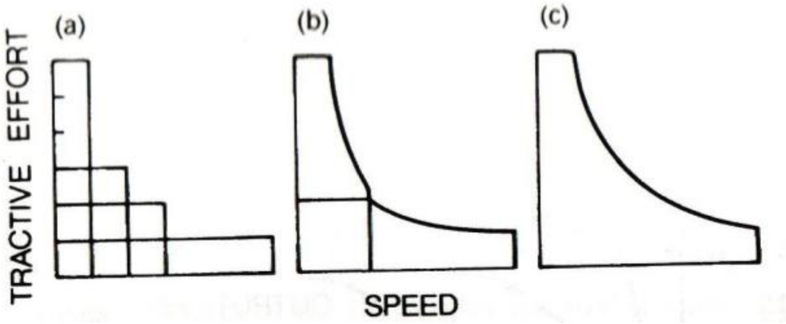


Figure 3.2: Tractive effort speed characteristic for Continuously Variable Transmission

Source**:** Wong, J.Y. (2001)

Figure 3.2 shows tractive effort-speed characteristic of Continuously Variable Transmission which consist of three types of graphs which are Figure 3.2(a) for constant displacement pump with fixed displacement motor, Figure 3.2(b) for variable displacement pump with fixed displacement motor, and Figure 3.2(c) for variable displacement pump and motor. Although the performance and control of this type of transmission are beyond question, the problem of cost, reliability, maintenance and service remain to be solved (Wong, 2001).

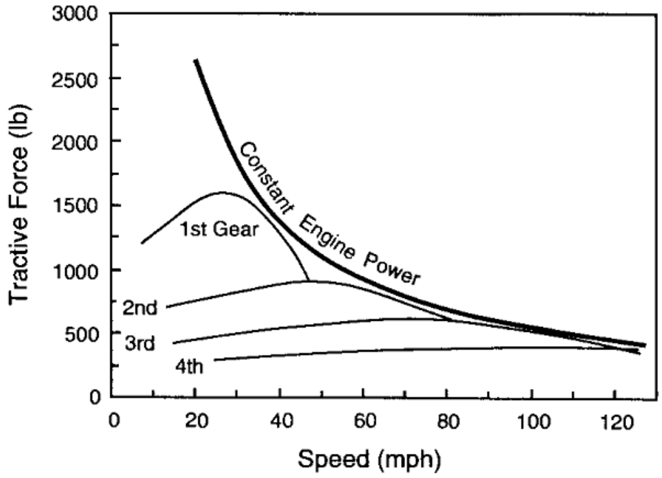


Figure 3.3: Tractive Effort Speed Characteristic for Manual Transmission

Source**:** Gillespie, T. D. (1992).

Figure 3.3 shows the tractive effort speed characteristic for manual transmission. The constant engine power line is equal to the maximum power of the engine, which is the upper limit of the tractive effort available, less any losses in the driveline. It is only approaches when the engine reaches the speed at which it develops maximum power. The tractive force for each gear is the image of the engine torque curve multiplied by the ratios for that gear (Gillespie, 1992). So, the equation is

$$\mathrm{TF}_w = \frac{T_e \mathrm{G}\eta}{\mathrm{r}} \tag{3.8}$$

where,

T_e : Engine Torque

G : overall drive ratio

r : radius of tire

TF_w : Tractive effort

η : Efficiency

The curves illustrate visually the need to provide a number of gear ratios for operation of the vehicle. For maximum acceleration performance the optimum shift point between gears is the point where the lines cross. The area between the lines for different gears and the constant power curve is indicative of the deficiencies of the transmission in providing maximum acceleration performances (Gillespie, 1992).

3.3.2 Power Available

The engine should have sufficient power to overcome the internal resistance in transmission, rolling resistance of tires, and aerodynamics resistance at the maximum vehicle speed on the level road. The common practice is to select a gear ratio such that at the maximum vehicle speed, the engine speed is slightly higher than that at maximum engine power, as indicated in Figure 3.4 (Wong, 2001). Besides that, the power that produces by CVT increases and then maintain at maximum power, as indicated in Figure 3.5. Power available can calculate by using this equation

$$P = \frac{T_e Gv}{r} \tag{3.9}$$

where,

P : Power available

T_e : Engine Torque

G : overall gear ratio

r : radius of tire

v : vehicle speed

The required power is power that required overcome the force in certain vehicle speed

$$P_{req} = \frac{T_w \, \omega_w}{\eta} = \frac{R_w v}{\eta} \quad (3.10)$$

where,

P_{req} : Power required

R_w : Friction force

η : Efficiency

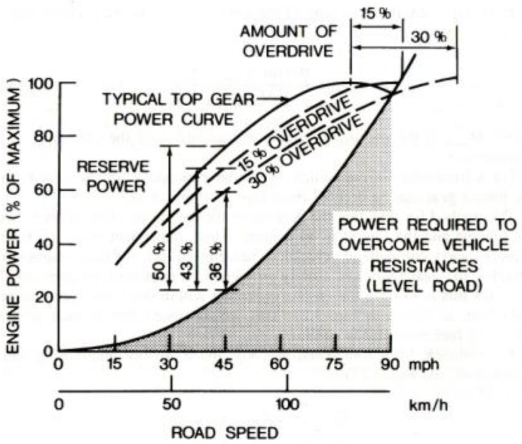


Figure 3.4: Graph engine power-road speed for Manual transmission

Source: Wong, J.Y. (2001)

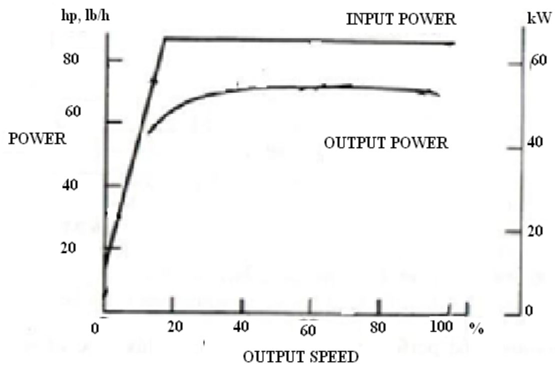


Figure 3.5: Graph engine power-road speed for CVT

Source: Wong, J.Y. (2001)

For calculate vehicle speed, v this equation are used

$$v = \frac{2}{60} \frac{N_e \pi r}{G} \quad (3.11)$$

where

G the overall transmission ratio (differential gear times transmission ratio).

N_e engine speed

3.3.3 Engine-Vehicle Speed

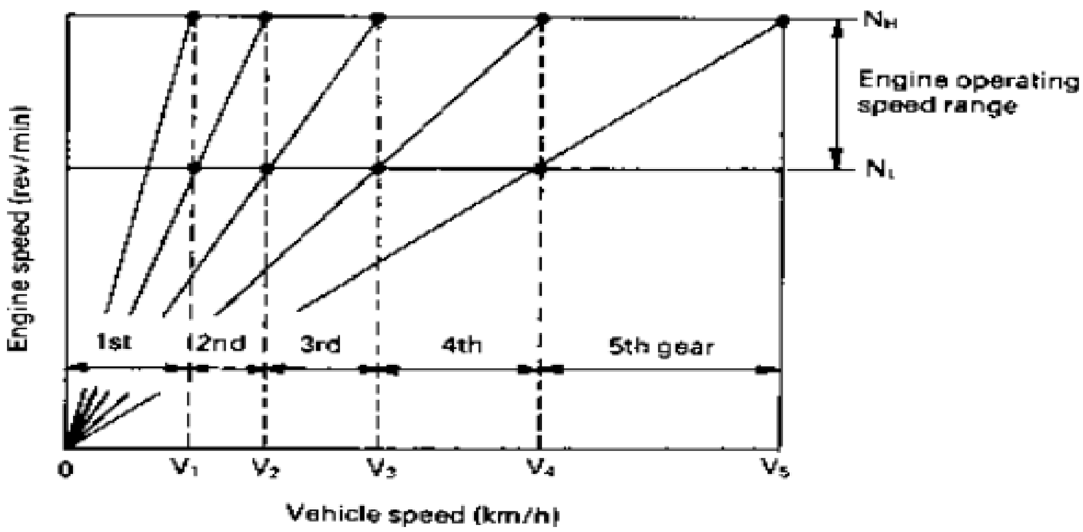


Figure 3.6: Engine Speed-Vehicle Speed Curve for Manual Transmission

Source: Heisler, H. (2002)

The method selecting the gear ratios for the intermediate gears between the highest and the lowest gear is, to a great extent, dependent upon the type of vehicle. The basis for this is to have engine operating within the same speed range in each gear as shown in Figure 3.6. This would ensure that in each gear the operating fuel economy is similar. (Wong, 2001) The road wheel speed can find by using this equation

$$RWS = \frac{N_e}{G} \tag{3.12}$$

where,

RWS : Road wheel speed

N_e : Engine rpm

G : Overall gear ratio

3.3.4 Fuel Consumption

The operating fuel economy of an automotive vehicle depends on a number of factors, including the fuel consumption characteristic of the engine transmission characteristic, weight of the vehicle, aerodynamic resistance, rolling resistance of tires, driving cycle and driver behaviour (Wong, 2001).

For given power requirement at a specific vehicle speed, the engine operating point is determined by gear ratio of transmission. Ideally, the gear ratio of transmission can varied to any desired value so that the engine operating point will follow the optimum fuel economy line for power setting (Wong, 2001).

3.4 PARAMETER OF TOYOTA iQ 1.0 LITER

The data specification for Toyota iQ 1.0 Liter as shown in Table 3.1 is used in the project.

Table 3.1: The parameters of Toyota iQ 1.0 liter Specification

Items	**Value**	**Unit**
Vehicle mass(m) (manual/CVT)	880 / 895	kg
Gravity(g)	9.81	m/s^2
Tyre radius(r)	0.3043	m
Frontal area (A)	2.2	m^2
Coefficient of drag	0.30	
Rolling resistance(C_a) (Gillespie 1992)	0.0013	
Coefficient of tyre (C_b) (Gillespie 1992)	0.00004	
Air Density (ρ) (sea level)	1.226	kg/m^3

3.5 SUMMARY

From this chapter, the knowledge about theory and formula of vehicle dynamic are very important for starting calculation. These calculations are use as method in this project to find performance of transmission. So, with this certain equation, calculations for performance transmission are found and the result of calculation will show with the exits of graph in chapter four.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter will discuss about the result obtained from the calculation of performance for manual and CVT transmission. The objective of this chapter is to compare the performance between Manual Transmission with CVT. In this analysis, the characteristic of performance that compared are power available, tractive effort, road wheel speed, and peak up of vehicle, fuel consumption and carbon dioxide emission. The example of calculation for each performance is showed in this chapter and the data that come from manual calculation are compiled in table and the tables are attached in appendices. The relationship between each characteristic of performance and speed is the main topics are also covered in this chapter. Besides that, the suitability of CVT to use in a car under 1 liter also discuss in this chapter. Finally, the price and maintenance for each transmission also discussed in this chapter.

4.2 PERFORMANCE OF POWER- TORQUE ENGINE FOR TOYOTA iQ 1.0 LITRE

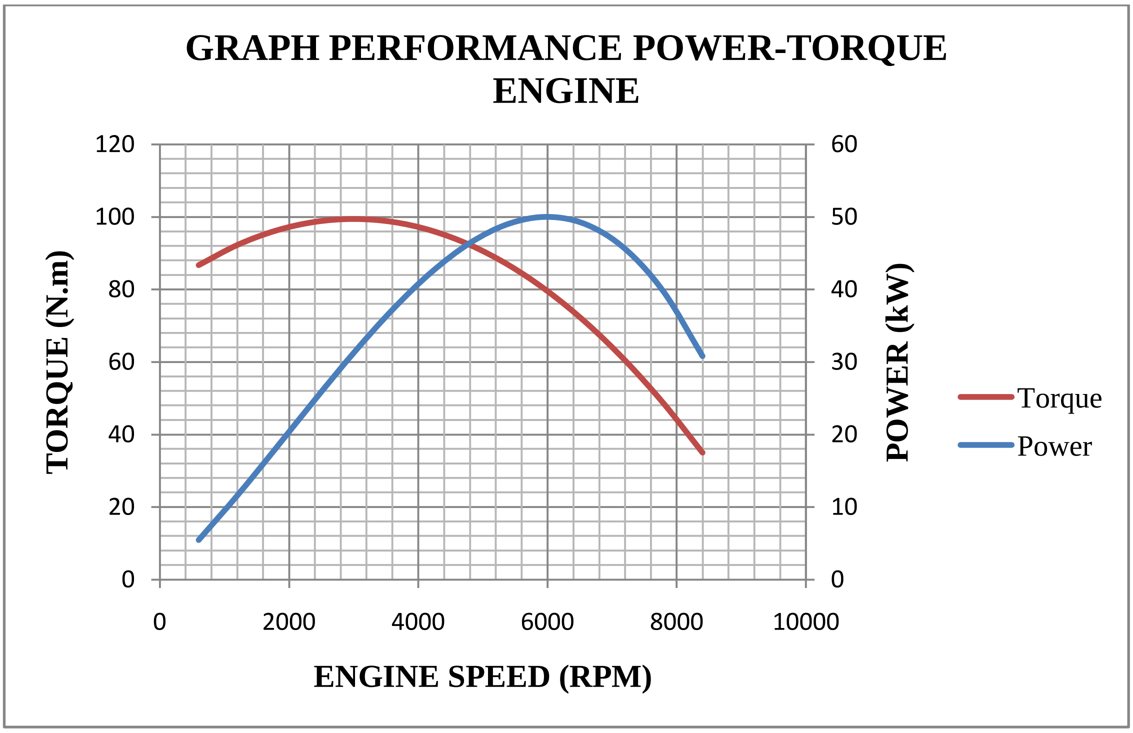


Figure 4.1: Graph Performance Engine for Toyota iQ 1.0 liter

Source of data: Toyota Motor Europe (2008)

This graph shows general performance of engine for Toyota iQ 1.0 liter. This graph was build from data that are compiled in Table 6.3 (Refer Appendix C). From the graph, the maximum power for this engine is 50 kW and the maximum for torque near to 100N.m. The internal combustion starts operating smoothly at a certain speed (the idle speed). Good combustion quality and maximum engine torque are reached at intermediate engine speed. As speed increases further, the mean effective pressure decreases because of growing losses in air-induction manifolds, and the engine torque also declines. Power output, however, increase with the increase of speed up to the point of maximum power. Beyond this point, the engine torque decrease more rapidly with increase of speed. This results in decline of power output (Wong, 2001). From this graph engine performance, the value of engine torque could be used to calculate power available and tractive effort.

4.3 EXAMPLE OF CALCULATION.

4.3.1 Power Available

N_e = 600 rpm

To find radius of tyre, the equation of 3.3 is used

$$\mathrm{r} = \frac{[2(175 \times 0.65) + (15 \times 0.0254)]}{2} = 0.3043\mathrm{m}$$

G = 13.21797

To find power, vehicle speed is needed. So, the equation 3.10 is used

$$v = \frac{2}{60}\frac{(600)\pi(0.3043)}{(13.21797)}$$

= 1.4465 m/s

After vehicle speed is calculated, calculate power available that taken from equation 3.8

For engine speed 600 rpm,

T_e = 86.702 N.m ,

v = 1.4465 m/s

G = 13.21797

r = 0.3043 m

So,

$$P = \frac{86.702\ \mathrm{N.m}\ \mathrm{x}\ 13.21797\mathrm{x}1.4465\ \mathrm{m/s}}{0.3043}$$

P = 5.4498 kW

Before find power required, R_w are required to calculate which taken from equation 3.1,

For v = 10m/s

Use equation 3.4 to find R_a

$$Ra = \frac{1}{2} x1.226x\ 0.30x\ 2.2x\ 10^2,$$

= 40.458 N

After that, use equation 3.5 to find R

r

$$Rr = (0.013 + 0.00004(10))880x9.81,$$

= 14.678N

After R_a and R_r are calculated, therefore

$$Rw = 40.458\ N + 14.678N$$

= 55.1338 N

After that, power required are calculated, P_{req} is taken from equation 3.9,

For

v : 10 m/s

R_w : 55.1338 N

η : 0.83

So

$$P_{req} = \frac{55.1338\ x10}{0.83}$$

= 664.263 Watt

4.3.2 Tractive Effort

To calculate tractive effort, the equation of 3.7 is required,

For engine speed 600 rpm

T_e : 86.702 N.m

G : 13.21797

r : 0.3043 m

η : 0.83

Therefore,

$$TF_w = \frac{86.702 \text{ N.m x } 13.21797 \text{x } 0.83}{0.3043}$$

TF_w = 3127.0605 N

4.3.3 Road Wheel Speed

To calculate RWS, the equation 3.11 are used

N_e : 600 rpm

G : 13.21797

Therefore,

$$RWS = \frac{600}{13.21797}$$

= 45.3928 rpm.

*All data that are calculated are compiled in tables which are attached in appendices according their characteristic of performance.

4.4 VEHICLE PERFORMANCE GRAPHS AND BAR CHARTS

4.4.1 Power Available

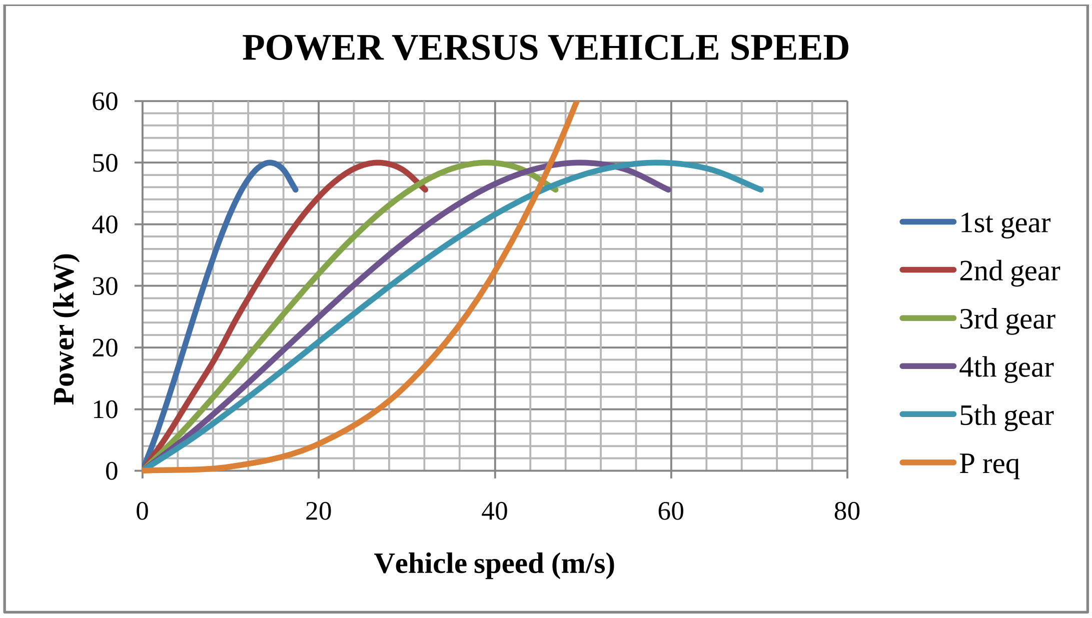


Figure 4.2(a): Graph of Power versus Vehicle Speed for Manual Transmission.

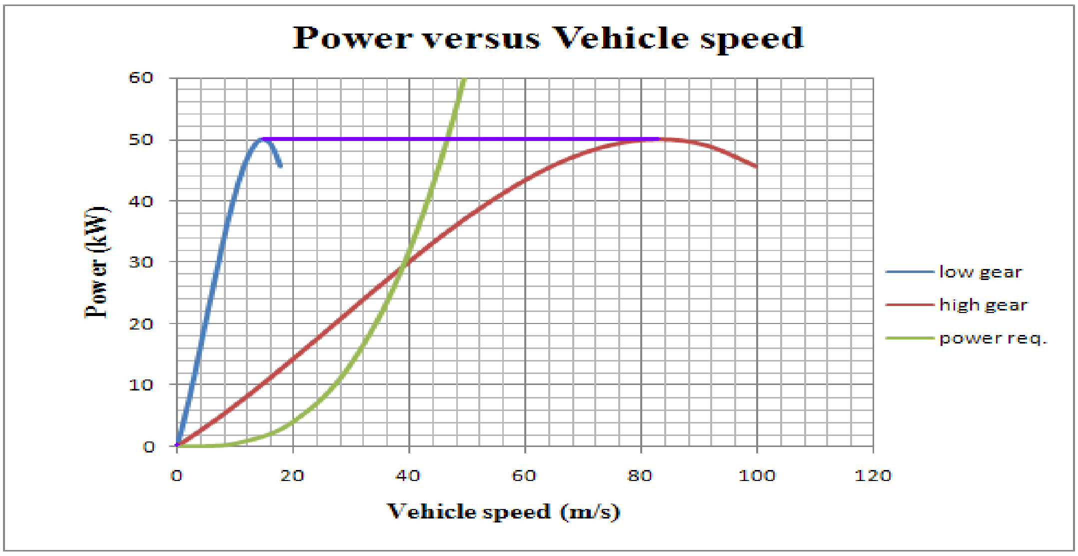


Figure 4.2 (b): Graph of Power versus Vehicle Speed for CVT.

From table 6.6 and 6.7 that are attached in appendix E1and E2 respectively, the graphs power available was build. The Figure 4.2(a) and 4.2 (b) are showing the graph of the effect having gear ratio on the power available at the road to drive the car forward. For the Figure 4.2 (a) which show power available for manual transmission, each gear has certain vehicle speed to achieve power maximum. For example, gear one required 18 m/s in vehicle speed to achieve power maximum. After reach maximum point, the power was decreased.

It is compared to the Figure 4.2 (b), the power are continuously used smoothly from low gear to high gear. This occurred because of CVT able to provide infinite gear ratios between two finite limits. It can cause CVT able to handle the power flows between the electric motor, the internal combustion engine and vehicle wheel.

4.4.2 Tractive Effort

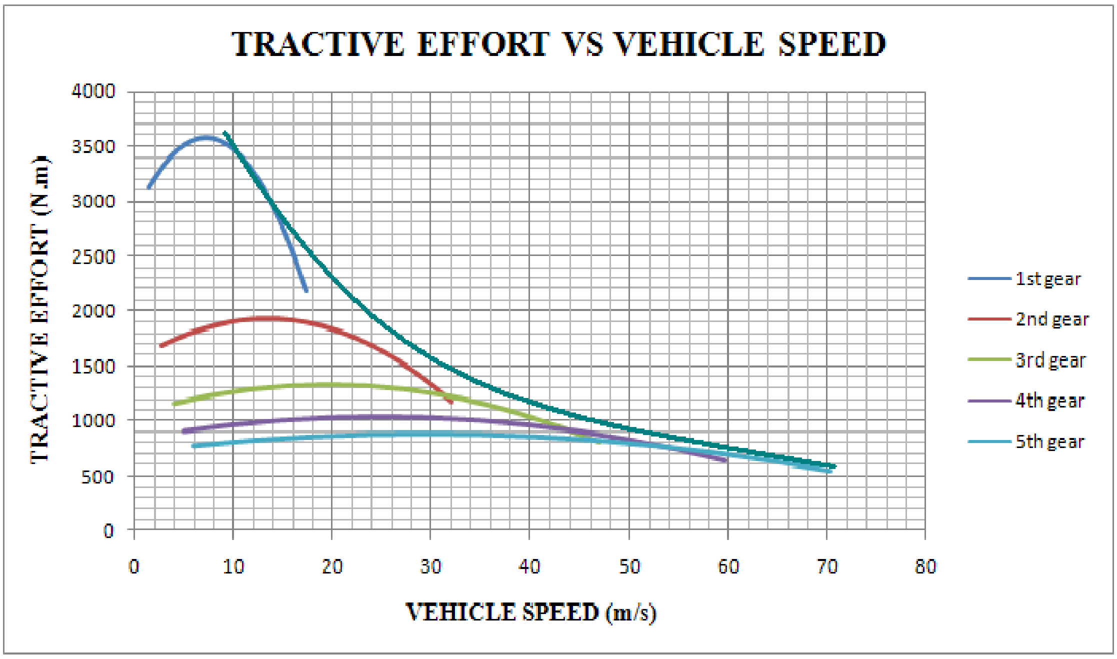


Figure 4.3 (a) : Graph of Tractive Effort versus Vehicle Speed for Manual Transmission.

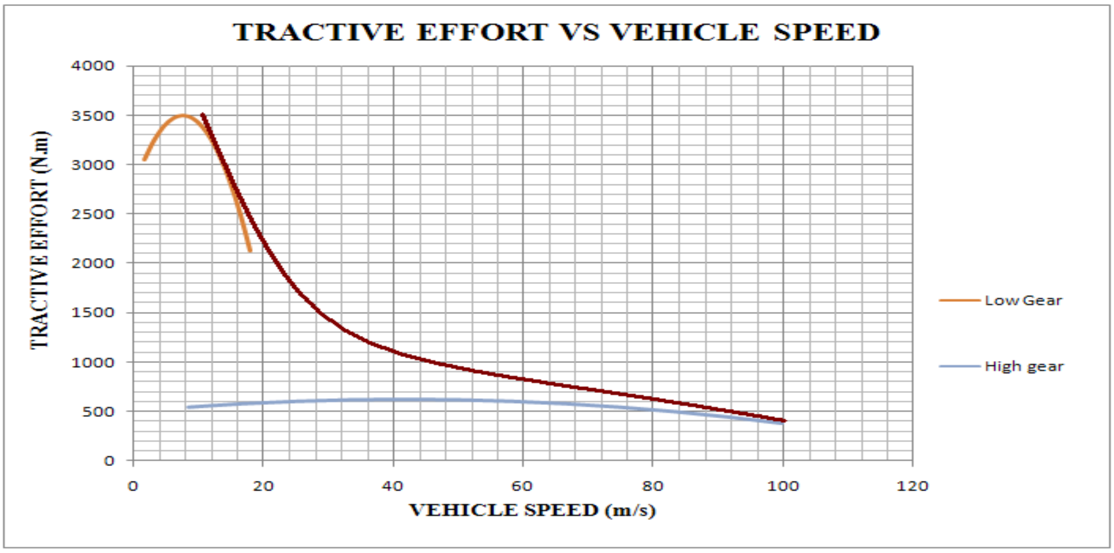


Figure 4.3 (b) : Graph of Tractive Effort versus Vehicle Speed for CVT

According to general rule, the drive axle has constant gear reduction ratio which is determined by usual practice requiring direct drive in the gearbox in the highest gear: if there is no overdrive gear. From table 6.4 (Refer appendix D1) and 6.5 (Refer appendix D2), the graphs tractive effort were build. As shown in figure 4.3(a), the number of gear ratios is chosen to provide the vehicle with the tractive effort-characteristic as close to the ideal as possible in the cost effective manner.

It is compared to CVT. Figure 4.3(b) shows that tractive effort for CVT is narrower than manual transmission. This show that CVT is less friction in transmission compare to manual transmission. It is because CVT are able to provide an infinite gear ratios between two finite limits, so tractive effort and vehicle speed range can be extend because of the gearbox is frequently employed.

4.4.3 Road Wheel Speed

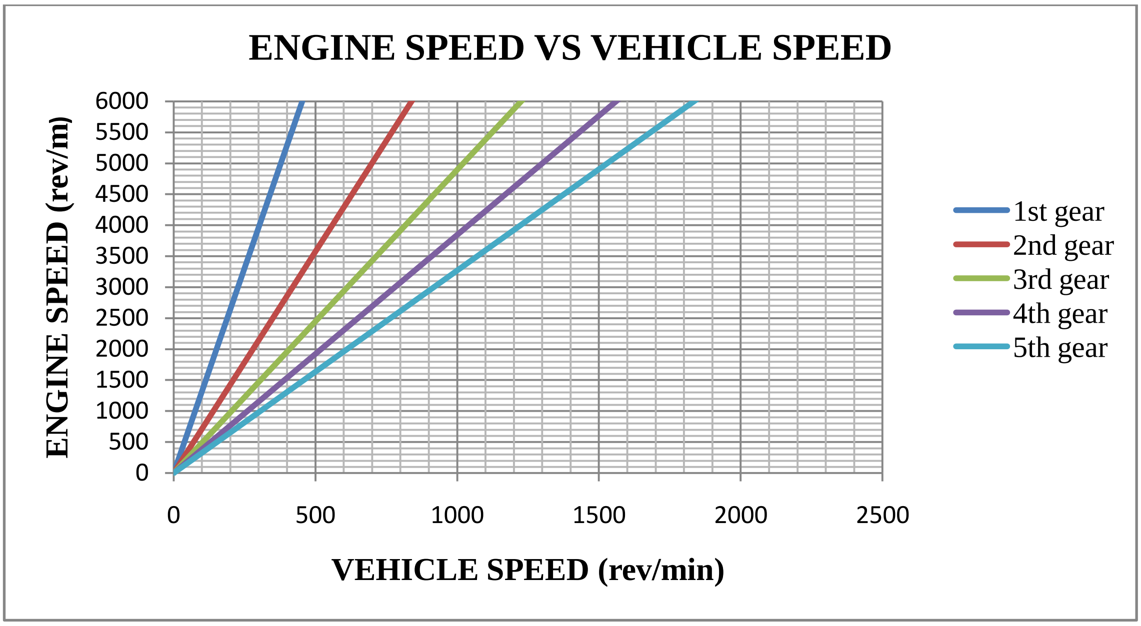


Figure 4.4 (a): Graph of Engine Speed versus Vehicle Speed for Manual Transmission

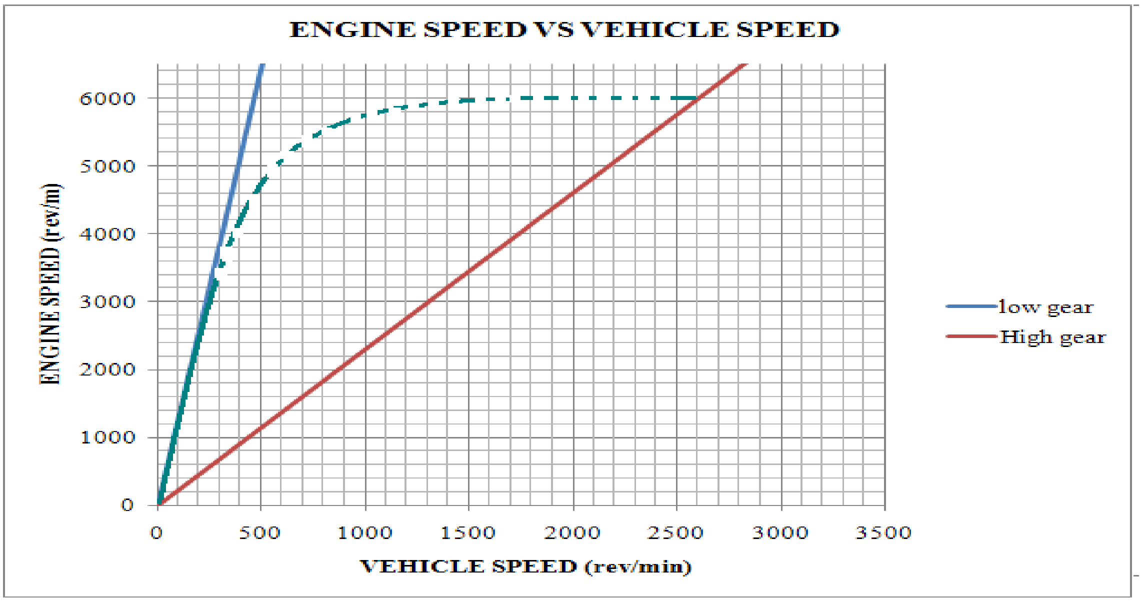


Figure 4.4 (a): Graph of Engine speed versus Vehicle speed for CVT

These graph shows relationship between engine rpm and road wheel speed for each transmission. The graphs road wheel speed were build according to table 6.8 (Refer appendix F1) and 6.9 (Refer appendix F2). From the figure 4.4 (a), each gear has own road wheel speed that is required to achieve until the maximum engine speed, 6000 rev per minute. For example, the speed had been taken in rpm from gear two to gear three is around 400 rpm. After achieve the maximum power, the gear would be shift upward to the higher gear such as from gear three to gear four. It will be happen small shift shock during shifting gear.

It is compared with CVT transmission. From the figure 4.4 (b), when the engine speed achieved to maximum, it still maintained in maximum engine speed from low gear to high gear. It is because the CVT has no problem to tie a given road speed directly to a given engine speed. So, the CVT can vary the engine speed as needed to access maximum power as well as maximum fuel efficiency.

4.4.4 Fuel Consumption

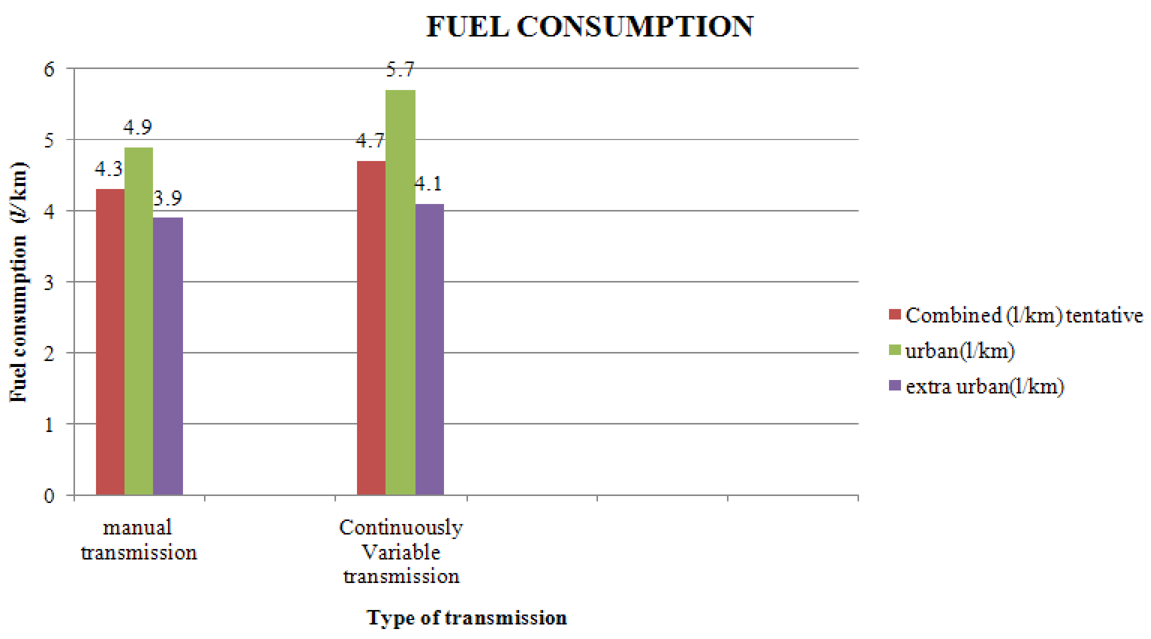


Figure 4.5: Bar chart of Fuel consumption of Manual transmission and CVT

Several studies have shown that CVT may improve the fuel savings and reduce the vehicle polluting emission. For instance a medium class CVT car may achieve fuel saving of about 10 percentages in comparison with Manual transmission (Carbone et al., 2002; Mangialardi et al., 2004; Brace et al., 1997). The data of fuel consumptions is come from technical data which got from brochure. Then, the bar chart is built from table 6.10 (refer appendix G).

However, based on the Figure 4.5 which the data are measured in controlled environmental in accordance with the requirement directive 80/1268/EEC incl, shows that the manual transmission are more saving compare to CVT. It shows with three categories which are urban, combined tentative and extra urban. For urban, the manual transmission only required 4.9 l/km compared to CVT which is required 5.7 l/km. For extra urban, manual transmission required 3.9 l/km but CVT required 4.1 l/km. In combined tentative, the manual transmission required 4.3 l/km but CVT required 4.7 l/km. In order to achieve a significant reduction of fuel consumption, it is fundamental to have good control strategy of the transmission, able to adjust the axial clamping forces acting on the moveable pulley with great precision. This is necessary in order to regulate the speed ratio and the shifting speed and allow the engine to operate on its economy line, without affecting the CVT mechanical efficiency.

4.4.5 Carbon Dioxide Emission

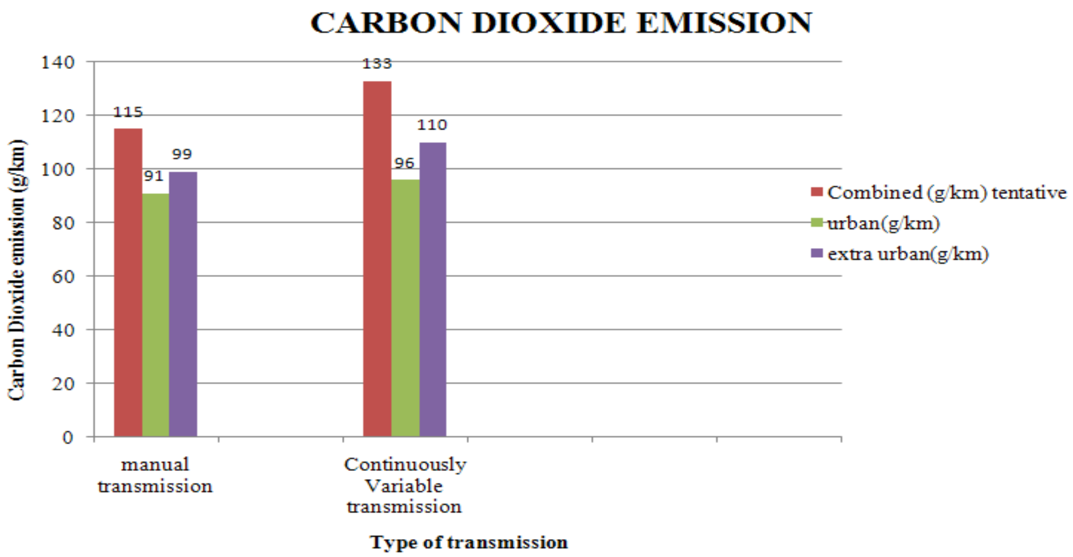


Figure 4.6 : Bar chart of CO_2 Emission for Manual Transmission and CVT

The bar chart was build from the table 6.11 (refer appendix G) and all data got from brochure. The data are measured in controlled environmental in accordance with the requirement directive 80/1268/EEC incl. From the figure 4.6, CVT has produce 133 g/km for combined tentative. It compared to manual transmission which only emit 115 g/km. For urban condition, CVT emit 96 g/km but manual transmission emits 91 g/km. This showed that CVT is more emit carbon dioxide compare to the manual transmission. According theory, CVT may reduce the vehicle polluting emission (Carbone et al., 2002; Mangialardi et al., 2004; Brace et al., 1997). This is occurred because of carbon dioxide emission are depend on the driving behavior and other factor such as road conditions, traffic, vehicle condition, installed equipment, load, and number of passenger.

4.4.6 Peak up of Vehicle

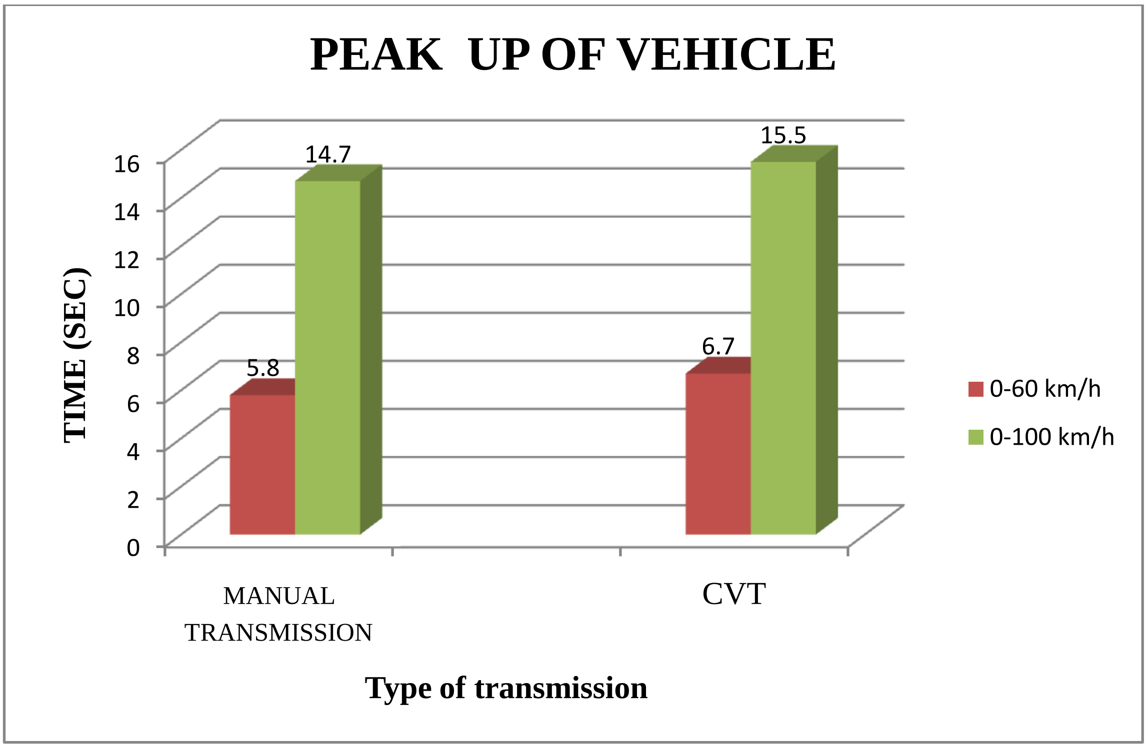


Figure 4.7 : Bar chart of Peak up of Manual transmission and CVT

The data of peak up of car is come from technical data which got from brochure. Then, the bar chart is built from table 6.12 (refer appendix L). From the figure 4.7, for 0- 60 km/h experiment, manual transmission only took 5.8 seconds compared to CVT which are taking 6.7 seconds. It also happen to 0 to 100km/h experiment which manual transmission take short time compared to CVT. Manual transmission has more peak up compare to the CVT whether in 0 to 60 km/h or 0 to 100 km/h. Basically, CVT is more power compare to manual transmission. This is because CVT can vary the engine speed as needed to access maximum power. The reverse result is occurred because of influence of driving behavior and CVT vehicle has more weight compare to manual transmission.

4.5 DISCUSSION

4.5.1 Comparison in Maintenance and Price.

Today, only a handful of cars worldwide make use of CVTs, but the applications and benefits of CVT can only increase based on today's research and development. As automakers continue to develop CVTs, more and more vehicle lines will begin to use CVT. As development continues, fuel efficiency and performance benefits will inevitably increase and this will lead to increased sales of CVT-equipped vehicles. Increased sales will prompt further development and implementation, and the cycle will repeat ad infinitum. Moreover, increasing development will foster competition among manufacturers consist of automakers from Japan, Europe, and the U.S. which are already either using or developing CVTs and will in turn lowers manufacturing costs. Any technology with inherent benefits will eventually reach fruition and the CVT has only just begun to blossom.

Since there are many advantages that already describes in term of performance, manual transmission and CVT also have their problem and required some maintenance to give them properly work. Normally manual transmission need to change the transmission fluid every 30,000 miles. Transmission fluid lubricates the transmission, ensures that it does not overheat and keeps the gear changing smoothly. To replace the fluid, a mechanic must drive the car for a few minutes to get the fluid warm. Once the engine is warm, a plug is removed from the bottom of the transmission to drain the fluid away. Once this is done, the plug is returned and the transmission is once again filled with fluid. Manual transmissions will use either gear oil or common engine oil to lubricate the transmission. It also can do by the owner of vehicle. It is compared to CVT which is inability to check the fluid level by own and need to get it checked by the dealer. It is more expensive than the conventional transmission, which certainly affects the user acceptance in an adverse manner.

Besides that, the problem that always occurs to manual transmission is clutch problem. If the gear box clutch is worn, the shaft assembly of the transmission, what connects the transmission to the rear axle of the car, may increase the cycling of internal components, causing unneeded wear to the transmission. The clutch should be taken apart once a year to make sure it is seated properly and is not worn down. It is similar to CVT that also have a clutch. The CVT clutch is a wonderful device when it functions exactly as intended. Unfortunately, it is almost impossible to ensure that the calculated clutch ratios are the true clutch ratios actually delivered by the sheaves. It also needs to give some alignment to overcome the problem and it will cost higher because only the dealer just know to align the clutch of CVT.

Besides the maintenance, the CVT and manual transmission also difference in term of price. CVT's cars normally more expensive compare than the car that using Manual Transmission. It is because CVT is still new technology and still in research compared to manual transmission which already well known. It can prove by price for model Toyota IQ which the difference CVT model with manual transmission model is around one thousand pound Euro. Besides that, CVT development has been hindered by cost. Low volume and a lack of infrastructure have driven up manufacturing costs, which inevitably yield higher transmission prices. With increased development, most of these problems can be addressed simply by improvements in manufacturing techniques and materials processing. This is other reason CVT is more expensive compare Manual Transmission. Otherwise, the cars that use CVT transmission are heavier than cars that use manual transmission. Since conventional automatics weigh far more than manual transmissions and CVTs outweigh automatics. Most cars equipped with automatic transmissions have a curb weight between 50 and 150 pounds heavier than the same cars with manual transmissions. It can simplify that CVT transmission is more expensive compare than manual transmission in term of price and maintenance since it is new technology and still in development and research in automobile industrial.

4.5.2 Compatibility of CVT for A Car under 1 Liter Engine

Normally, majority of the car under 1 liter engine on the road used conventional automatic and manual transmission as their drivetrain. It is because CVT technology still new for a car for under 1 liter engine.

CVT transmission was blossom for a car under 1 liter engine because of it automatically shifts its effective gear ratio to optimum effective gear ratio thus improving performance, efficiency, and drivability. CVTs can be deceptively simple mechanisms. A CVT is comprised of a primary drive pulley and secondary drive pulley transmitting power through a belt. Each pulley has a set of circular sheaves that forms a V shaped groove where the belt wraps around. Depending on the position of the sheaves, the belt will ride the spinning pulleys at a certain diameter to create the effective gear ratio.

CVT become suitable for a car under 1 liter engine because of better in performance characteristic consist of effective gear ratio, power consumption and tractive effort. The power that used in CVT transmission is continuous smooth from low gear to high gear. It is proved by the graph (refer figure 4.2 (b)). This is occurred because of CVT are able to provide infinite gear ratios between two finite limits. It can cause CVT able to handle the power flows between the electric motor, internal combustion engine and vehicle wheel. Better tractive effort also make CVT are suitable for a car under 1 liter engine because CVT is less fractions in transmission compare than manual transmission. It is occurred because it component is not complicated such manual transmission. Since CVT able to provide infinite gear ratios between two finite limits, tractive effort and vehicle speed can be extending because gear box is frequently employed.

Besides that, the advantages in elimination of shift shock during shifting gear make CVT is suitable for a car under 1 liter engine. It is because when the engine speed achieved to maximum, it still maintained in maximum engine speed from low gear to high gear. It is occurred because CVT has not problem to tie a given road speed directly to a given engine speed. So, CVT can vary the engine speed as required to access maximum power as well as maximum fuel efficiency.

Although CVT has advantages in power consumption, tractive effort and the use of gear, it also lack in fuel consumption, peak up and CO_2 emission. Manual transmission is better in fuel consumption rather than CVT. It is because the weight of car influence in peak up of vehicle and fuel consumption. Since CVT transmission is heavier than manual transmission, so the fuel consumption is increases but the peak up of vehicle is decrease. The fuel consumption, peak up of vehicle and CO2 emission also depend on driver behavior and condition of road. CVT also suitable used in city because it is not required to shift or changing gear during in traffic jam condition.

4.6 SUMMARY

From this chapter, the result show that CVT is better compared to the manual transmission in term of performance especially in power, tractive effort and road wheel speed. Based on result, CVT also shows that it has lack in fuel consumption, peak up of vehicle and CO_2 emission. Besides that, CVT also suitable to use in a car under 1 liter engine although the maintenance and cost are more expensive compared to manual transmission because CVT is the new product and need more research to develop this transmission in order to give the best performance to vehicle.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of this study is to compare performance between manual transmissions with CVT transmission. Based on analysis graph of performance had been plotted, CVT transmission has more advantages compared to manual transmission. It is proved in power consumption, tractive effort and road wheel speed. Since CVT has no gears to tie a given road speed directly to a given engine speed, the CVT can vary the engine speed as needed to access maximum power as well as maximum fuel efficiency.

Although the result shows that the manual transmission is more economy in fuel consumption, but it actually depend on the driving behavior and other factor such as road conditions, traffic, vehicle condition, installed equipment, load, and number of passenger. Several studies have shown that CVT may improve the fuel savings and reduce the vehicle polluting emission. For instance a medium class CVT car may achieve fuel saving of about 10 percentages in comparison with Manual transmission.

Besides that, CVT give comfort in driving because of smoothness in shifting of gear. Its compare to manual, when reached maximum power, the gear required to change. Then, it will affect to driving comfort because a small shift shock will occurred when the driver can’t shift gear properly. Many small vehicle designers have chosen to use a CVT over a manual transmission because it automatically shifts its effective gear ratio to what is hopefully an optimum effective gear ratio thus improving performance, efficiency, and drivability.

5.2 RECOMMENDATIONS

Much of the existing literature is quick to admit that the automotive industry lacks a broad knowledge base regarding CVTs. Whereas conventional transmissions have been continuously refined and improved since the very start of the 20th century, CVT development is only just beginning. As infrastructure is built up along with said knowledge base, CVTs will become ever-more prominent in the automotive landscape. Even today's CVTs, which represent first-generation designs at best, outperform conventional transmissions. Automakers who fail to develop CVTs now, while the field is still in its infancy, risk being left behind as CVT development and implementation continues its exponential growth. Moreover, CVTs are doing not fall exclusively in the realm of IC engines.

Efficiency, package and weight are becoming more and more important in automotive industry. At the same time, drivers do not want to do without driving comfort and driving fun. CVT represent an excellent way to meet these requirements, which is evidenced by the data from current CVT applications. The number of CVTs produced worldwide has been increasing. Despite the already very good current designs, experts are continuously working on improving the details of CVTs. The effects of these improvements can be described very clearly using measurement results and simulation results. CVTs can be used effectively in applications ranging from small cars to luxury vehicles. However, this requires the relevant components to be adjusted to a specific application.

Future work, this comparison between manual transmission and CVT must do in experimental or simulation since CVT technology just begun to blossom to Malaysia. There are many factors that required to do research by experimental especially in performance and driveability.

REFERENCES

Ariyono, S. 2008. *Driveline Model,* PhD Thesis.Universiti Teknologi Malaysia.

Brace, C., Deacon, M, Vaughan, N.D., Burrows, C.R. and R.W. Horrocks. 1997. *Integrated passenger cat diesel CVT powertrain control for economy and low emissions.* ImechE International Seminar S540, Advanced Vehicle Transmission and Powertrain Management.

Brace, C., Deacon, M., Vaughan, N.D. , Horrocks, R.W., and Burrows C.R. 1999. The compromise in reducing exhaust emissions and fuel consumption from a diesel CVT powertrain over typical usage cycles. *Proceedings of the CVT'99 Congress,* Eindhoven, TheNetherlands: pp. 27–33.

Birch, S. 2000. *Audi Takes CVT From 15th Century to 21st Century*. Automotive Engineering International Online. SAE International, January, 3. SAE International.

Bohen, J., 2006. Shifting Through the years: A brief history of transmissions.2 November, (online) http://www.startribune.com/cars/11357916.html (13 February 2010).

Boos, M. and Mozer, H. 1997. ECOTRONIC – The Continuously Variable ZF Transmission (CVT) SAE Paper No. 970685, in SAE SP-1241, *Transmission and Driveline Systems Symposium*, pp. 61-67 SAE.

Broge, J.L. 1999. *GM Powertrain's evolving transmissions*.Automotive Engineering International .

Carbone. G, Mangialardi, L. and Mantriota.G. 2002. Fuel consumption of a mid class vehicle with infinitely variable transmission. *SAE J Engines*. 110 (3) 2474–2483.

Carbone, G., Mangialardi, L., Mantriota, G., and Soria, L. 2004. Performance of a city bus equipped with a toroidal traction drive. IASME *Transmission and Driveline Systems Symposium.*

Crouse, W. and Anglin D. 1993. *Automotive Mechanics,* McGraw-Hill: 560-561.

Fussner. D. R. and Klunger, M. A. 1997. An Overview of Current CVT Mechanism, Forces and Efficiencies. SAE Paper No. 970688, in SAE SP-1241, *Transmission and Driveline Systems Symposium,* pp. 81-88 SAE

Gibbs, J. H. 2009. *Actuated Continuously Variable Transmission For Small Vehicles,* Master Thesis .University of Akron.

Gillespie, T. D. 1992. *Fundamental of Vehicle Dynamics*, Society of Automotive Engineering Inc. 400 Commonwealth Drive Warendale.

Heisler, H. 2002. *Advanced Vehicle Technology*, Elsevier Butterworth- Inc. Heinemann : 153-154

Jazar, R. N. 2008. *Vehicle Dynamics : Theory and Application*, Springer Science Business Media, LC, 233 Spring Street, New York, NY 10013, USA.

Kershaw, F.,J.and Halderman, J. D. 2007. *Manual drivetrain and axles. Shop manual* Pearson Practice Hall.

Kluger, M.A. ,and D. M. L. 1999. An Overview of Current Automatic, Manual and Continuously Variable Transmission Efficiencies and Their Projected Future mprovement. *SAE paper*_1999-01-1259.

Kobayashi, D., Mabuchi, Y. and Katoh, Y. 1998. A Study on the Torque Capacity of a Metal Pushing V-Belt for CVTs. SAE Paper No. 980822, in SAE SP –1324, *Transmission and Driveline SystemsSymposium*, pp. 31-39 SAE,

Lang, K. R. 2000. *Continuously Variable Transmission: An Overview of CVT Research Past, Present and Future*, May 3.

Law, A. M. and McComas, M. G. 2001. How to Build Valid and Credible Simulation Models. *Proceeding of the 2001 Winter Simulation Conference*. 9-12 December. Tucson, USA, 1:22-29.

Lechner,G., H. N. 1999. *Automotive Transmissions: Fundamentals, Selection, Design and Application,* Springer, Berlin, New York.

Nissan Motor. 2008, XTRONIC CVT Technology Overview (online). www.nissanglobal.com (28 June 2010)

Smith, M. H. 1998. *Vehicle Powertrain Modeling and Ratio Optimization for a Continuously Variable Transmission*. PhD Thesis. Georgia Institute of Technology.

Takahashi, M., Kido, R., Nonaka, K., Takayama, M. Fujii, T. 1999. Design and development of a dry hybrid belt (BANDO AVANCE) for CVT vehicle. *International Congress on Continuously Variable Power Transmission Proceedings.*

Denton, T. 2000. *Advanced Automotive Fault Diagnosis*. Elsevier Butterworth Inc. Heinemann

Toyota Motor Europe. 2008. Brochure: Paris08 (online). www.toyota-media.com. (28 June2010)

Wehage, R. A. 1987. Vehicle Dynamics. *Journal of Terramechanics*.

Wong, J.Y. 2001. *Theory of Ground Vehicle*, John Wiley & Sons, Inc.

Yamaguchi, J. 2000. Nissan's Extroid CVT, *Automotive Engineering International Online, SAE International*, February.

APPENDICES

APPENDIX A1

NO	ITEM\WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Task given	■															
2	Project title, objective and scopes of project		■	■	■												
3	Get info Viva 1000 cc for project					■	■										
4	Study of transmission						■	■	■	■							
5	Study of Vehicle dynamics							■	■	■	■	■					
6	Literature review								■	■	■	■					
7	Determine best formula and methodology									■	■	■					
8	Detailed methodology										■	■	■				
9	Draft of report							■	■	■	■	■	■	■			
10	Submit draft report													■			
11	FYP 1 Presentation														■		

Figure 6.1: Gantt chart for FYP 1

APPENDIX A2

NO	ITEM\WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Literature study and change Toyota iQ 1.0 liter as a car that use in project	■															
2	Verify Methodology		■	■													
3	Verify calculation			■	■	■											
4	Analysis project				■	■	■										
5	Graph of performance plotted					■	■	■									
6	Analysis of Graph							■	■								
7	Data verification								■	■							
8	Discussion of project									■							
9	Conclusion of the project										■	■					
10	Writing report												■				
11	Final presentation													■			
12	Submit report														■		

Figure 6.2: Gantt chart for FYP 2

APPENDIX B1

Table 6.1: Technical Data for Toyota iQ 1.0 Liter (CVT)

Dimension and Weight	Overall length	mm	2985
	Overall width	mm	1680
	Overall height	mm	1500
	wheelbase	mm	2000
	Kerb weight	kg	860-895
	Seat capacity	persons	5
	Luggage space	*l*	32/238
	C_d		0.299
	Valve mechanism		12 valves DHOC, chain drive with VVT-i
	Total displacement	cc	996
	Compression ratio (:1)		10.9
	Type		3 cylinders, in-line type
	Max. output(DIN)	kW/rpm	50/6000
	Max. torque(DIN)	Nm/rpm	91/4800
Transmission	Transmission Gear ratio	2.386~0.426	
		Reverse	2.505
		Final gear ratio	5.403
performance	Acceleration 0-100km/h	secs	15.5
	Top speed	Km/h	150
	Average mileage	km	4.71/100
	Mileage urban	km	5.71/100
	Mileage extra urban	km	4.11/100
	CO_2 emissions	gr/km	110

Source of Data : Toyota Motor Euro (2008)

APPENDIX B2

Table 6.2: Technical Data for Toyota iQ 1.0 Liter **(**Manual Transmission)

Dimension and Weight	Overall length	mm	2985
	Overall width	mm	1680
	Overall height	mm	1500
	wheelbase	mm	2000
	Kerb weight	kg	845-880
	Seat capacity	persons	5
	Luggage space	*l*	32/238
	C_d		0.299
	Valve mechanism		12 valves DHOC, chain drive with VVT-i
	Total displacement	cc	996
	Compression ratio (:1)		10.9
	Type		3 cylinders, in-line type
	Max. output(DIN)	kW/rpm	50/6000
	Max. torque(DIN)	Nm/rpm	91/4800
Transmission	Transmission Gear ratio (CVT: 3.538~0.875)	1^{st}	3.538
		2^{nd}	1.913
		3^{rd}	1.310
		4^{th}	1.029
		5^{th}	0.875
		Reverse	3.333
		Final gear ratio	3.736
performance	Acceleration 0-100km/h	secs	14.7
	Top speed	Km/h	150
	Average mileage	km	4.3/100
	Mileage urban	km	4.9/100
	Mileage extra urban	km	3.9/100
	CO_2 emissions	gr/km	99

Source of Data: Toyota Motor Euro (2008)

APPENDIX C

Table 6.3: Table of Performance of Power and Torque Engine

Engine Speed	Power	Torque
600	5.4498	86.7352
1200	11.59997	92.3057
1800	18.14995	96.2845
2400	24.7998	98.6718
3000	31.24984	99.4676
3600	37.1999	98.6719
4200	42.3499	96.2846
4800	46.3996	92.3061
5400	49.04997	86.7353
6000	50	79.5732
6600	48.9501	70.82
7200	45.6004	60.4754
7800	39.6504	48.5384
8400	30.8006	35.01032

APPENDIX D1

Table 6.4: Table of Tractive Effort versus Vehicle Speed for Manual Transmission

1st Gear		**2nd Gear**		**3rd Gear**		**4th Gear**		**5th Gear**	
Vehicle Speed	**Tractive Effort**	**Vehicle Speed**	**Tractive Effort**	**Vehicle Speed**	**Tractive Effort**	**Vehicle Speed**	**Tractive Effort**	**Vehicle Speed**	**Tractive Effort**
1.4465	3127.061	2.6752	1690.805	3.9066	1157.853	4.9735	909.471	5.8488	773.3684
2.893	3327.894	5.3504	1799.395	7.8132	1232.215	9.9471	967.8809	11.6976	823.0374
4.3395	3471.341	8.2057	1876.958	11.7198	1285.329	14.9206	1009.601	17.5464	858.5141
5.786	3557.403	10.7009	1923.495	15.6264	1317.198	19.8941	1034.633	23.3952	879.8003
7.2325	3586.101	13.3761	1939.009	19.5331	1327.821	24.8676	1042.978	29.244	886.896
8.67897	3557.414	16.0513	1923.497	23.4397	1317.199	29.8412	1034.634	35.0928	879.8012
10.1255	3471.345	18.7266	1876.96	27.3463	1285.33	34.8147	1009.6	40.9416	858.515
11.57196	3327.908	21.4018	1799.403	31.2529	1232.22	39.7986	967.8851	46.7904	823.0499
13.0185	3127.064	24.077	1690.807	35.1595	1157.854	44.7734	909.472	52.6392	773.3693
14.465	2868.85	26.7522	1551.19	39.0661	1062.25	49.7482	834.373	58.488	709.809
15.9114	2553.271	29.4274	1380.556	42.9727	942.396	54.723	742.59	64.3368	631.462
17.3579	2180.317	32.1027	1178.9	46.8793	807.3031	59.6979	634.121	70.1856	539.225

APPENDIX D2

Table 6.5: Table of Tractive Effort versus Vehicle Speed for CVT

Lower Gear		High Gear	
Vehicle Speed	**Tractive Effort**	**Vehicle Speed**	**Tractive Effort**
1.48312	3049.849	8.30679	544.528
2.96623	3245.723	16.61358	579.4999
4.44935	3385.629	24.92036	604.479
5.93246	3469.573	33.2272	619.4666
7.41558	3497.555	41.53394	624.4627
8.89869	3469.576	49.8407	619.4672
10.38181	3385.632	58.1475	604.4797
11.86493	3245.737	66.4543	579.5024
13.34804	3049.853	74.7611	544.5287
14.83116	2798.013	83.06788	499.5646
16.31427	2490.227	91.3747	444.6116
17.79739	2126.482	99.6815	379.6677

APPENDIX E1

Table 6.6: Table of Power Available for Manual Transmission

1st Gear		2nd Gear		3rd Gear		4th Gear		5th Gear	
Vehicle Speed	**Power available**	**Vehicle Speed**	**Power available**	**Vehicle Speed**	**Power available**	**Vehicle Speed**	**Power available**	**Vehicle Speed**	**Power available**
0	0	0	0	0	0	0	0	0	0
1.4465	5.4498	2.6752	5.4497	3.9066	5.44972	4.9735	5.4497	5.8488	5.44973
2.893	11.5995	5.3504	11.5994	7.8132	11.5994	9.9471	11.5995	11.697	11.5994
4.3395	18.1493	8.2057	18.1492	11.719	18.1492	14.920	18.1492	17.546	18.1492
5.786	24.799	10.700	24.7989	15.626	24.7988	19.894	24.7989	23.395	24.7989
7.2325	31.2485	13.376	31.2486	19.533	31.2487	24.867	31.2486	29.244	31.2487
8.6789	37.1984	16.051	37.1983	23.439	37.1985	29.841	37.1984	35.092	37.1984
10.125	42.3483	18.726	42.3482	27.346	42.3482	34.814	42.3482	40.941	42.3482
11.571	46.3981	21.401	46.3982	31.252	46.3981	39.798	46.4102	46.790	46.3981
13.018	49.0478	24.077	49.0477	35.159	49.0476	44.773	49.0604	52.639	49.0476
14.465	49.9975	26.752	49.9973	39.066	49.9973	49.748	50.0103	58.488	49.9973
15.911	48.9471	29.427	48.9472	42.972	48.9473	54.723	48.9599	64.336	48.9473
17.357	45.5973	32.102	45.5974	46.879	45.5973	59.697	45.6093	70.185	45.5974

APPENDIX E2

Table 6.7: Table of Power Available for CVT

Lower Gear		**High Gear**	
Vehicle Speed	**Power available**	**Vehicle Speed**	**Power available**
0	0	0	0
1.48312	5.4497	8.30679	5.44973
2.96623	11.5995	16.61358	11.59948
4.44935	18.1492	24.92036	18.1492
5.93246	24.7016	33.2272	24.79897
7.41558	31.2487	41.53394	31.24867
8.89869	37.19841	49.8407	37.19841
10.38181	42.3482	58.1475	42.34817
11.86493	46.3981	66.4543	46.3981
13.34804	49.0477	74.7611	49.0477
14.83116	49.9973	83.06788	49.99732
16.31427	48.9473	91.3747	48.9473
17.79739	45.5974	99.6815	45.5974

APPENDIX F1

Table 6.8: Table of Road Wheel Speed for Manual Transmission

Engine Speed (RPM)	Road Wheel Speed				
	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
0	0	0	0	0	0
600	45.39275	83.95166	122.5941	156.0793	183.5424
1200	90.7855	167.9033	245.1882	312.1586	367.0847
1800	136.1782	251.855	367.7823	468.2379	550.6271
2400	181.571	335.8066	490.3764	624.3172	734.1695
3000	226.9637	419.7583	612.9705	780.3964	917.7118
3600	272.3565	503.71	735.5645	936.4757	1101.254
4200	317.7492	587.6616	858.1586	1092.555	1284.797
4800	363.142	671.6133	980.7527	1248.634	1468.339
5400	408.5347	755.5649	1103.347	1404.714	1651.881
6000	453.9275	839.5166	1225.941	1560.793	1835.424
6600	499.3202	923.4683	1348.535	1716.872	2018.966
7200	544.713	1007.42	1471.129	1872.951	2202.508

APPENDIX F2

Table 6.9: Table of Road Wheel Speed for CVT

Engine Speed (RPM)	Road Wheel Speed	
	Low Gear	High Gear
0	0	0
600	46.54193	260.6769
1200	93.08387	521.3538
1800	139.6258	782.0307
2400	186.1677	1042.708
3000	232.7097	1303.384
3600	279.2516	1564.061
4200	325.7935	1824.738
4800	372.3355	2085.415
5400	418.8774	2346.092
6000	465.4193	2606.769
6600	511.9613	2867.446
7200	558.5032	3128.123

APPENDIX G

Table 6.10: Table of Fuel Consumption

	Manual Transmission	CVT
Combined (l/km) tentative	4.3	4.7
Urban(l/km)	4.9	5.7
Extra urban (l/km)	3.9	4.1

Table 6.11: Table of CO_2 emission

	Manual Transmission	CVT
Combined (g/km) tentative	115	133
Urban (g/km)	91	96
Extra urban (g/km)	99	110

Table 6.12: Table of Peak up of Vehicle

	Manual Transmission	CVT
0-60 km/h (sec)	5.8	6.7
0-100 km/h (sec)	14.7	15.5

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