DESIGN A CVT LUBRICANT TEST DEVICE

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DESIGN A CVT LUBRICANT TEST DEVICE

By

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ABSTRACT

DESIGN A CVT LUBRICANT TEST DEVICE

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NOVEMBER 2006

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Faculty : Engineering

The technology of metal pushing V-belt (MPVB) Continuously Variable Transmission (CVT) is now commercially available in the market but to date the questionable reliabilities and limited torque capabilities have inhibited their growth. Belt slip is one of the major losses that cause inefficiency in CVT and limited the transferred torque from the engine to the tyres. One of the factors that believe cause this belt slip is because of unstable in oil lubricant behaviour especially due to operate in high temperature and pressure. Therefore, this report presents the work which has been carried out on designing a CVT Lubricant Test Device which capable to investigate the phenomena of film collapse in a CVT mechanism. Modern design concepts and methods have been applied in designing this device where a five phase design model as proposed by Eggert has been used. The five phase designs are formulation, conceptual design, configuration design, parametric design and detail design. The device is significant because, hence to study and investigate film collapse, this device also capable to study and investigate the other specific parameters which affect the transmission efficiency such as differ in contact angle, contact area and material used.

ABSTRAK

REKABENTUK ALAT UJIAN PELINCIR CVT

Oleh

MOHD AZWIR BIN AZLAN

NOVEMBER 2006

Pengerusi : Dr. Abdul Rahim Bin Abu Talib

Fakulti : Kejuruteraan

Teknologi Transmisi Berubah Berterusan (CVT) yang menggunakan talisawat jenis logam atau dikenali sebagai "*Metal Pushing V-Belt*" (MPVB) telah dikomersialkan dan terdapat di pasaran masakini, walaubagaimanapun keraguan dari segi keboleharapan dan keupayaan daya kilas yang terhad telah menyekat pertumbuhan dan kepesatannya. Kegelinciran talisawat adalah penyebab utama kehilangan kecekapan pada CVT dan seterusnya menghadkan penghantaran daya kilas dari enjin ke tayar. Salah satu faktor utama yang mengakibatkan kegelinciran talisawat adalah disebabkan oleh sifat minyak pelincir yang tidak stabil terutamanya ketika beroperasi di dalam suhu dan tekanan yang tinggi. Oleh itu, laporan ini membentangkan kerja yang telah dijalankan di dalam merekabentuk alat ujian pelincir CVT di mana ia boleh digunakan untuk menyiasat fenomena kegagalan filem di dalam mekanisme CVT. Alat ini telah direkabentuk dengan menggunakan kaedah dan konsep rekabentuk terkini yang telah dicadangkan oleh Eggert di mana rekabentuk model lima fasa telah digunakan. Lima fasa tersebut adalah, persediaan, rekabentuk konsep, rekabentuk konfigurasi, rekabentuk parametrik dan rekabentuk terperinci. Alat ini penting kerana, selain digunakan untuk mempelajari dan menyiasat kegagalan filem, alat ini juga boleh digunakan untuk mempelajari dan menyiasat parameter-parameter lain khususnya yang memberi kesan terhadap kecekapan transmisi seperti kelainan pada sudut sentuhan, luas sentuhan dan bahan yang digunakan.

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Last but not least, author would like to acknowledge the role played by his wife Nor Hasrina Hasni, son Najmi, daughter Nazihah and other family members, especially to both his parents and parent in laws for their continual support and understanding.

APPROVAL

I certify that an Examination Committee has met on **23th November 2006** to conduct the final examination of **Mohd Azwir bin Azlan** on his **Master in Innovation and Engineering Design** project report entitled **"Design a CVT Lubricant Test Device"** in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the project report is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

(...)

MOHD AZWIR BIN AZLAN

Date: 4 Disember 2006

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A vehicle that is powered by an internal combustion engine will be quite impossible to be driven smoothly and comfortably without the aid of a transmission system. These by itself explained the purpose and importance of a transmission unit in a vehicle. That is, they are the components that made it possible to transfer the power or torque from the engine to the driving wheels (Tawi, 1997). Power is the rate or speed at which work is performed, while torque is turning or twisting force. Multiple ratio gearboxes are necessary because the engine delivers its maximum power at certain speeds, or *rpm* (rotations per minute). It is necessary to change the gear ratio between the engine and the drive wheels in order to use the same engine *rpm* at different road speeds and this occurs inside the transmission.

Generally, transmission can be classified into two categories, "steply" and continuously variable transmission (CVT). Both of them can be further classified as manual and automatic transmission as shown in Figure 1.1. "Steply" transmissions or gearboxes are those that use gears as their means to steply vary the gear ratios. The manual steply gearboxes usually consist of six sets of gear train. Namely first, second, third, forth, fifth and reverse gears. The forward gears are usually of helical type because of its smooth and quiet performance, while the reverse gears are of spur type, which is a bit noisy (drivers should be able to recognise this) but can be easily dogged with its meshing spur gear via an idler spur gear, hence eliminate the use of synchromesh as in the forward gears. These types of gearboxes are usually manual in nature, i.e. the drivers select the required gear ratios themselves through gear linkages.

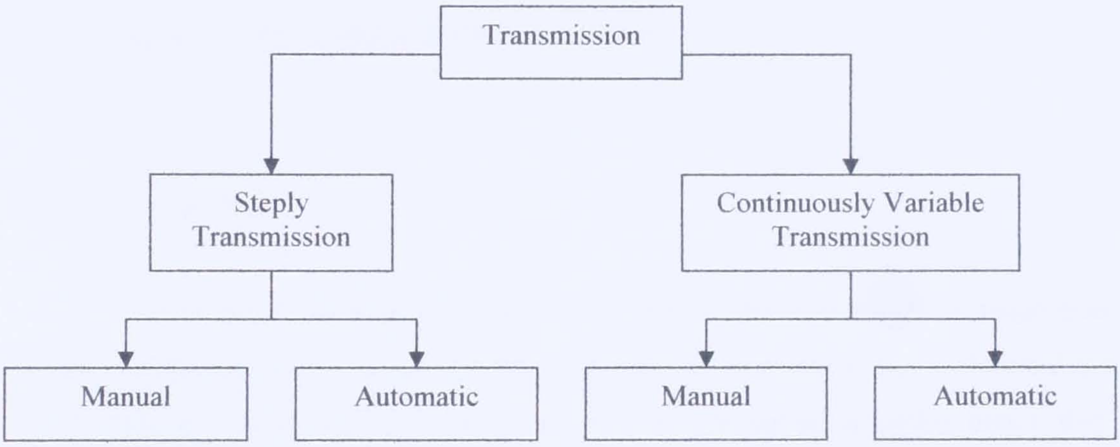


Figure 1.1: Types of Transmission

Currently for automatic steply gearboxes, most cars use epicyclic gear train and they are hydraulically controlled. Epicyclic gear train (Figure 1.2) consists of sun, planet and ring gears. They can be of spur type (noisier but cheaper) or helical type (quieter, smoother but a bit expensive). The advantage of epicyclic gear train is that gear ratio change can be done easily by just stopping either the sun, planet or ring gear to change gear (two forwards and one reverse).

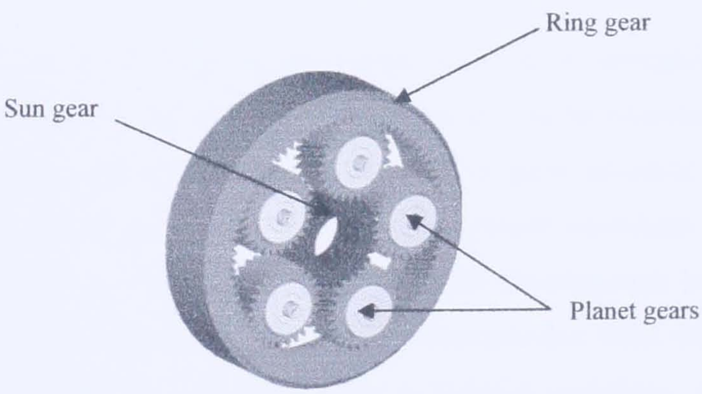


Figure 1.2: Epicyclic Gear Train

Other categories of transmission are known as CVT. CVT also can be further classified as manual, automatic or combination of these. More detail about CVT will be explained in the background. Nowadays, we can see many car manufacturer is start to get involve into the continuously variable types due to the promising of their performance. Many well-known car manufacturers like Audi, General Motor, Honda and Nissan have been produced their own product.

1.2 Background

Transmission development started with very simple designs of a manual gear boxes. Then, an automatic step gear transmission was introduced due to demand for more comfort. Even though the control of automatic transmission getting better, they still have jerking during changing gear ratio causes uncomfortable drive. The third generation of gear box was called continuous variable transmission (CVT).

Brace (1992) has studied in comparison between manual, automatic and continuously variable transmission. He concluded in the graph as shown in Figure 1.3, which he had concluded each of transmission has advantages and disadvantages. These advantages and disadvantages are set in scale one to five rating which one represent unsatisfactory and five represent very good. Manual transmission has disadvantages in the performance of driving, but this disadvantage can be overcome by both automatic and CVT. Size, cost, mass, and fun of driving become less value in both automatic and CVT.

The CVT concept allows the engine speed to be operated independently of the vehicle speed and therefore the engine can always be operated in its most fuel-efficient operating point. Therefore CVTs have a great potential to offer both fuel consumption and lower output of harmful exhaust emissions, which has been confirmed by different research projects. Torotrak Development Ltd. claimed (2006) 20% less fuel consumption for their CVT transmission than with a conventional automatic gearbox along with a reduction in harmful emissions. A simulation study by Kriegler (1997) of AVL compares different CVT concepts with a manual transmission for gasoline and diesel engines and show up to 10% less fuel consumption for gasoline engines and up to 19% for diesel engines.

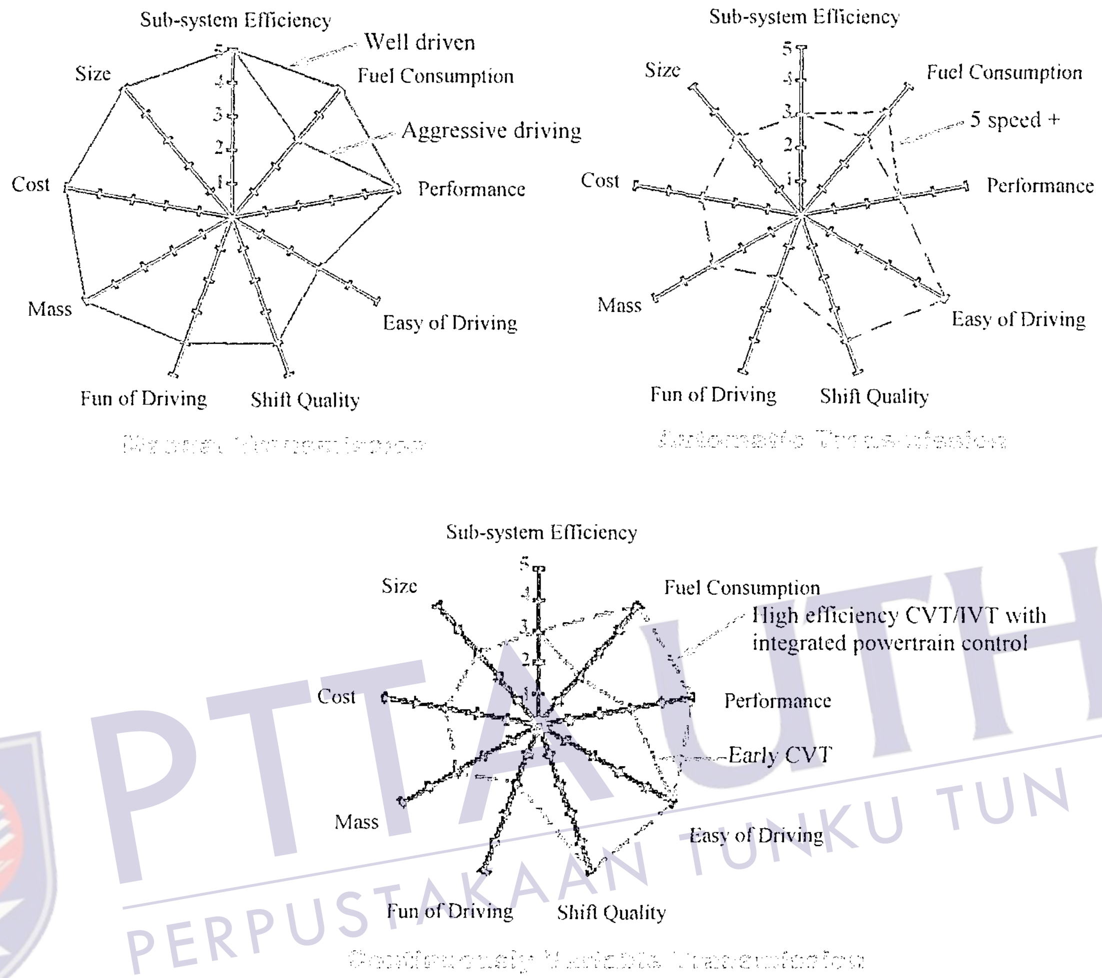


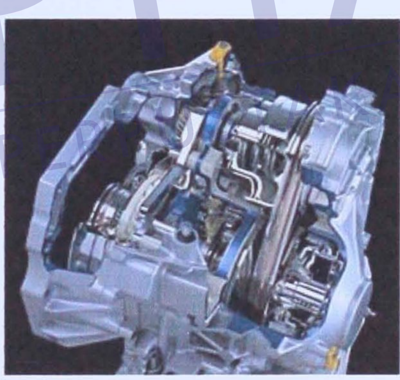
Figure 1.3: Transmission Characteristic. (Brace, 1992)

The first commercially available belt type CVT was introduced in 1958 and was based on rubber V belt (Birch, 2000). Meanwhile the CVT principle has evaluated to a fully electronic controller transmission system, based on a metal belt, and is capable to be adapted to engines of almost size.

A number of studies have been conducted on the CVT because it is regarded as an ideal transmission for internal combustion engine vehicles. CVT tended to be regarded as just a transmission without shift shock and this causes more comfort comparing with the conventional automatic transmission. CVT eliminated the two major problem of the automatic transmission which is shift shock and time lag resulting in better fuel consumption (Kevin, 2000).

CVT used the entire range of ratios between low and high gears compare to a conventional automatic transmission, which shifts among up to five gear ratios. It achieves better fuel economy and drivability by constantly changing ratios to keep the engine running in its most efficient rpm range based on driver demands.

CVT is beyond all doubt the theoretically optimum gearbox for automotive applications. There are four basic concepts on which extensive modern-day CVT developments have been or are currently based that are belt drive CVT, hydrostatic pump and motor combinations CVT, friction or traction drive CVT and lastly variable stroke CVT (Gott, 1991). Currently there are only two types of CVT commercially success to the market that are belt drive CVT and traction drive CVT as shown in Figure 1.4(a) and 1.4(b). Both types have already powering more than million cars including Fiat, Ford, Nissan, Honda, Subaru, Toyota, General Motor, Audi and Volvo.



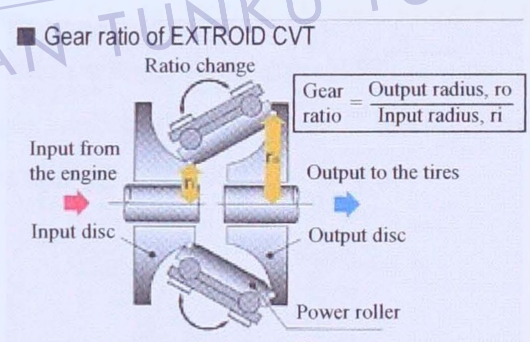


Figure 1.4(a): Pushing Metal V-belt CVT Figure 1.4(b): Metal Disk type CVT
(Transmission: CVT (Continuous Variable Transmission), Mark, 1998)

Early belt drive CVT used simple rubber band and cone system as low power industrial drives and light-duty vehicle applications such as snowmobiles, go-karts and all-terrain vehicle. In 1958 DAF (now Volvo) introduced a small passenger car equipped with a rubber belt CVT. However, the maximum torque, which can be transmitted, is limited by the strength of the belt and the coefficient of friction between the belt and the pulley (Gott, 1991). Then, a new belts which its power-rating can now meet the requirement of automotive application has been introduced in the market since late 80s. It is called as Metal Pushing V-Belt (MPVB), which develops by Van Doorne from Van Doorne's Transmissie (a company spun out of DAF-van Doorne's Automobile Factory). This belt consists of a large number of flat segments, which are held together by two packs of steel bands, each pack containing eight to ten bands for flexibility. Then this belt has been put into production by Ford, Subaru and Fiat. Borg-Warner and Fiat had formed a consortium with van Doorne in the mid'70s to develop a CVT based on the van Doorne belt (Gott, 1991). Borg-Warner later removed them from the consortium to pursue their own interests. They have developed a similar variable cone pulley transmission concept using a chain, which produced, by Suzuki in early 1990s. Another approach is by PIV-Reimers chain-type CVT that is reportedly being examined by Ford, Volvo and ZF (Gott, 1991).

In 1999, Nissan was the first automaker to introduce a CVT for the front-transverse driveline in conjunction with an engine having greater than 100-kW (135-hp) output. The Primera features engine torque of about 190 N.m. One of the latest CVTs is the CFT 23 developed by ZF, which is designed for engine torque up to 250 N.m and features an overall gear-ratio span of 5.8. In 2000, Audi introduced a CVT for a front-longitudinal driveline in connection with a six-cylinder 2.8-L engine. The VL 300 was the first CVT for high torque applications-280 N.m. It has wet clutch and chain and an overall gear-ratio span of 6.05 (Birch, 2000).

1.3 Problem Statement

CVT have been used in automobiles for decades; however limited torque capabilities and questionable reliability have inhibited their growth. Today ongoing CVT research has led to ever more robust transmissions and thus ever more diverse automotive applications. The trend toward greater performance in small cars and the development of higher-torque diesel engines have sharpened the design focus on overcoming the CVT's torque limitations.

The efficiency of a vehicle transmission system is an important factor in the overall efficiency of any vehicle. It is important to understand where the inefficiencies lie within a transmissions design in term of emissions and fuel consumption because the increased environmental constraints which today vehicle much reach.

CVT should allow better matching of the engine operating conditions to the variable driving conditions that may be experienced by effecting having an infinite number of gear ratios. However, the reduced fuel consumption and emissions predicted for CVT have not been realized by production cars. Comparison fuel consumption between CVT and equivalent fixed ratio has resulted they have been at best equal and in most cases considerably lower. This can be concluded that existing CVT system have a lower efficiency that their fixed ratio counterparts although the control strategy for reduced fuel consumption is well founded. This inefficiency has been linked to a number of possible inherent parasitic losses associated with pushing V-belt CVT, namely torque losses within the belt mechanism itself, belt slip and hydraulic control system pumping losses. Belt slip is one of the major losses that caused inefficiency in CVT. There are two reasons why this belt slip happens. The first factor is caused by insufficient clamping force that used to squeeze the belt for transferring torque from input shaft to output shaft. Another factor is lubricant film collapse due to operating temperature increase.

Lubricants used in CVT have a large number of performance characteristics to satisfy, such as lubrication, heat transfer, pump ability and traction transfer. Belt drive CVT and traction drive CVT use special lubricant formulations which added with more traction additives to increase the torque transfer capability. These traction additives increase the coefficients of friction between other surfaces in relative motion to each other and avoid slip between belt and pulley, but too many will make the oil become condense and cause the transmission need more power from engine to rotate hence decrease its efficiency. Slip must be minimized to protect the CVT mechanism from wear. However, unstable in oil lubricant behaviour, especially when it viscosity change due to operate in extreme condition such as in high temperature and high pressure, will effect the transmission efficiency.

Hence, this study is one of the pioneer works in UPM towards acquiring the knowledge and technology of CVT system. A design for basic clutch-like CVT mechanism and experimental facilities set-up are proposed, to study the phenomena of lubricant film collapse between the power transmitting plates. This film collapse is crucial as a result of slip between the plates, affecting the overall transmission efficiency.

1.4 General Objective :

To design a CVT lubricant test device that capable to investigate the phenomena of film collapse in a CVT mechanism.

1.5 Specific Objectives :

i. To conduct literature study based on the Van Doorne Metal Pushing V-Belt CVT.
ii. To produce detail design of a CVT lubricant test device suitable for small size car, (less than 1 litre engine).
iii. To propose an experimental facility for film collapse investigation in a CVT mechanism.

1.6 Significance of Design

As stated previously, existing CVT are usually limited in their performance. Most CVT have drawbacks such as limited range of variability, limited power handling capabilities and efficiency. All these factors have encouraged the author to rise to the challenge of designing a lubricant test devise in a CVT mechanism. The main purpose is to investigate the phenomena of film collapse in actual condition which the author believes it is the main reason that affect the transmission efficiency. Its also hope that by using this devise, other specific parameters that are related to the power transferred such as belt-pulley contact angle, belt-pulley contact area, material used, clamping force needed and other parameters can also be investigate.

This design is significant because, it capable to study and investigate the specific parameters differ from what have been done by other researchers. Other researchers used a whole unit of CVT gearbox to run the performance test which gives the result for overall efficiency of the CVT system. It's difficult to see the connection among the parameters and how much they contribute in effecting the transmission efficiency and power transfer capability. Therefore, this lubricant test devise are designed in order to carry out specific test such as to investigate phenomena of lubricant film collapse as well as other parameters in the CVT mechanism. This devise is expected to produce valuable information for researcher to optimize and improve power transfer capability and efficiency of the CVT gearbox.

1.7 Project Report Organization

This project report consists of five individual chapters. It is organized as follows. Up to this point, Chapter 1 as the introduction of the thesis has covered the required background to understand basic information of CVT transmissions, their potential benefits and limitation. During Chapter 1 also, reader had been explained the important of having a lubricant test device in problem statement and significant of the design. Chapter 2 gives some reviews of the CVT mechanism, basic lubricant concept and work done by other researchers in investigating the CVT performance. The findings were used to generate initial idea in concept design in Chapter 4. Chapter 3 gives the methodology of this work on how the project was done. Chapter 4 describes the whole design process to develop a CVT lubricant test device from idea generation till detail design including the design analyses. Finally, Chapter 5 presents the overall conclusions of the work and suggestion for future work including proposal for experimental facilities. Appendix A and B show the flow chart of works need to be carried out in two semester to complete the project and meanwhile Appendix C shows the planning and execution of this project in Gantt Chart form.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Most literature published on metal pushing V-belt CVT for automotive applications usually discussed the belt only in general terms. It's history, advantages and disadvantages, performance and limitations, its future use and potentials, but very few really went into the engineering aspects such as, mechanical and design aspects of the metal pushing V-belt itself. This literature review will focus on two issues that the author feel it is important ones must have knowledge about CVT mechanism itself and basic lubrication before designing a CVT lubricant test device that capable to investigate the phenomena of film collapse in a CVT mechanism.

2.2 CVT Mechanism

2.2.1 Basic Components

The Van Doorne metal pushing V-belt CVT comprises basically two pair of variable V-shape pulleys (secondary and primary) and an endless composite metal belt. The endless metal pushing V-belt (MPVB) as shown in Figure 2.1 is wound around both the pulleys. The input pulley which is usually called the primary pulley is driving the transmission (hence sometimes called the driven pulley), which in turn is connected to the vehicle wheels through the final drivetrain. The pulleys are constructed in such a way that, one-half of each pulley is fixed to the shaft while the other halves are adjustable through sliding along their respective shafts. The axially adjustable V-shaped pulleys enable the MPVB to slide radially outwards and inwards and thus the effective belt radius can be steplessly adjusted.

Generally, the control is designed in such a way that the primary pulley determines the speed ratio while the secondary pulley, ensures that the proper belt tension is always maintained to prevent slipping (Tawi, 1997).

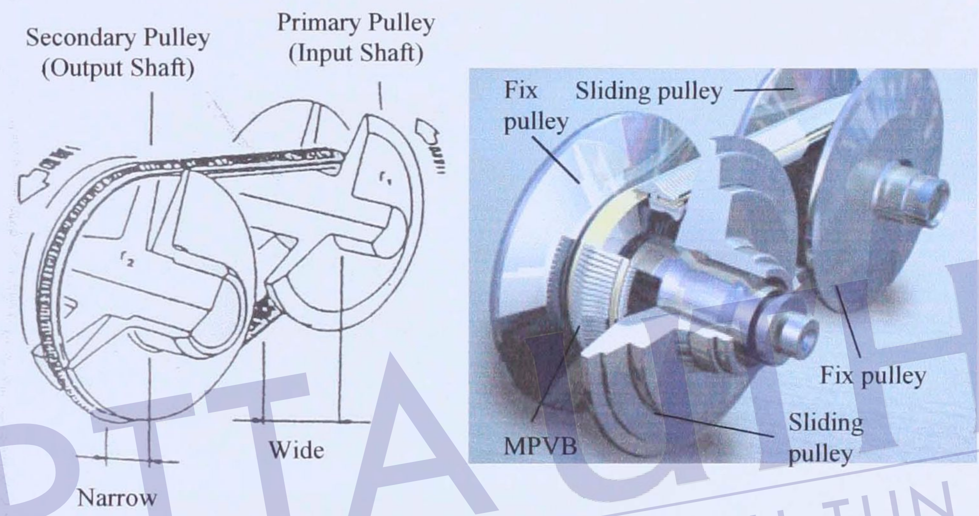


Figure 2.1: General concept of CVT (Bosch 2006).

2.2.2 Metal Pushing V-Belt (MPVB)

Van Doorne metal pushing V-belt comprises basically of two sets of thin metallic band strips and a number of thin metallic plates usually called segments or blocks as shown in Figure 2.2.

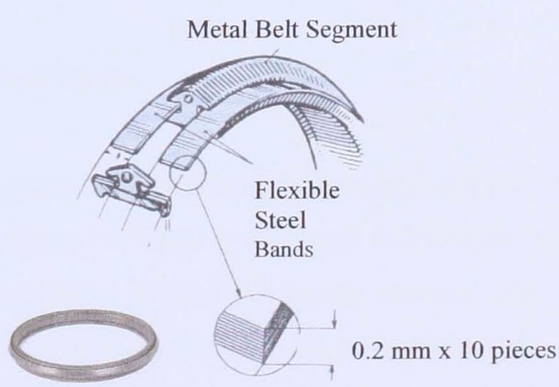


Figure 2.2: Van Doorne metal pushing V-belt (Gott, 1991).

The segments are sprung together by the two sets of bands through the segments location slots. These slots allow the segments to slide freely along the sets of bands. Currently, the number and size of segments and the number of band strips determine the metal pushing V-belt power capacity class. There are now a range of belt configurations, available from the Van Doorne Transmissie belt manufacturer as shown in Table 1.

Table 1: Van Doorne metal pushing V-belts product specifications. (*Personal communication with Markus T., Marketing Director,* Van Doorne Transmissie Manufacturer, Holland, 2001).

24/9 belts:	**901031**	**901027**	**901018**
Diameter ring # 1 [mm]	191.7	196.8	208.8
Nominal torque [Nm]	110	140	150
Ratio coverage [-]	5.8	5.5	5.5
Center distance [mm]	143	146	155
24/12 belts:	**901023**	**901033**	
Diameter ring # 1 [mm]	208.8	228	
Nominal torque [Nm]	180	180	
Ratio coverage [-]	5.5	6	
Center distance [mm]	155	170	
30/9 belts:	**901032**		
Diameter ring # 1 [mm]	229.4		
Nominal torque [Nm]	200		
Ratio coverage [-]	6.6		
Center distance [mm]	172		
30/12 belts:	**901028**		
Diameter ring # 1 [mm]	225.7		
Nominal torque [Nm]	220		
Ratio coverage [-]	5.4		
Center distance [mm]	168		

2.2.3 Changing Speed Ratio

A CVT, by contrast, relies on a belt-and-pulley system. The inner faces of the pulley sheaves angle inward to form a V-shaped belt groove. During gear changes, the pushing belt must adjust its position on the pulleys. The belt slides over the surface of the pulleys. The pulleys surfaces are covered by a thin lubricant oil film to minimize wear at that interface. However this lubricant oil will reduces the torque transferring friction. Therefore large clamping forces are needed on the pulleys, to ensure that the proper belt tension is always maintained to prevent slipping.

Computer-controlled hydraulic system used to control the CVT ratio by pushing the pulley sheaves together, forcing the steel belt to ride farther out or father in from the shaft. The increases or decreases of the pulley diameter makes possible changing the "gear" ratio continuously, rather than step-wise. This CVT "gear" ratio is adjusted by determines the relationship between the speed of the engine and the speed of the wheels (Ashley, 1995).

Underdrive or low gear is achieved when the effective primary pulley radius is less than the effective secondary pulley radius. Conversely, overdrive or high gear is achieved when the effective primary pulley radius is greater than the effective secondary pulley radius. A 1:1 speed ratio is achieved when the effective radius of both the pulleys is the same. Figure 2.3 below shows the belt situation at Overdrive ratio, 1:1 ratio and underdrive ratio.

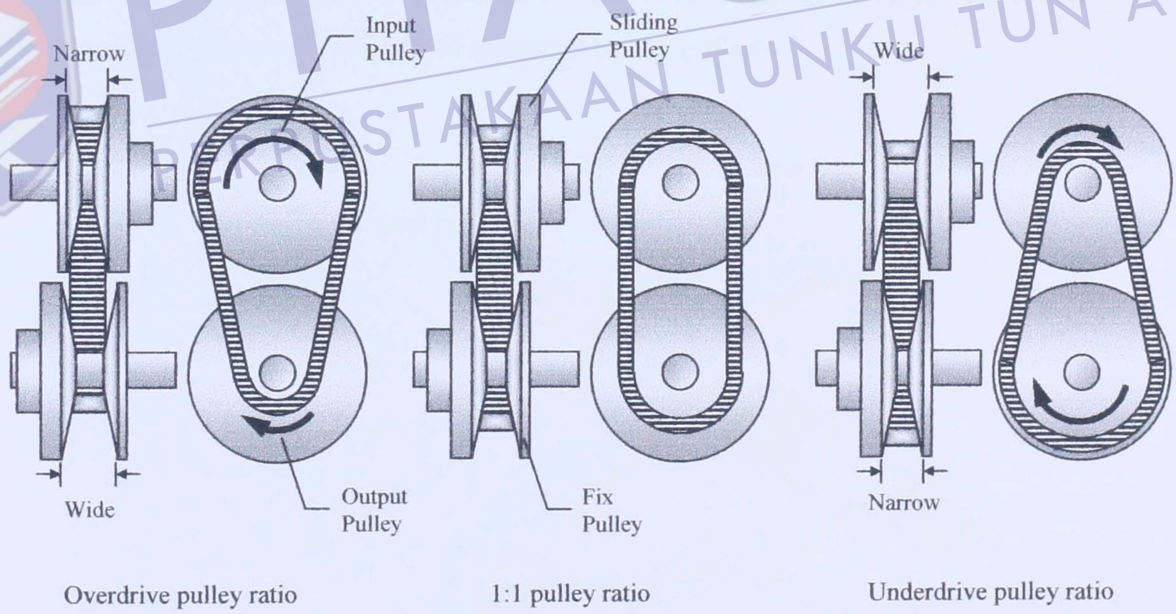


Figure 2.3: The CVT speed ratio.

2.2.4 CVT Power Transfer

It is here that researchers differ in their opinion on how actually the CVT MPVB transmits power from the primary to secondary pulley. There are two ideas of thoughts on this matter. The first idea of thought, that the researchers like Kurosawa et al (1999), Kuwabara et al (1998), Tawi (1997), Fujii (1993) and Sun (1988) predicted that power is transferred through Columb friction while, the second idea of thought of researchers such as Micklem (1990) based on his viscous shear and elastrohydrodynamic (EHD) theory.

Basically, the CVT includes an input shaft delivering power from an engine to the output shaft, which is connected, to the vehicle wheels through the final drive train. Each of the shafts includes a pair of pulleys, drive pulleys and a driven pulleys transferring power from the input shaft to the output shaft through the metal pushing V-belt as shown in Figure 2.4. This belt is being squeezed by the drive pulleys to ensure the torque from input shaft then flows and converting as a force to the segments through the interfacial contacts between the primary pulleys cone surfaces and the segment sides. Red colour of the belt at drive pulley in Figure 2.4 shows the area that has been contacted and squeezed by the pulleys.

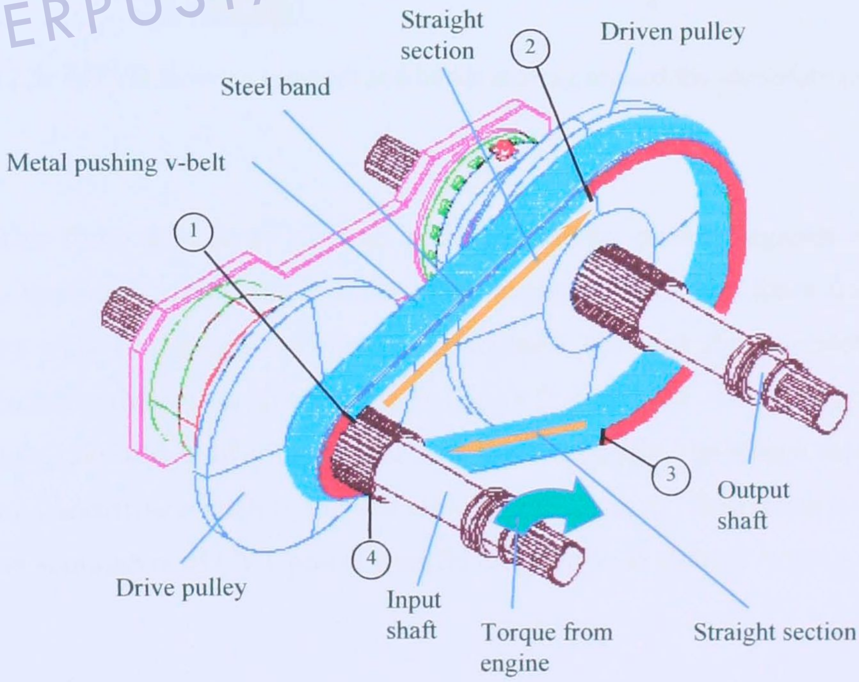


Figure 2.4: Mechanism of CVT showing the power transferred by the engine to the output CVT shaft.

The steel bands at top of the segment shoulder (blue in colour) are placed under tension by this squeezing action. The bands are in tension in order to hold the segments in line with each other as the belt run between pulleys as shown in Figure 2.5. The power is actually transmitted by the segments pushing against themselves, eliminating the tensile strength of the belt as a directly limiting factor (Gott, 1991). Tension in the steel bands need to prevent the stack of metal segments from buckling and also to hold them in contact with the pulley faces with sufficient normal force to generate adequate tangential friction forces.

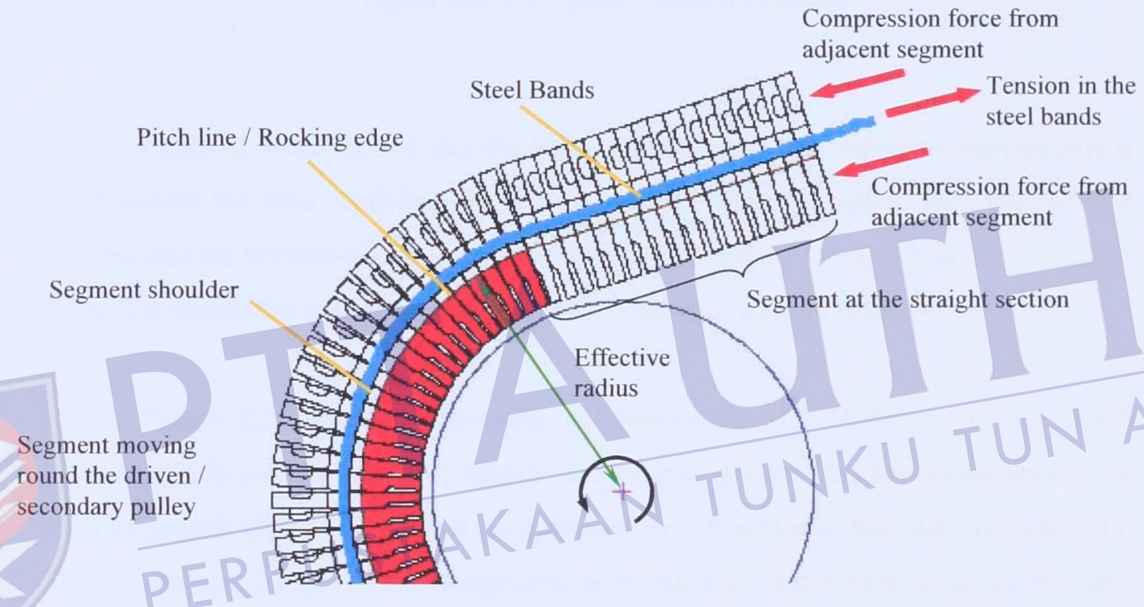


Figure 2.5: MPVB showing segment and bands moving around the secondary pulley.

This force then flows through each segment by pushing against each other forward, via their rocking edges and surface contacts. Then, the force flows to the secondary pulleys through the interfacial contacts between the segment sides as shown in red colour at driven pulley in Figure 2.4 and 2.5 which this secondary pulleys cone surfaces converting it back as a torque. Finally, the torque then flows to the output transmission shaft to the vehicle wheel through the final drive train. Figure 2.6 shows summarize of CVT power transfer diagram as explained recently.

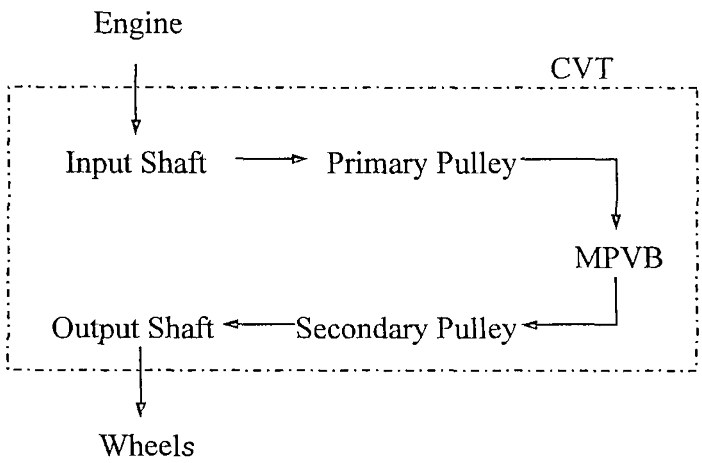


Figure 2.6: CVT power transfer diagram.

Figure 2.4 also shows that the belt are divide into four different regions which lie between the four stations, the section on the primary pulley, the two straight section and the section on the secondary pulley (Micklem, 1994). These four stations indicated which the compression or tension in the belt change linearly.

Figure 2.7 shows compression and tension in MPVB from Micklem CVT modelling analyses using EHD theory. This figure shows that the bands tension is always greater than the segment compression in all sections and stations when the belt is running. Compression in segments is increase from station four to one because of the torque transfers from drive pulley to the belt. Than, the segments deliver the torque in compression force form to the driven pulley. This action cause compression force transfer at nearly constant and its can be seen in straight line started from station one till station two. Station two to station three shows that the compression force is decrease due to the compression force has converted back as a torque and transfer it to the driven pulley. There is no compression in segments in station three because the segments are unloaded at exit from the driven pulley (station 3) and will be carried forward by the faster moving bands until they meet the segments ahead (Micklem, 1994).

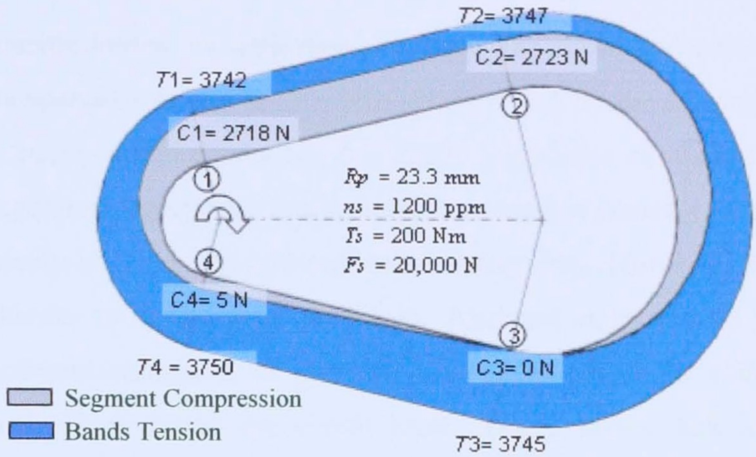


Figure 2.7: Compression and tension in metal pushing V-belt in steady state condition.

The metal segments must have sufficient transverse compressive strength to withstand the axial loads required to generate adequate frictional forces. A potential durability problem exists if friction forces are inadequate. Skidding of the metal belt against the pulley may cause galling which could lead to rapid belt or pulley failure. Friction forces must be sufficiently high to guard against skidding caused by sudden torque impulses from potholes, spinning wheels or driver abuse. Sufficient tangential force can be generated by squeezing the belt tighter between the faces of the pulleys. This action required greater axial force in order to transmit higher power from input pulleys to output pulleys. However, the normal contact stresses between the belt segments and the pulleys becomes limiting as axial forces increase. Excessive forces will lead to reduced life due to fatigue and wear (Gott, 1991).

2.2.5 CVT Losses

Work by Simner (1995) defines the losses that occur within a transmission into four distinct areas: parasitic losses, power proportional losses, weight and inertia, and transmission configuration and control. A number of papers have been written on the subject of CVT, control strategy and a number of models have been produced analyzing ratio change for the metal pushing V-belt CVT design. However, only a few researchers had investigated the parasitic or the power proportional losses in CVTs, even though the parasitic losses are becoming more important.

Parasitic losses, by definition are those that occur under no-load conditions and are independent of the power being transmitted by the transmission. Parasitic losses are mainly speed dependent, but due to the effects of viscosity, they are also highly temperature dependent. In a manual transmission parasitic losses are simple to define, namely oil churning and seal and bearing drag. However, within a CVT it becomes harder to define parasitic losses. Akehurst et al. (2001) proposed seven possible inherent categories of parasitic losses that affect the efficiency of CVT performance. These losses are clutch losses, pump losses, belt losses, belt slip, meshing losses, bearing losses and seal friction losses.

A clutch loss is associated with the drag on the disengaged forward or reverse clutch. This is due to the shearing of the oil film between each adjacent clutch plate and the oil film separating the plates. One of the major losses within the transmission is the torque absorbed in driving the hydraulic pump. The pump supplies the ratio control pressures and lubrication flow for the transmission. In many operating situations the pump torque is the largest loss mechanism in the transmission.

The belt is possibly the least understood of all the components in the transmission and is fundamental to the modelling of the overall transmission losses. A number of papers have been written in recent years related to the modelling of the metal pushing V-belt transmission, notably by Micklem et al. (1994a, 1994b and 1996), Fujii et al. (1993a, 1993b and 1994) and Akehurst et al. (2004a and 2004b).

Micklem et al. (1994b) produced an empirical model for the torque losses in the belt drive. He proposed three specific torque loss mechanisms within the belt. The first and the largest component is a wedging force as the segments are forced into and pulled out of the pulley contact arc. The belt will be retained by the pulley to a radius smaller than the contact radius on exit from the primary pulley, and on entry into the secondary pulley the belt will be forced out to a radius greater than the contact radius. Secondly Micklem proposed a viscous shear film between any belt components having a relative motion to a neighbouring component. Hence, he proposed losses between the segments and the band packs and between individual bands assembled in the band packs. Further to this Micklem also proposed a viscous shear film, based on elastohydrodynamic (EHD) theory, as the means of torque transfer between the belt and pulleys, this too has an effect on the total belt torque loss, and belt slip.

Fujii et al. (1993a, 1993b and 1994) have written a number of papers describing experimental work in which a belt has been instrumented with strain gauges to measure segment compressive forces and ring tension variation throughout the belt pulley system. Furthermore Fujii et al. (1994) describe the existence of an idle arc within both pulley wrap angles, in which the compressive load upon the segments does not change. The magnitude of this idle arc will have an influence on the force loading seen by individual segments as they pass through the loading and unloading arcs.

A few papers have been produced discussing the measurement and possible mechanisms of belt slip in metal V-belt drives. Micklem proposed model based on an EHD Lubrication regime, as the means of force transfer between the pulley and segment sides is effectively a model of belt slip. Another paper by Kobayashi et al. (1998) investigates the mechanisms causing micro slip in the metal V-belt. The analysis focuses on the distribution of gaps between the segments of the belt. It is hypothesised that gaps exist between the segments and these gaps cause slip to occur between the segments and the pulley in order that the gaps may be closed to generate compression force between them. The paper presents experimental validation for the gap theory by using a high speed camera to photograph a belt in operation with 26 mm of segments removed from it.

Meshing Losses in the CVT is happen in the final drive because it is similar with any conventional transmission. The losses due to gears can be treated, as they would be in a conventional transmission, using conventional gear meshing loss theory. Bearing losses can be based on conventional bearing theory as proposed in bearing manufacturers catalogues. Lastly, the torque loss associated with seals is due to the friction occurring between the seal and the sealing surface. This is likely to depend on a range of factors, including seal design, fluid pressure, rubbing speed and surface finish. A number of seal manufacturers have provided available data on the friction losses due to their products.

2.2.6 CVT Testing

A number of experimental techniques have been developed to measure a CVT performance. Most of the experimental techniques depend on what parameters want to be measure. A simple experimental technique which uses only a torque meter and a dynamometer can only measure CVT transferable torque and its efficiency. More complicated experimental which uses more instrumental devices can measure more parameters such as belt radius, bands tension, segment compression, transferable torque, belt loses, belt slip, CVT efficiency, sufficient amount of clamping force and many more.

One example of CVT experimental rig that has been done by DRG is shown in Figure 2.8. DRG or known as Drivetrain Research Group was one of the groups in research and development of drivetrain technologies especially on CVT for automotive application in University Technology of Malaysia (UTM) (Tawi, 2003). Figure 2.8 illustrates the schematic diagram of the experimental set up that has been developed by the group.

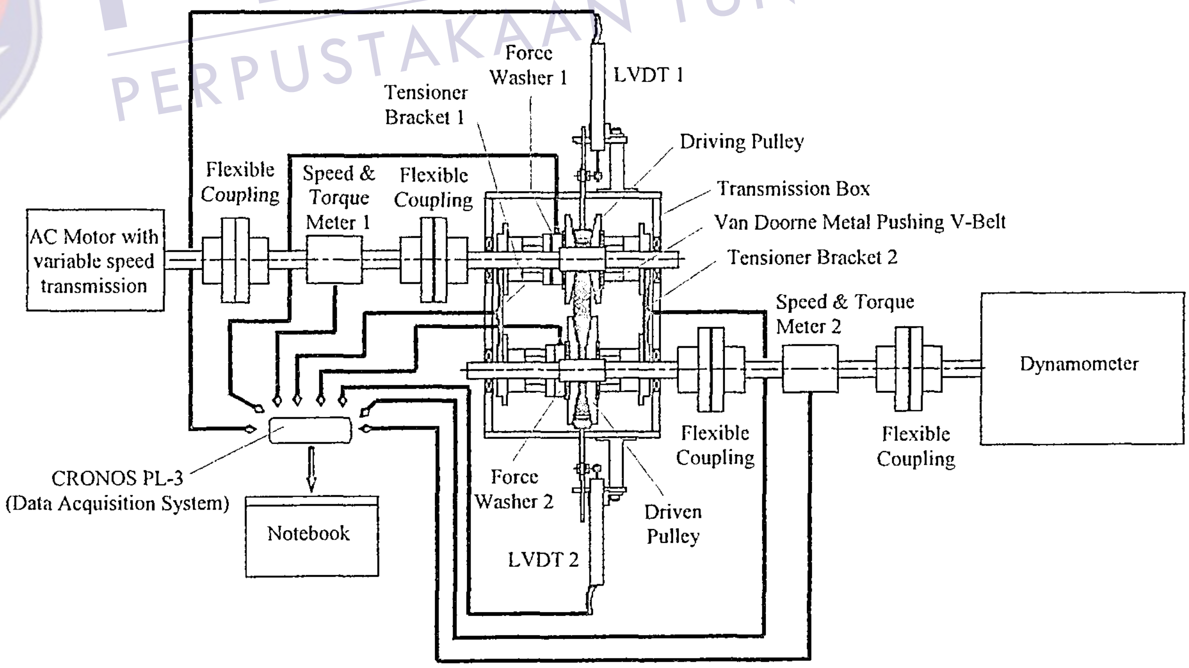


Figure 2.8: Schematic diagram of the experimental test rig.

Power was supplied to the input shaft by an AC motor capable of transferring 22 kW at 1400 rpm. At the output shaft, power is then absorbed by a water brake dynamometer capable of absorbing 190 kW at 2000 - 6000 rpm. Input torque and speed were measured by torque/speed meter mounted between the AC motor and the transmission input shaft, while the output torque and speed were measured by another torque and speed meter mounted between the water brake dynamometer and the transmission output shaft. Table 2 lists all the apparatus used in the experiment and their functions.

Table 2: List of testing apparatus (Tawi, 2003).

ITEM	FUNCTION
Torque meter	○ to measure input and output torque
Speedometer	○ to measure input and output rpm
Force Washer	○ to measure input and output axial force
Linear Variable Displacement Transducer (LVDT)	○ to measure input and output belt radii
Strain gauge	○ to measure approximate belt tension
Data Acquisition System (DAS) – CRONOS PL-8	○ It is an integrated platform concept to collect the experimental data independently or in conjunction with the PC.

2.3 Lubrication

Lubrication occurs when opposing surfaces are completely separated by a lubricant film. The applied load is carried by pressure generated within the fluid, and frictional resistance to motion arises entirely from the shearing of the viscous fluid. Lubrication is classified into three major categories: (Lubrizol Corporation, 2006)

- Hydrodynamic lubrication
- Elastohydrodynamic lubrication
- Boundary lubrication

Hydrodynamic lubricant is occurring when a system is fully support by the lubricants. In this situation the surfaces are kept apart by a pressurized fluid such as oil or air. The clearance space is much larger than the average surface roughness, and therefore the surfaces can be considered smooth. The pressurization of the fluid is achieved by external means in hydrostatic bearings, but is accomplished in hydrodynamic contacts by the relative motion and geometry of the surfaces. Examples of this case such as crankshaft main bearings in internal combustion engines (oil-lubricated hydrodynamic journal bearings), shaft support bearings in power generating turbines (often a combination of oil-lubricated hydrostatic and hydrodynamic journal bearings), piston rings (oil-lubricated hydrodynamic slider bearings), dentists' drills (air-lubricated hydrostatic bearings for shaft support) and magnetic disk heads (air-lubricated hydroynamic slider bearings). The friction coefficient in liquid-lubricated contacts falls typically within a range of 0.004 to 0.01 (Lubrizol Corporation, 2006).

In elastrohydrodynamic lubricant, there are situations in liquid lubricated arrangements where the loads are so high that the pressure in the lubricant causes local elastic distortions of the surfaces. This form of hydrodynamic lubrication is called elastohydrodynamic lubrication. The nominal clearance can still be such that surface roughness effects can be ignored, although mixed elastohydrodynamic lubrication can occur. Elastohydrodynamic lubrication is most commonly found in gears and rolling element bearings. The CVT is said are having this type of lubricant between the contact component especially at pulleys and belt surface.

In boundary lubricant regime, the entire applied load is carried by the surface asperities, and the friction and wear which arises depends upon the lubrication properties of the molecules on the surfaces. Coefficients of friction between 0.06 and 0.1 are typical when a low shear strength surface film is present. If no such film is present, then coefficients ranging between 0.2 and 0.4 can be exhibited, even rising as high as 1.0 in some cases (Lubrizol Corporation, 2006).

2.3.1 Lubricant Properties

Lubricant properties are use to determine the physical characteristics of lubricants at certain condition in standard experimentation for categories the lubricant which it will use in selection for various applications. These terms are well known to the lubricant supplier but are not always fully understood by the user. Among of the lubricant properties are:

- Viscosity
- Viscosity Index
- Pour Point
- Flash Point
- Precipitation Number
- Corrosion Number
- Oiliness
- Extreme-Pressure Lubricants
- Chemical and Physical Stability
- Cloud Point
- Carbon-Residue Test
- Ash Test

The basic functions of a lubricant are friction reduction, heat removal and suspension of contaminants. Designing a lubricant to perform these functions is a complex task, involving a careful balance of these properties both in the base oil and the performance enhancing additives.

This report focus on the viscosity and viscosity index study. This is because these two factors are the most important physical properties of lubricating oil and the temperature effect at these properties will alter the performance of the CVT.

2.3.2 Viscosity

Viscosity is one of the factors responsible for the formation of lubricating films under both thick and thin film conditions. Viscosity affects heat generation in bearings, cylinders and gears due to internal fluid friction. It affects the sealing properties of oils and the rate of oil consumption. It determines the ease with which machines can be started at various temperatures, particularly cold temperatures. The satisfactory operation of any given piece of equipment depends on using oil with the proper viscosity at the expected operating conditions.

The basic concept of viscosity is shown in the Figure 2.9, where a plate is being drawn at uniform speed over a film of oil. The oil adheres to both the moving and stationary surfaces. Oil in contact with the moving surface travels at the same velocity, *V*, as that surface, while oil in contact with the stationary surface is at zero velocity. The oil film can be visualized as many layers in between, each are being drawn by the layer above it at a fraction of velocity *V* proportional to its distance above the stationary plate.

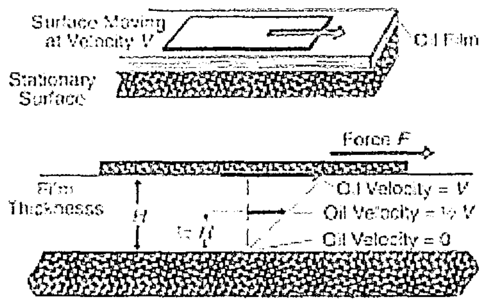


Figure 2.9: Concept of dynamic viscosity (Lubrizol Corporation, 2006).

A force *F* must be applied to the moving plate to overcome the friction between the fluid layers. Since this friction is related to viscosity, the force necessary to move the plate is proportional to viscosity. Viscosity can be determined by measuring the force required to overcome fluid friction in a film of known dimensions. Viscosity determined in this manner is called dynamic or absolute viscosity.

Newton viscosity of law stated that "the shear stress in a viscous flow is proportional to the velocity gradient in the direction perpendicular to the plane of shear". The constant of proportionality is known as the viscosity. A simple equation to describe Newtonian fluid behaviour is

$$\tau = \mu \frac{du}{dy}$$

where;

τ is the shear stress exerted by the fluid ("drag"), N/m^2

μ is the fluid dynamic viscosity - a constant of proportionality, N.s.m^{-2}

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