DEVELOPMENT OF POSITION CONTROL BASED ON CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

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ABSTRACT

Continuously Variable Transmission (CVT) is one of the latest technologies in automotive industries. Many researchers apply CVT in their system especially in speed control but not much was reported in position control. This project develops a control system design using the concept of CVT by replacing the fixed gearing system in conventional position control system into variable gear ratio. The variable gearing gearbox can be modeled by two continuously separated cones with different ratio banded by a belt that transfers the power from motor to the load. Simulation study in closed loop system is done to find how speed ratios can control position of the output load as the ratio change from under-drive to over-drive stage. Designed CVT system is analyzed based on settling-time, rise-time, peak-time, and overshoot compared to the conventional fixed gearing system. The output position of designed system can be controlled by only varying speed ratio, thus making system's performance easily tuned from under-drive to over-drive stage. From the analysis, designed CVT model shows better in overshoot compared to the fixed gearing system. As a result, a system with CVT have advantage over fixed gear and add up a new degree of freedom in control system design, which position can be control by only varying the speed ratio instead of applied forward and feed gain.

ABSTRAK

Continuously Variable Transmission (CVT) merupakan antara teknologi terkini yang digunakan di dalam bidang automatif. Kebanyakan penyelidik menggunakan *CVT* di dalam penyelidikan mereka terutama untuk mengawal halaju walaubagaimapun kurangnya terdapat dokumentasi dalam kawalan posisi. Projeck ini bertujuan untuk membangunkan system kawalan berasaskn *CVT* bagi menggantikan sistem menggunakan gear tetap kepada gear boleh ubah.. Sistem gear boleh ubah dapat diilustrasikan melalui dua kon berbeza diameter yang disatukan dengan talisawat yang mana menyalurkan tenaga dari motor ke beban. Kajian secara simulasi dilakukan bagi melihat bagaimana reaksi kadaran jejari boleh mengawal posisi beban apabila berlaku perubahan dari halaju rendah kepada halaju tinggi. Sistem yang dibangunkan dianalisa berdasarkan masa untuk capai nilai akhir (*settling time*), masa untuk memacu (*rise time*), dan peratusan melebihan nilai ahkir (*overshoot*) dan dibandingkan dengan sistem bergear tetap. Posisi beban mampu dikawal dengan variasi kadaran jejari, seterusnya mampu mengaturcara prestasi sistem dengan hanya mengubah kadaran jejari. Hasil analisa mendapati, *CVT* sistem mempunyai kelebihan mengatasi sistem dengan gear tetap dari segi peratusan melebihi nilai akhir (*overshoo*t). Konklusinya, sistem *CVT* mempunyai kelebihan terhadap system dengan gear tetap dan mengusulkan cara baru untuk mengawal posisi melalui variasi kadaran jejari bebanding menggunakan kadaran terus (*forward gain*).

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LIST OF ABBREVIATIONS

D, d	-	Diameter
F	-	Force
J	-	Moment Inertia
L	-	Length
T	-	Torque
r	-	Radius
CVT	-	Continuously Variable Transmission
EHD	-	Elastrohydrodymanic
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Continuously Variable Transmission (CVT) becomes one of the latest applications in automotive industries since 1460 which being develop by Leonardo Da Vinci. Due to the limitation of technologies in the earlier centuries, CVT is unsuitable for a car greater than 100 horse power. Todays, our national automobile company PROTON, has stated using CVT in their model. The new SAGA FLX run with CVT technology adapted the new technology in automotive technology history which is started by Nissan.

Engine transmission can be classified into two categories, “steeply” and Continuously Variable Transmission (CVT) or the best word as manual and automatic transmission. The manual and automatic are classified in “steeply” transmission use gears as their mean to steeply vary the gear ratios. Manual gearboxes basically consist of six sets of gear trains, which are first, second, third, fourth, fifth and reverse gears while in automatic it have the same gear train but with less of number of gears.

CVT can further be classified as the hybrid of automatic and manual transmission. The detail about of CVT will be explained in the background. Nowadays, car manufacturer start involve the new type of gearboxes such as Nissan, Audi, Honda and also our national car manufacturer PROTON have use this technologies in their new model.

1.2 Project Background

Transmission development can be as simple as manual gear boxes but there always demand on more comfortable driving experience. Even the transmission technologies getting advance nowadays, they still have jerking while changing gear ratio causes uncomfortable drive. CVT is a type of automatic transmission that provides more usable power better fuel economy and better driving experience than the traditional automatic. The main concept of CVT is by constantly relate between the engine speeds to the car speed, by which allowed it operated independently and therefore the engine can operated at its most fuel operating point. Torotrak Development Ltd. (2006) claimed that 20% less fuel consumption in CVT compared with conventional automatic transmission by then reduces the harmful emission.

The furthermore, while driving a car with CVT system, the passenger never feel or hear the transmission shift which is it simply raises or lowers the engine speed as needed, and calling higher up for better acceleration while calling down for fuel efficiency, by which is drop 4% in urban driving environment while drop 10% on highways. This provides CVT a quicker acceleration compare with the conventional automatic or manual transmission.

This type of engine function based on the belt-pulleys system. William Harris in web of How Stuff Works (2006), explained that as the radius of one pulley decrease, another radius increase in order to maintain the belt tight. When the pulleys change radii relative to another, they provide an infinite gearing number gearing ratio. Figure 1.1 shows that when the radii of pulley at the driving part small and large at the driven pulley, the rotational speed at the driven is lower which can be notice as lower gear. While in Figure 1.2, when the radii of pulley at the driving part large and small at the driven pulley, the rotational speed at the driven is higher which can be notice as higher gear. The drive pulley connected to the engine and the driven to the wheel of the vehicle.

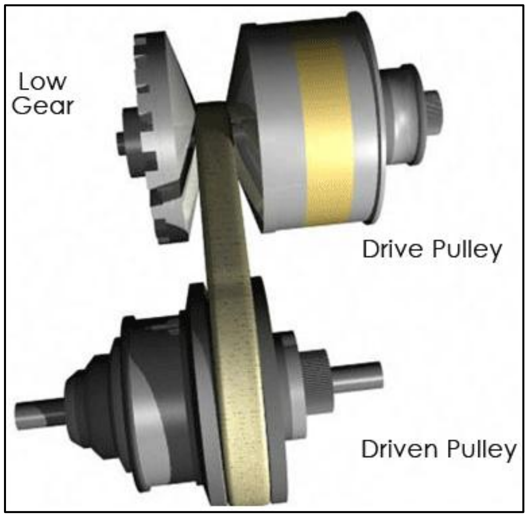


Figure 1.1: Lower Speeds

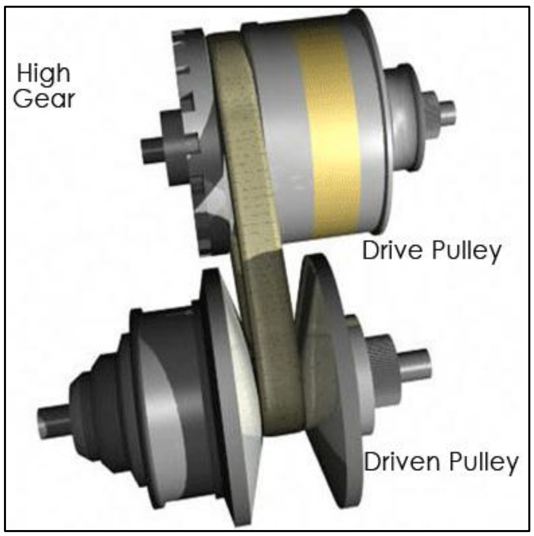


Figure 1.2: Higher Speeds

A new belt was developed by Van Doorne known as Metal Pushing V-Belt (MPVB) replaced the earlier rubber belt develop by DAF in 1958. This kind of belt consist of a large number of thin flat segments, which held together by two packs of steel band, each pack containing eight to ten bands for flexibility.

Van Doorne formed a consortium with Fiat and Borg-Warner in mid’70s to develop a CVT based on the belt was design by him [9]. The belt system can be described as a mechanism to adjust the drive and driven sheaves. Both side attached to a spring loaded and torque sensitive mechanism. The driver sheaves would typically connect to a centrifugally actuated control. At idle speed, the drive sheaves halves are separated and no power is transmitted. When the engine speed increases, the sheaves are bought together, which set the belt at minimum sheaves radius, provide maximum speed reduction and maximum torque.

As the engine power increase further, the centrifugal actuated continues to move the sheaves halves closer, while the driven sheaves move further apart as response to the increasing of belt tension. In this project, a mathematical modeling of a position control system based on CVT and applied to arm robot as the load was introduced. The control algorithm will replace the conventional position control strategy using fixed ratio into variable gears train. Based on develop model, the stability and performance analysis will be conducted. By studying and modeling the CVT concept, arm robot can be controlled with an alternative system by just need little understanding about the belt-pulley system.

1.3 Problem Statements

In the last few decades, development regarding to the position control have caught lot of researcher interest into this problem. They usually design on how to improve the conventional positioning control using fixed gearbox system, by using several type of controller such as Proportional Integrator Differentiation (PID), Fuzzy Logic, Neural Network, and many more, without taken into account about the possibility of using variable gearing ratio in their system.

In the conventional positioning control, a fixed gear train has been use that is in the ratio of spur and pinion. This gear train functions to transfer the power from the motor to the load. This cause from the error between the output position and the reference input, then this error will be amplified and make the motor to move according the error and finally adjust the position. The issue here is, instead we are using fixed gear and other controller, is that an alternative way by varied the ration of the gears train to control position of a load.

This similar concept is applied to a car engine that used CVT compared with a conventional automated transmission car. A passenger in a car with conventional automated transmission will fell the shifting gear when the car accelerate, and that situation still will happened if a car with CVT is used. So, we applied the same concept use in car manufacturer to the conventional position control system. Therefore in this project, we are develop a mathematical modeling of a position control by using variable gearing ratio has been use in CVT. We also interested to know either there have any point of improvement when people design a position control algorithm using variable ratio system compared to fixed ratio in their system.

1.4 Project Objectives

The main objectives of this project are:

a) To develop a mathematical model of position control based on continuously variable transmission (CVT).
b) To investigate the performance of CVT system and compare it with conventional position present by fixed gear system.

1.5 Project Scopes

There are two limitations of this project are:

a) Parameter:
   This project developed a position control instead of speed control.
b) Application
   Only a simulation study will be conducted and the hardware is not included.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Most literature publish on CVT usually discussed on speed control of their system that be applied for automotive application. It's control strategy, advantages and disadvantages, variable speed control at different driving condition, system stabilities, performance and limitation of the system but very few really when into engineering aspects such as, mechanical and design aspects of the metal pushing V-belt itself. This literature will focus on mechanism of Continuously Variable Transmission (CVT). Author believed that by knowing the mechanism of CVT, the better understand on now this system would be.

2.2 CVT Mechanism

The Van Doorne metal pushing V-belt CVT comprises an endless composite metal belt with two pair of variable V-shape pulleys (secondary and primary). The illustration of endless metal pushing V-belt as in Figure 2.1 that wound around both pulleys. The input pulley is usually called the primary pulley that driving the transmission (driven pulley), which in then connected to the vehicle wheels through the final drivetrain (driving pulley).The construction of the pulleys such way that, one-half of each pulley are fixed to the shaft while the other half are adjustable as it can be slide along their respective shafts.

The axially adjustable V-shaped pulleys enable the MPVB to slide radially outwards or inwards. Thus, the effective belt radius can be sleeplessly adjusted. General control has been designed in such way that the primary pulley determine the speed ratio while at the secondary pulley, ensured that the proper belt tension always be maintained to prevent slipping [21].

2.2.1 Metal Pushing V-Belt (MPVB)

The belt that was designed by Van Doorne basically comprises two sets of thin metallic band strips and a number of thin metallic plates (segment) as illustrated in Figure 2.2 below. The entire segment a bend together by two sets bands through the segments location slots. This situation allowed the segment to slide freely along the sets of bands. Noted, the number and the size segments and the number of band strips determine the MPVB power capacity class. Now there is range of belt configuration available in the market has been inspired by the Van Doorne Belt.

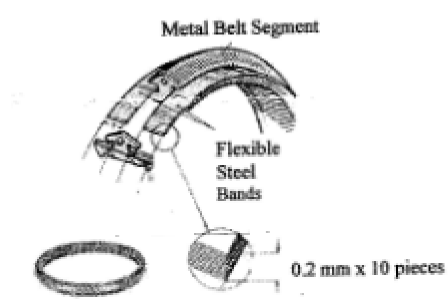


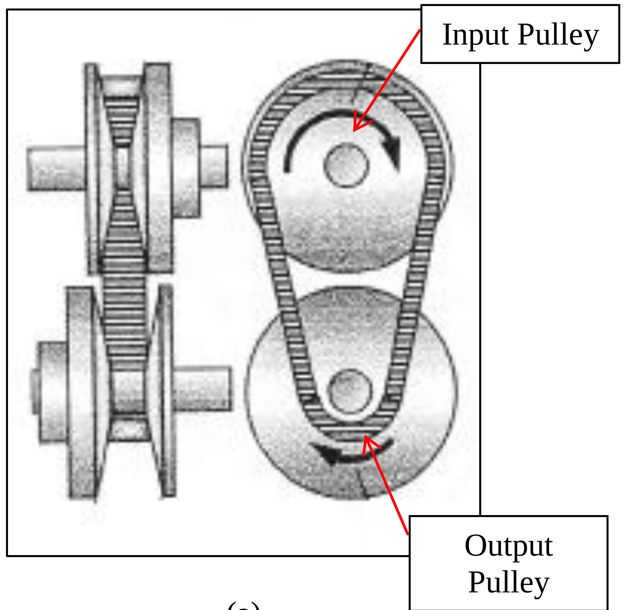
Figure 2.2: Van Doorne Metal Pushing V-Belt [9]

2.2.2 Changing Speed Ratio

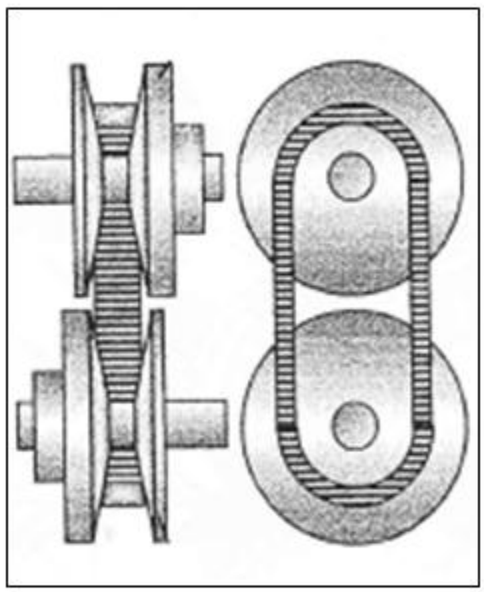
Continuously Variable Transmission (CVT) gets inspired by belt-pulley system. The belt shape itself, make the inner faces of the pulley sheaves angle inward to form a V shape belt groove. During gear changes, the belt must adjust its position on the pulleys and slides over the surface of the pulleys. In order to make it slide nicely, a thin lubricant oil film is covered at the surface of the pulley to minimize the wear of interface [2]. However, the present of lubricant oil may reduce the torque transferring friction. Thus, it needs a large clamping force on the pulleys, as to prevent belt slip to be occurred.

Computer-controlled hydraulic system used to control the CVT ratio by pushing together the sheaves of the pulley which cause the steel belt to ride freely outward or inward from the shaft. The variation of pulley diameter either increase or decrease make the possible of changing gear ratio (speed ratio) continuously, rather than step wise as present in conventional automatic vehicles.

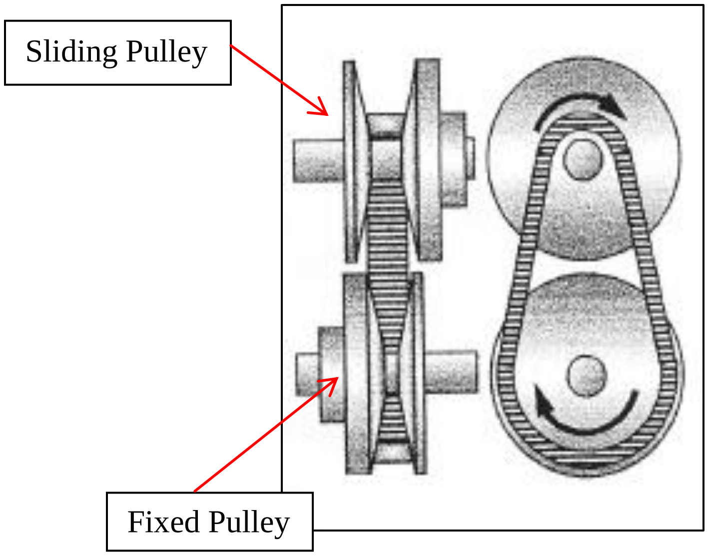
CVT continuously variable the speed ratio at least may involve three stages. Those are under-drive, one to one ratio, and over-drive. Under-drive or low gear is achieved when the effective primary pulley radius is less than secondary radius while the over-drive or high gear achieved when the effective primary is greater than effective secondary pulley radius. A 1:1 happen where both of pulleys have the same effective radius. All of the stages are illustrated in Figure 2.3 below.



(a)



(b)



(c)

Figure 2.3: (a) Under-Drive Pulley Ratio
(b) 1:1 Ratio Pulley
(c) Over-Drive Pulley

2.2.3 CVT Power Transfer

CVT structure basically includes an input shaft delivering power from engine to the output shaft which connected to the vehicle wheel through the final drive train. Each shaft includes of a pair of pulleys, driven pulleys and driving pulleys, transferring power from the input shaft the output shaft through the metal pushing V-belt as shown in Figure 2.4. The belt being squeezed by the driven pulleys to ensure the torque from the input shaft then flows and converting as a force to the segment through the interfacial contact between the primary pulleys cone surfaces and the segment sides.

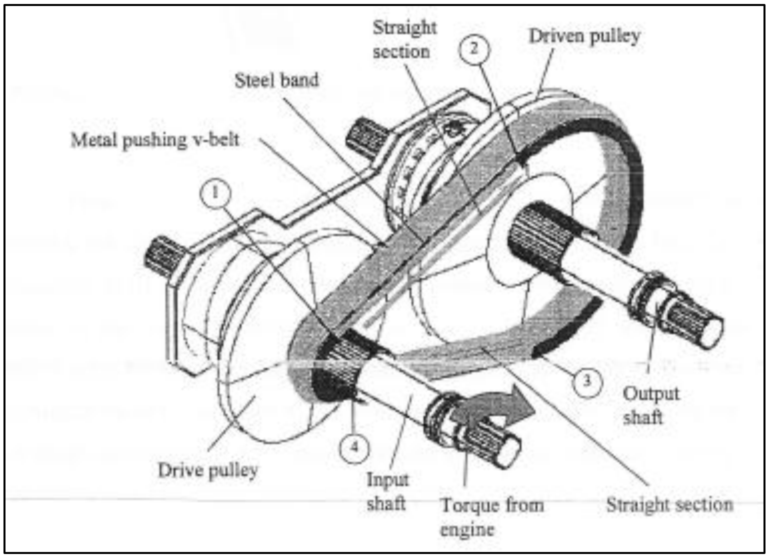


Figure 2.4: CVT power transfer from the input to the load through MPVB

The steel bands at the top of the segment shoulder are placed under tension due to the squeezing action of the belt. The bands are in tension in order to hold the segments in line with each other as the belt run between pulleys as illustrated in Figure 2.5. Power actually transmitted by the segments pushing against themselves, eliminating the tensile strength of the belt as a directly limiting factor [9]. 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.

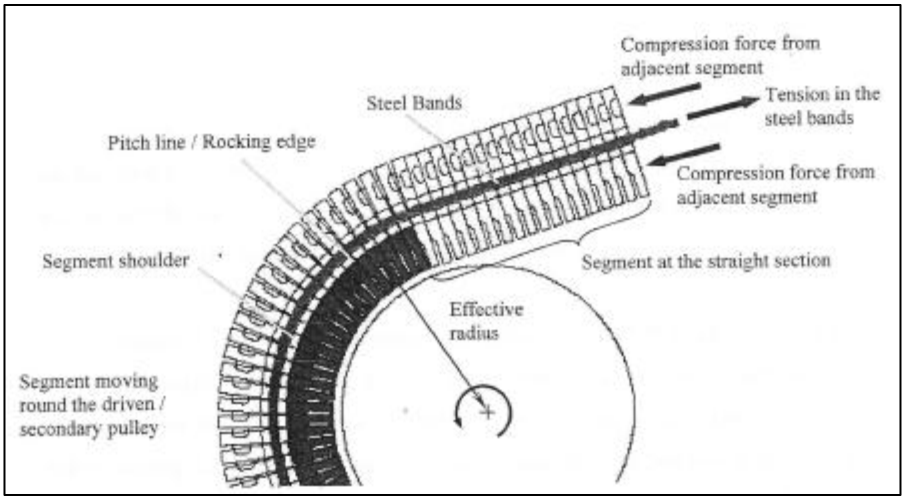


Figure 2.5: MPVB segment and bands moving around the secondary pulley

The force then flows through each segment by pushing against each other forward, via their rocking edge and surface contacts. Then, the force flows to the secondary pulleys through the interfacial contacts between the segment sides as shown 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 flow 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.

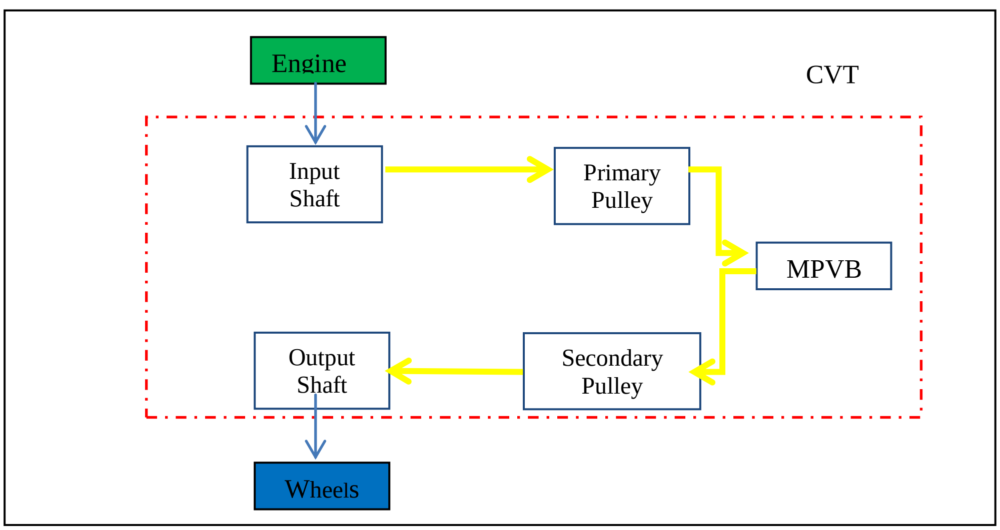


Figure 2.6: CVT power transfer diagram

Figure 2.4 also shows that the belt can divide into four different regions which lie between the four stations, the section on the primary pulleys, two straight sections and secondary pulley [14]. These four stations indicated which the compression or tension in the belt change linearly.

Figure 2.7 shows the compression and tension in MPVB from Micklem CVT modeling analyses using ETD theory. Refer to the figure, the bands tension is always greater than the segment compression in all section and stations when the belt is running. Compression in segments is increase from station four to one because of the transfers from drive pulley to the belt. Then, the segments deliver the torque in compression force form to the driving pulley. This action cause compression force transfer nearly constant and its can be seen in straight line started from station one till station two. Station two to station three, the compression force is decrease due to the compression force has converted back as a torque and transfer it to the driving pulley. There is no compression in segments in station three as the segments are unloaded at the exit from the driven pulley (station 3) and will be carried forward by the faster moving bands until they meet the segments ahead [14].

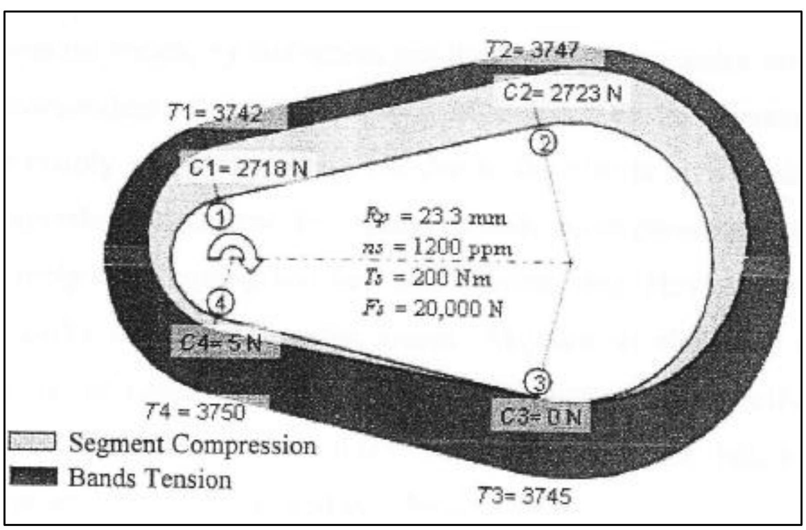


Figure 2.7: Compression and tension in MPVB in steady state condition.

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 [9].

2.3 CVT Testing Device

Numbers of experimental techniques have been developed to measure a CVT performance. Most of the techniques depend on what parameters want to be measure. A simple experimental technique which uses only a torque meter can only measure CVT transferable torque and its efficiency. More complicated experimental which uses more instrumental devices can be 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 experimental device has been done by DRG (Drivetrain Research Group) who do research and development of drivetrain technologies especially on CVT for automotive application in UTM (Universiti Teknologi Malaysia) [22]. Figure 2.8 illustrates the schematic diagram of the experimental set up that has been developed by the group.

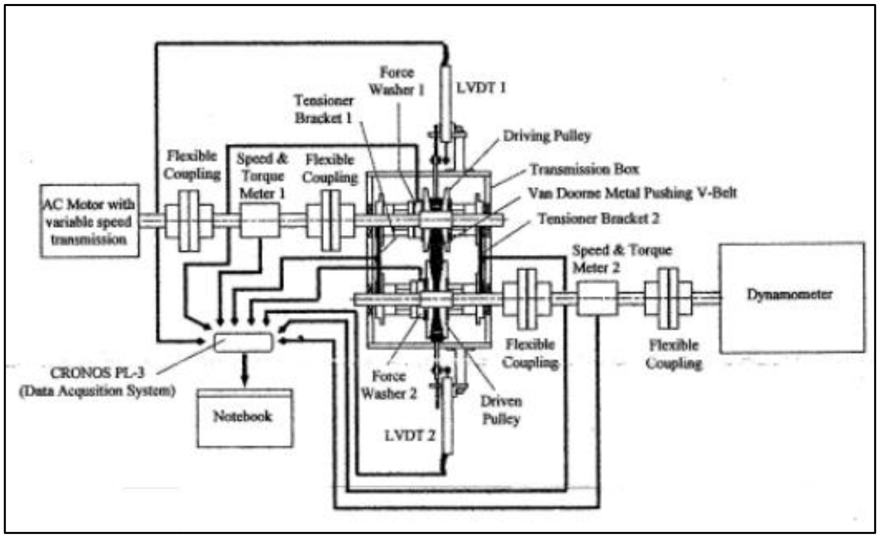


Figure 2.8 Schematic Diagram of the Experimental Test Rig

2.4 Determination of CVT Pulley Radius

Refer to research done by Mohd Azwir (2006), in order to determine the effective ratio of Continuously Variable Transmission (CVT) at both pulley, some formulation has to be considered. As shown in Section 2.2, the power transmission of CVT from engine to the wheel may involve few stage of speed ratio.

So, this researcher has calculated the radius that should be considered while designing the CVT. At the beginning, he considered designing power transmitting plates with different contact radius which the size of power transmitting plates depend on the belt radius while operating inside a CVT gearbox. Three ratio were selected which are under-drive ratio, one-to-one ratio, and over-drive ratio as illustrated in Figure 2.3. Commonly, normal CVT have the speed ratio between ranges of 0.5 to 2.0. 0.5 is the minimum value under-drive ratio that a normal CVT can achieve. Meanwhile, 2.0 is the maximum value of over-drive ratio condition. This kind of ratio may conclude that the design of CVT system should include three stages as reference point and must within the range of 0.5 to 2.0.

Next stage is to obtain the specific sizes of power transmitting plates by knowing the mechanism of belt itself. There is an effective line on the Metal Pushing V-Belt (MPVB), which claimed that each segment is continuously connected to its adjacent calculation for obtaining speed ratio based on this line. Figure 2.8 shows MPVB as a continuously line passing through around the two pulleys.

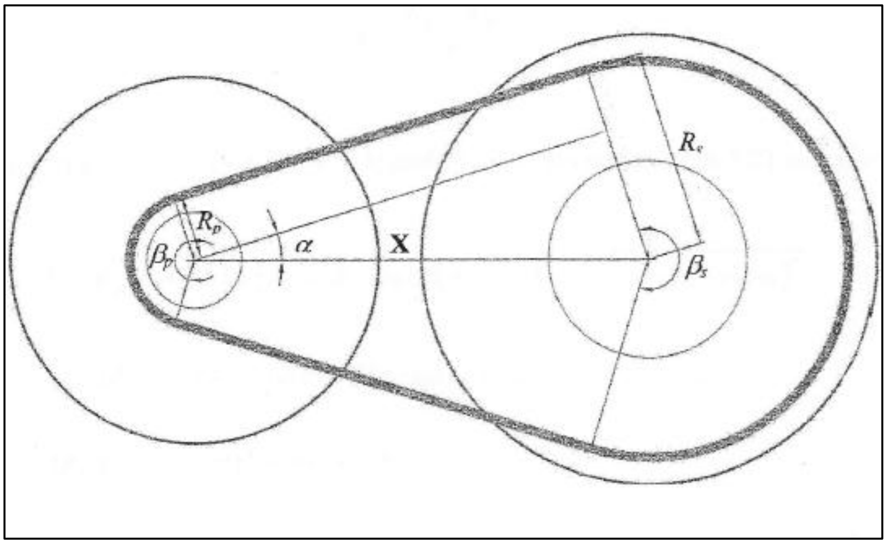


Figure 2.9: The Belt Geometry

The belt lengths can be expressed as in Equation 1 by developing a geometrical relation above. Two assumption need to be considered:

i) No belt elongation occurs during operation

ii) Effective line is continuous along the pitch line

$$L = R_p\beta_p + R_s\beta_s + 2\sqrt{X^2 - (R_s - R_p)^2} \qquad (1)$$

where

R_p	-	radius of belt at primary pulley
R_s	-	radius of belt at secondary pulley
β_p	-	angle of lap on a primary pulley
β_s	-	angle of lap on secondary pulley
X	-	pulley center distance
α	-	angle of belt at straight line

The parameters that are already know are the belt length and itscenter distance while the other are unknown. Other relation needs to be considered

$$\beta_p = \pi - 2\alpha \qquad (2)$$

$$\beta_s = \pi + 2\alpha \qquad (3)$$

$$\sin\alpha = \frac{R_s - R_p}{X} \qquad (4)$$

Substituted above equation into Equation 1 will give;

$$L = R_p(\pi - 2\alpha) + (R_p + X.\sin\alpha)(\pi + 2\alpha) + 2\sqrt{X^2 - (X.\sin\alpha)^2}$$

$$L = 2R_p\pi + 2X\alpha.\sin\alpha + X\pi.\sin\alpha + 2\sqrt{X^2(1 - (\sin\alpha)^2)}$$

$$2R_p\pi + (2\alpha + \pi)X.\sin\alpha + 2X.\cos\alpha - L = 0$$

$$(2\alpha + \pi).\sin\alpha + 2.\cos\alpha + \left(\frac{2R_p\pi - L}{X}\right) = 0 \qquad (5)$$

Equation 5 is used to determine the angle of the belt at straight line, α, with a specific radius of belt at primary pulley. This equation cloud not easily be done by normal mathematical approach but must be done using iteration method using software such as Microsoft Excel. A series of $R_p$that varying from minimum to maximum pulley diameter is arranged in one column as shown in Appendix C. Then, some initial value for α were set up at next column. Equation 5 is then inserted into third column and by clicking solver at tools menu, the value of α can be obtained using iteration method. Thus, α then substituted in Equation 6, which has been rearranged from Equation 4 to get the value of secondary pulley.

$$R_s = R_p + X.\sin\alpha \qquad (6)$$

2.5 Present Research on Continuously Variable Transmission (CVT)

Continuously Variable Transmission (CVT) advantage in automotive has get many interest by control system researcher to implement this technology into their field of interest. Many of them apply CVT in speed control as it main advantages may result good fuel efficiency. Research conduct by Zhou & etc. (2006), they developed a CVT modeling and do a simulation study to control the speed of the engine. They aim the vehicle will run with minimum fuel consumption and good power performance. Whole vehicle dynamic model of CVT has been design including the engine, clutch, the CVT gearbox itself and the load. PD controller also be applied to get better performance. There have three steady speed of the car with meet the theoretical value that are 109.40 Km/h, 39.93 Km/h and 74.48 Km/h.

A group of researchers name as Drivetrain Research Group (DRG) from UTM developed a control system that may cause fuel efficiency vehicles. By taking the advantages of CVT with wider range of ratio, good fuel efficiency, shifting ratio continuously and smooth drive ability, They develop a nonlinear system by using Adaptive Neural Network Optimization Control (ANNOC) that indirectly control the engine speed by adjusting the CVT pulley ratio. The ANNOC is highly may control the engine satisfactorily [1].

A study on the velocity ratio control using CVT for tractor has been developed against to optimize the engine performance to get the maximum performance of the tractor. In accordance of the working features of agricultural tractors, a speed ratio regulation law has been formulated based on CVT and also the controller of the velocity ratio. They compared their system with the hardware and it works accordingly [32].

Schulte, (2010) develop a control system to have an optimized engine performance for fuel efficiency specially for off-road vehicle and agricultural machines using the concept of CVT. A power-split CVT design by combining both the conventional system with CVT and this system guarantees smooth variations of transmission ratio with high efficiency and also high power density with maximize tractive force at low speed. He using Takagi- Sugeno (TS) fuzzy observer by using LMI based condition for simulation study and then compared with the experimental result.

Among the latest research apply using CVT is by using it for hybrid electric car by introducing the control system and it working principle. An energy management strategy based on the logic threshold control method has been carry forward. The torque and rotating speed difference distribution of the internal combustion engine and ECVT are control reasonably in order to achieve dynamic switching among the different operation mode. The result of this system showed that the whole ECVT system can run in highly efficient as designed [33].

CHAPTER III

METHODOLOGY

3.1 Introduction

The objective of this control system is to control the position of a mechanical load according to the reference position. The main goal is to replace the fixed gearing system into a variable gearing present by CVT. Derivation of the system with CVT based on the real system in the car and the complete transfer function the system evaluate in this chapter.

3.2 Project Methodology

Gear train or power transmission is the motion transformer in form of mechanisms by which transfer and transform rotational or translational motion. They are used to when a changed of motion, speed, or even though torque is needed. There is lots of power transmission available in the market, but the main of power transmission can be classified fixed ratio and variable ratio motion transformers [12]. Fixed ratio system basically applied for a system that the driving motor runs with higher speed compared to the driven machine. It consists of two kind of gear, the larger gear wheel called spur while the smaller is pinion. The gear ratio is given by the ratio of the number of the teeth of both wheels.

While variable ratio mostly apply continuously adjustable ratio of the transmission is required. Recently there are variety of mechanical solution such as Continuously Variable Transmission (CVT) and Hydraulic Transmission. By taking the advantages of CVT, a position control system was developed instead of speed control in recent application [12].

3.2.1 Conventional Position Control System

Conventional position control system is a system to control the load position based of the variation of input to the system. As there have an error from the potentiometer refer to the reference point, motor will move to reflect the error. The value of error then been amplified and enough current will supply to the motor rotate the gear which then move the load. Load move according to the error within the input and output. Figure 3.1 illustrated the schematic diagram of this conventional position control using fixed gear system present by pinion and spur.

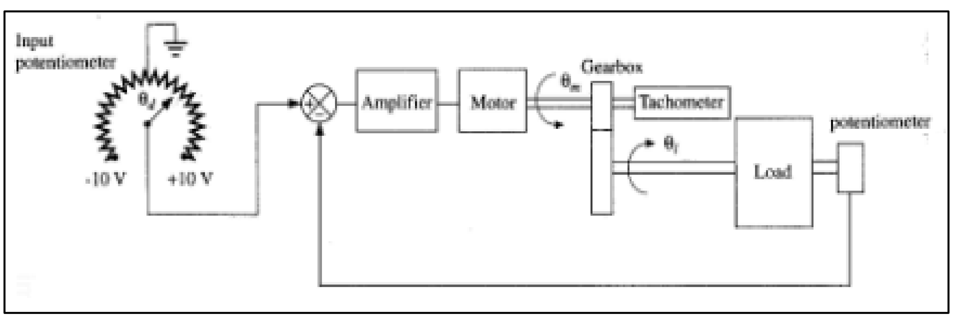


Figure 3.1: Schematic Diagram of Conventional Position Control with Fixed Gear Train

This gear train then been added up to the complete system with feedback to get a better system response. Figure 3.2 below shows the complete block diagram of closed loop position control and Equation 7 is the transfer function of the systems. As in the final transfer function, conventional position control system parameters that may influence the system are the potentiometer gain, K_p and the tachometer gain, K_g. The other parameters are fixed including the ratio of the gearbox. This system can be tuned by manipulating the both parameters in design process.

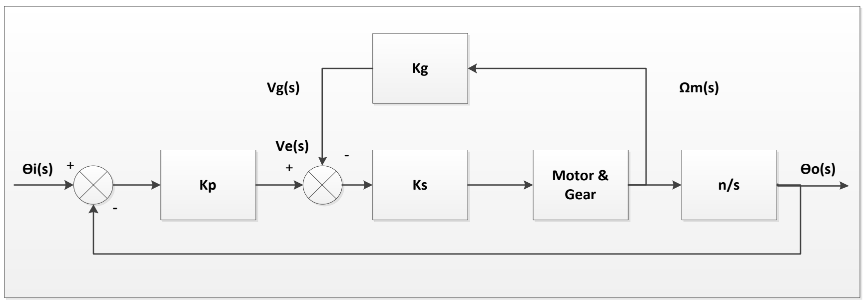


Figure 3.2: Block Diagram of Closed Loop Position Control with Fixed Gear Train

$$\frac{\theta_0(s)}{\theta_i(s)} = \frac{K_p K_m K_S n}{T_m s^2 + (1 + K_g K_m K_s)s + K_p K_m K_S n} \qquad (7)$$

3.2.2 Model of Belt-Pulley System

Continuously Variable Transmission (CVT) model from the belt-pulley system which consists of two pulleys connected with a belt. Same as the gearing function, belt system also have the large and small pulley then connect to motor and load. The force F_U at the discs is created as the difference between the load force of the tight side $F_1(t)$ and the slack side$F_2(t)$. These forces generate the torques and rotating speed of the pulleys [12]. Figure 3.3 shows the schematic diagram of belt drive system.

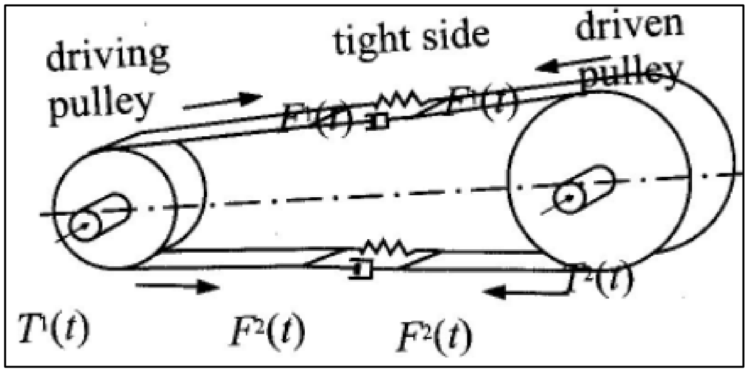


Figure 3.3: Schematic Diagram of Belt Drive

This system then can be model as shown in Figure 3.4 below. The equivalent model has been simplified by stating few assumptions as below:

- The belt is massless.
- The shaft distance is constant.
- The effect of the centrifugal forces is neglected.
- The deformation of the wheels and the shafts is neglected compared to the belt deformations.
- Certain load status, the modulus of elasticity is constant over the total belt length, such as that Hooke's law applies.
- Friction belts, extension slip only occurs.

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