ELECTRO-MECHANICAL SINGLE ACTING PULLEY RUBBER V-BELT CONTINUOUSLY VARIABLE TRANSMISSION (EMSAP RVB-CVT) FOR SCOOTER

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ABSTRACT

The rubber v-belt continuously variable transmission (RVB-CVT) in motorcycle is very important because it affects good drive ability in terms of response and smoothness for the rider or passenger. RVB-CVT mechanically consists of primary clutch, secondary clutch and V-belt. The new mechanism of mechanical RVB-CVT components with electric motor is introduced. The objectives of this thesis are to design and to simulate a new actuate the electro-mechanical single acting pulley rubber V-belt continuously variable transmission. The electro-mechanical single acting pulley rubber V-belt continuously variable transmission (EMSAP RVB-CVT) system consists of two sets of pulleys, primary pulley and cam mechanism placed on input fixed shaft and secondary pulley placed on the secondary fixed shaft. The primary pulley design changes to reduce the centrifugal force generated by the mass of the weights and clutch spring, replaced the cam mechanism which is controlled by a DC motor through a gear's mechanism. Each set of the pulley has two moveable sheaves that can be shifted axially along the shaft. A spring is inserted in the back of the secondary pulley sheave to provide continuous clamping force to the belt and to reduce excessive slip during transmission ratio change. Solidwork software used to drawing detail of EMSAP RVB-CVT. Simulation using Matlab and Simulink software to determine the CVT ratio obtained in addition to get the response of the design that has been created. The results show that a new design of EMSAP RVB-CVT is successfully design and simulate. The computer simulation result is present the Proportional, Integral and Derivative (PID) controller model works satisfactory for desired ratio transmission.

ABSTRAK

Tali getah sawat-V penghantaran pemboleh ubah berterusan (RVB-CVT) dalam motosikal adalah sangat penting kerana ia memberi kesan kemampuan pandu baik dalam segi tindak balas dan kelancaran untuk penunggang atau penumpang. RVB-CVT mekanikal terdiri daripada cekam utama, cekam menengah dan sawat-V. Mekanisme baru komponen mekanikal RVB-CVT dengan motor elektrik diperkenalkan. Objektif tesis ini adalah untuk reka bentuk dan untuk selaku baru menggerakkan elektro-mekanikal tunggal bertindak takal getah V-sawat penghantaran pemboleh ubah berterusan. Elektro-mekanikal tunggal bertindak takal tali getah sawat-V penghantaran pemboleh ubah berterusan (EMSAP RVB-CVT) sistem terdiri daripada dua set takal, takal utama dan mekanisme sesondol yang diletakkan di atas sesondol input tetap dan takal menengah diletakkan pada sesondol tetap menengah. Perubahan reka bentuk utama takal untuk mengurangkan daya emparan yang dihasilkan oleh jisim berat dan spring cekam, menggantikan mekanisme sesondol yang dikawal oleh motor DC melalui mekanisme gear. Setiap set takal mempunyai dua kerek alih yang boleh dipindahkan paksi sepanjang batang. Spring dimasukkan di belakang takal kerek menengah untuk menyediakan tenaga berterusan pengapitan untuk tali sawat dan untuk mengurangkan slip berlebihan semasa perubahan nisbah penghantaran. Perisian Solidworks digunakan untuk lukisan terperinci EMSAP RVB-CVT. Simulasi menggunakan perisian Matlab dan Simulink untuk menentukan nisbah CVT diperolehi di samping untuk mendapatkan maklum balas reka bentuk yang telah diwujudkan. Keputusan menunjukkan bahawa reka bentuk baru EMSAP RVB-CVT berjaya reka bentuk dan menyelaku. Keputusan simulasi computer pengawal kini; berkadaran, kamiran dan terbitan (PID) model kerja yang memuaskan untuk penghantaran nisbah yang dikehendaki.

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LIST OF SYMBOLS

μ	Friction coefficient
A	Oscillation amplitude
A_l	Arc length of female cam
B	Friction coefficient
c	Circumference of female cam
C	Centre distance
d	Amplitudo feedback signal
d_p	Diameter of inner cam
F_z	Clamping force
I_m	Motor current
K_d	Derivative gain
K_e	Back emf constant
K_i	Integral gain
K_p	Proportional gain
K_T	Torque constant
K_u	Ultimate gain
L	Cam length inner
L_b	Belt length
L_m	Motor inductance
n	Gear speed
P_u	ultimate period
r	Radius of female cam
r_{CVT}	CVT ratio
R_m	Motor resistance
R_p	Primary pulley radius
R_{p0}	Minimum primary radius
R_s	Secondary pulley radius

r_s	Speed ratio
sJ	Rotor inertia
sL	Inductance
T_{clm}	Torque of clamping condition
T_h	Number of teeth
T_{rls}	Torque of release condition
V_m	Motor voltage
X_p	Axial movement of primary pulley
X_s	Axial movement of secondary pulley
α	Angle of maximum female cam rotation
π	Pi, the constant is approximately equal to 3.14
ω_m	Motor shaft angular velocity
ω_p	Angular speed of the primary pulley
ω_s	Angular speed of the secondary pulley
μ	Friction coefficient
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A_l	Arc length of female cam
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LIST OF ABBREVIATIONS

AT	Automatic transmission
CVT	Continuously variable transmission
DC	Direct Current
EHL	Elasto hydrodynamic lubricant
EMF	Electro motive force
EMSAP RVB-CVT	Electro-mechanical single acting pulley rubber v-belt continuously variable transmission
EV	Electric vehicles
FCEV	Fuel cell electric vehicles
HEV	Hybrid electric vehicles
I	Integral
ICE	Internal combustion engine
MPVB	Metal pushing v-belt
MT	Manual transmission
P	Proportional
PD	Proportional derivative
PI	Proportional integral
PID	Proportional integral derivative
RPM	Revolutions per minute
WTO	Wide-open throttle opening

CHAPTER 1

INTRODUCTION

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Over the past few decades, Automotive Transmission Technology has undergone several refinements, in order to meet the goals of increased vehicle performance and reduced exhaust emissions. One of the most promising technologies to have been introduced in the automotive market is the continuously variable transmission (CVT). CVT is a power transmission device, whose speed ratio can be varied continuously between two finite limits (Park, 2009).There are many kinds of CVT designs, each having their own characteristics, e.g. Belt CVT, Spherical CVT (Kim et al., 2002), Hydrostatic CVT (Lino et al., 2003; Kanphet et al., 2005), E-CVT (Miller, 2006), Toroidal CVT (Fuchs et al., 2002; Tanaka, 2003; Akehurst et al., 2006), Power-Split CVT (Mucino et al., 2001; Mantriota, 2001; 2005), Chain CVT, Milner CVT (Milner, 2002), Ball-Type Toroidal CVT (Belfiore, 2003), etc. However, among all of them, chain and belt types are the most commonly used CVTs in automotive applications (Zheng et al., 2011).

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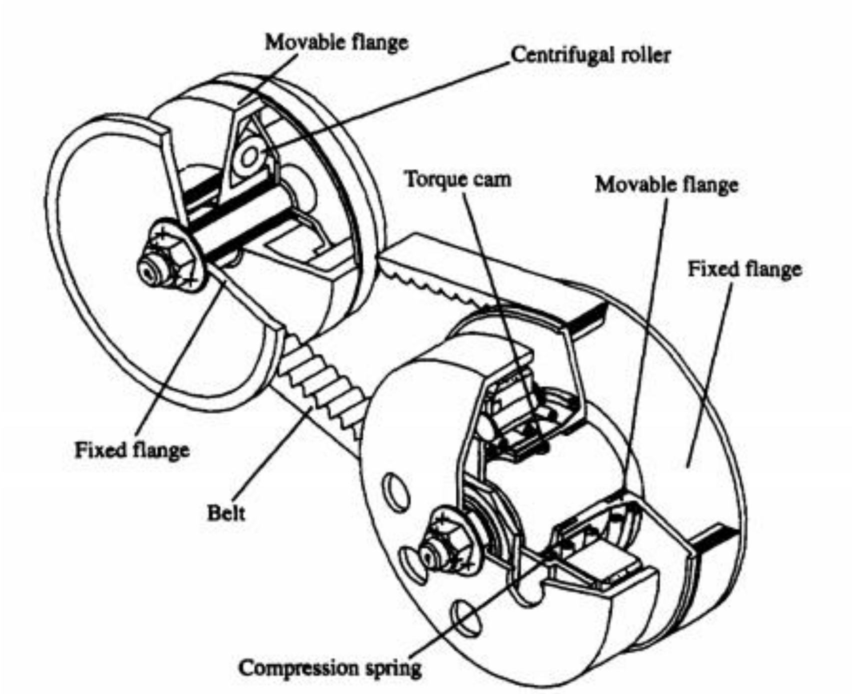

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The area of low-power rubber v-belt CVT research has received the most attention over the past several decades. It has been focused to better understand the changing belt radius, due to tension and axial compression differences along the contact arc, the variation of friction along the contact arc, and belt-pulley interaction, but it did not focus on overcoming centrifugal force. The present work is to design a new alternative actuator that replaces the centrifugal weights, cams, and return spring on the driver pulley, to allow the electro-mechanical actuation of the rubber v-belt CVT.

1.2 PROBLEM STATEMENTS

Rubber v-belt CVTs are usually actuated by centrifugal force. A key feature of the mechanically actuated CVT is that sensing, and actuation, is all contained within the components on the spinning shafts. Ultimately, the speed ratio of this CVT design depends on the design parameters, including the mass of the weights, the cam profiles, the rates of the springs, the belt tension, and the geometry of the output pulley cams (Manes, 2011).

The main purpose of the centrifugal force is to press the belt and to provide an adequate up-shift force. In actual fact, the centrifugal force generated by the flyweight would surely over stretch and destroy the belt. Operation scrubbing power must be passed by the CVT clutch. Most of the centrifugal force transfers the scrubbing operation to the clutch structure, but not to the belt (Xinetal, 2011).

In this work, a new alternative actuator, such as an electro-mechanically actuated CVT, is proposed to overcome the centrifugal force, by replacing the centrifugal weights, cams, and return spring on the driver pulley.

1.3 OBJECTIVE OF THE RESEARCH

The main objectives of this research are stated as follows:

1. To design a new actuated Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT).
2. To simulate the axial position of the primary pulleys of an Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT) using a Proportional, Integral and Derivative (PID) controller.

1.4 SCOPE OF THE RESEARCH

The following are the scopes of the study:

i. Design & drawing the conceptual components of the drive & driven pulley, also the cam mechanism using Solidworks software.
ii. Simulation on the controlling ratio of the Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT) Matlab Software.
iii. Calculate the gear ratio that is produced from the CVT design.
iv. Determine the effective position of the DC motor so that it can move the pulley to the desired gear ratio.

1.5 METHODOLOGY

This research covers the design and simulation works on controlling the ratio of the Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT) system. The simulation part will deal with the modelling of the EMSAP CVT and by determining the PID control scheme. The flow chart of the research methodology is shown in Figure 1.2 and can be briefly described as follows:

In the literature review, it describes some technical details when comparing the advantages over conventional technologies and these will be highlighted. A review of the relevant research on CVTs and belts will also be included. Furthermore, presented are the inherit weaknesses and areas where improvements in design may lead to an increased viability of CVTs.

Designing Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT) is done after the data requirements are accomplished. Solidworks software is used in drawing the details of the EMSAP RVB-CVT. Simulation using Matlab and Simulink software is used to determine the CVT ratio obtained, in addition to getting the response of the design that has been created. The movement of the pulley, to generate the transmission ratio, is controlled using the electro-mechanical linkage.

Simulation of the EMSAP RVB-CVT ratio control is conducted. The EMSAP RVB-CVT model is developed by combining the DC motor model and the mechanical system model. Modelling of the EMSAP RVB-CVT is initiated by modelling the DC motor followed by modelling the mechanical system, which consists of the gear reducers and the cam mechanism. PID parameter tuning is required to achieve the desired result of the transmission ratio.

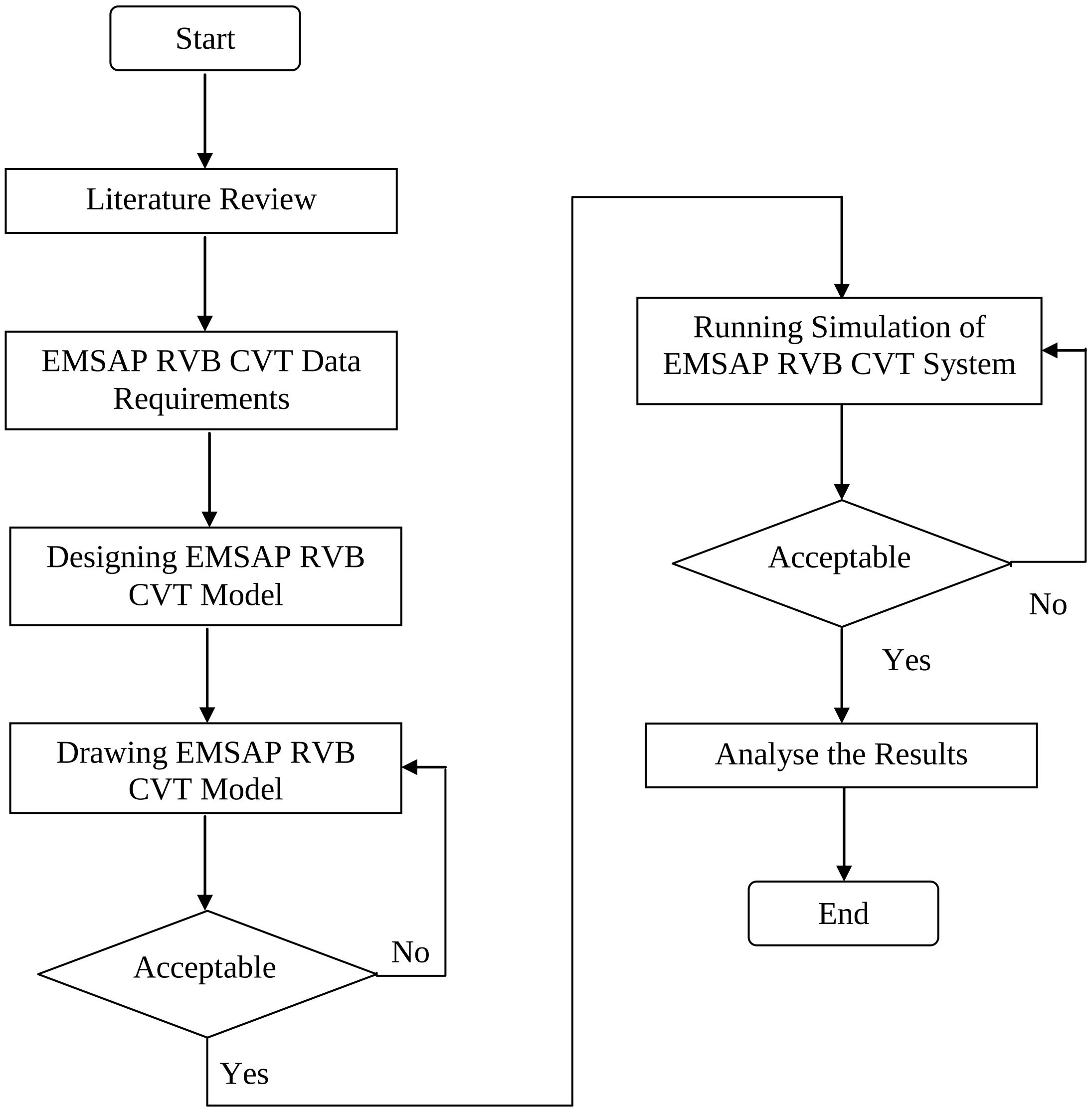

Figure 1.2: Flow chart of research methodology

1.6 SIGNIFICANCE OF THE STUDY

This research significance is to bring an alternative new design for the low power of the rubber v-belt CVTs. Therefore, a cheap and small dimension of the EMSAP RVB CVT can be implemented on a scooter/motorcycle.

1.7 THESIS STRUCTURE

In the current chapter, the background, the problem statement, the objectives, the scope, methodology and significance of the study of this thesis are outlined.

Chapter 2 presents a review of the existing work that has been undertaken in the field of this research. Literature reviews consist of the basic principles of CVT, the basic principles of EMSAP RVB-CVT, PID control methods, relay feedback methods, the DC motor, the gear reducer and the power cam mechanism.

Chapter 3 presents the EMSAP RVB-CVT block diagrams, the detail of CVT components; the DC motor, the train gears, the cam mechanism, the cam and moveable pulley, the driven pulley and the spring driven pulley. This chapter also describes the CVT ratio and the force of the cam relative to the rpm of the driver pulley.

Chapter 4 presents the simulating CVT ratio controller, and both the EMSAP RVB-CVT and the PID controller models will be combined, resulting in a close loop system. This close loop system will be simulated using Matlab and Simulink software by using its block diagrams. A variable input signal will be used to test the system's performance.

Chapter 5 presents the conclusions of the work undertaken. The conclusion explains the answer to the question in the problem statement, the objectives, the results and a discussion on this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 CURRENT STATE OF THE ART

Energy supply and pollution emissions have become major issues because of the prevalence of automotive transportation, leading to forecasts of oil shortages and price increases. The use of Internal Combustion Engines (ICE) in transportation also increases pollution emissions, which must be prevented to maintain the quality and viability of life on Earth. Much of the research conducted to gain economic advantage, increase efficiency and lower emissions, the concept of a conventional power train vehicle have shifted to Hybrid Electric Vehicles (HEV), Electric Vehicles (EV), and Fuel Cell Electric Vehicles (FCEV). To develop the efficiency of the power train, manual or automatic multilevel transmissions and CVTs have been developed to satisfy vehicle performance requirements and to advance ICE efficiencies. In the event that offers continuously variable gear ratio differences visible from Manual Transmission (MT) and the Automatic Transmission (AT) is no surprise shift, so that the high efficiency of its territory may be possible to operate.

Currently, the two standard designations in automotive transmissions are the manual and automatic transmission. These are established designs, which are common to almost any driver, but recent improvements in both technologies have blurred the line between the two systems in an effort to improve efficiency and the driver experience.

2.1.1 Manual Transmissions

The manual transmission is a system that is distinctive because of the driver's role in its operation; in this system, the driver undertakes the actuation force. The driver's right (or left) foot applies actuation force to the clutch while the left (or right) hand shifts between the gear ratios. There is a mechanical connection between the actuation elements of the clutch pedal, shift lever, and the transmission (Wagner, 2001). The driver is responsible for modulating the engine throttle in harmony with the clutch so that there is enough torque available for smooth transitions from a standing stop to motion, and the driver must select the proper gear ratio at a given vehicle speed for acceptable performance and economy.

The manual transmission system can be divided into two parts, the gearbox and the clutch. Inside of the most modern gearboxes, there are two parallel gear shafts that typically contain thirteen gears and four synchronizers. These gear shafts are supported across their length by three bearings. The gears are helical cut, and they are typically manufactured from high-strength steel and heat-treated to a RC 58 values (Kluger and Long, 1999). Designs with more or less forward gear ratios will only vary in the number of gears and synchronizers, as a significant increase in forward gear ratios would require another gear shaft. The clutch is interposed between the gearbox and the engine, and it serves two functions. The first function of the clutch is to allow the transmission and engine to be disconnected for the selection of a new gear ratio. The second function is to allow the driver to modulate the clutch so that the proper amount of torque is available for starting the vehicle from rest. This design is advantageous in that the driver can modify the shifting schedule so that the desired performance or economy is attained. The main disadvantage is that the power flow is interrupted during a gear shift when the clutch is engaged, which can hurt performance during hard acceleration (Wagner, 2001).

The manual transmission operates by passing power from the input shaft to a lay shaft, and then transmitting power from that lay shaft back to the output shaft. In this design, all of the gears stay in mesh and rotate at all times. Individual gears are locked to the output shaft by means of a splinted shift collar activated by the gearshift lever that changes the gear ratios. The resulting power path for this transmission starts from the engine, moves through the clutch into the input shaft, from the input shaft into the lay shaft, and then it moves from the lay shaft to the output shaft and into the differential. This path is used for all but the direct-drive fourth gear, where a 1:1 input to the output ratio exists. An average efficiency for the common five-speed manual transmission is 96 percent with a 3-5 percent increase in the direct-drive gear. Reducing the torque-dependent losses in the gears, reducing bearing losses, and minimizing the windage losses in the transmission case can increase the efficiency, but this increase would only be about one percent (Kluger and Long, 1999).

2.1.2 Automatic Transmissions

Automatic transmissions with multiple gear ratios are mechanical transmissions that shift on their own. The driver does not disengage the clutch to engage the driveline or select gear ratios with a gearshift lever. Because there is no clutch to engage, gear shifting occurs without an interruption of power through the driveline and these shifts are executed automatically with a shifting program in the transmission (Wagner, 2001).

The automatic transmission is divided into three main parts, the pump, torque converter, and gearbox. The pump is a driven accessory that pressurizes the transmission fluid to supply the torque converter and valve body. These pumps can be either crescent type, gear rotor, or hypocycloidal, with some manufacturers also moving toward variable displacement pumps to improve efficiency (Kluger and Long, 1999). The flow of electricity through the transmission is not interrupted by the automatic gear shifting due to the torque converter clutch to smooth the working fluid. The torque converter, like the clutch in a manual transmission, is also located between the engine and the gearbox. Most modern torque converters are based on the hydrokinetic type patented by Fottinger in 1905. In these torque converters, the drive shaft-mounted impeller imparts kinetic energy to a fluid, which is transferred to the driven turbine member (Fenton, 1996). At low engine speeds, the torque converter fluid coupling is not transferring much torque to the vehicle, and the vehicle can be held still with the brake pedal, while increasing engine speeds increase the torque output of the torque converter. The transmission can be shifted under power as this just changes the speed of the driven turbine in the fluid coupling. The gearbox in most common automatic transmissions uses epicyclical gears to shift between ratios. These gearshifts are accomplished through activating a combination of bands and internal clutches, which are operated by either a mechanical-hydraulic or electronic control system. The automatic transmission operates by passing power through the torque converter to the input shaft of the gearbox. This input shaft is then connected to the sun, ring, or planet carrier of a planetary gear set by means of bands and clutches that can connect, disconnect, or constrain these elements to produce multiple forward and reverse gear ratios. The control system of the automatic transmission must operate these bands and clutches sequentially in order to get the correct gear ratio for a given set of vehicular operating conditions. These control systems used to be purely mechanical and hydraulic, but microprocessor control systems are now the standard. Unlike the standard transmission, the automatic transmission has many components that require power to operate. The major sources for losses are in the pump and torque converter, and gearbox losses are comprised of gearbox windage, torque losses in the gear, bearing losses, and clutch pack drag. Variable displacement pumps and better design have minimized the pump losses, while torque converter losses can be reduced by installing a lockup clutch between the impeller and turbine. The gearbox losses can also be reduced through more thorough design of the individual components. The average mechanical efficiencies of modern five-speed automatic transmissions are around 85 percent, and further modifications to the current designs would only yield about a one-percent improvement in mechanical efficiency (Kluger and Long, 1999).

2.2 CONTINUOUSLY VARIABLE TRANSMISSIONS

A power device whose speed ratio can be varied in a continuous manner is often referred as a continuously variable transmission (CVT). A CVT transmits power without any abrupt changes in output torque and speed, and it has an infinite number of intermediate speed ratios between the bounds of its highest and lowest speed ratio (Singh and Nair, 1992). Even though automatic and manual transmissions still dominate the market for some time to come, CVTs will have an increasing presence in the

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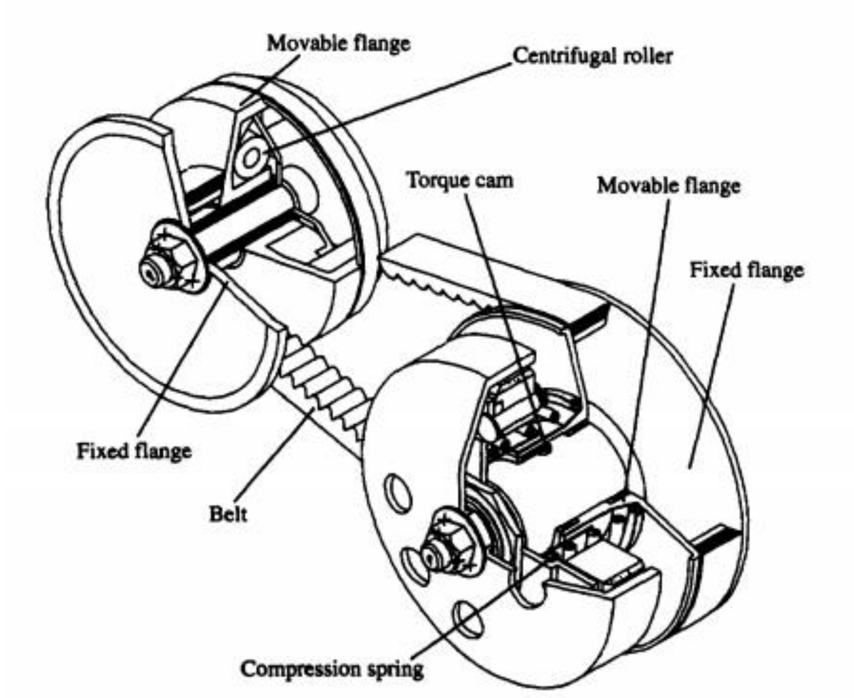

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CHAPTER 3

DESIGN OF AN ELECTRO-MECHANICAL SINGLE ACTING PULLEY RUBBER V-BELT CONTINUOUSLY VARIABLE TRANSMISSION

3.1 INTRODUCTION

This chapter explains and discusses a new design of the Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT); this system utilises a servomotor as an actuator. The EMSAP RVB-CVT system consists of two sets of pulleys; a pulley placed on the main input shaft that is fixed and is placed on the secondary pulley shaft and remains secondary. Each set has two pulley sheaves that move and that can slide axially along the shaft. A spring is inserted into the back of the secondary pulley sheave, to make continuous power available to the belt clamp, and to reduce excessive slippage during the change of the transmission ratio. It is a new CVT system which utilises the electro-mechanical concept. The EMSAP RVB-CVT structure is shown in Figure 3.1.

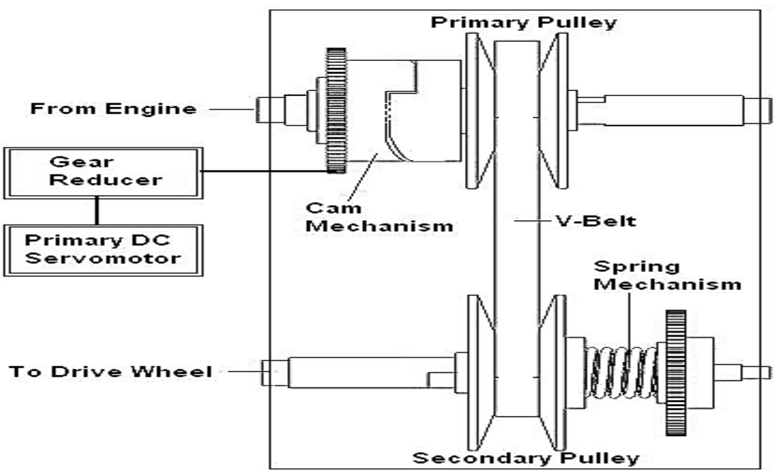

Figure 3.1: EMSAP CVT structure

3.2 GENERAL BLOCK DIAGRAM OF EMSAP

The mechanical model consists of a direct current (DC) motor, a gear reducer, a train gear and a power cam mechanism model. Figure 3.2 presents the mechanical block diagram of the EMSAP CVT. The DC is coupled to the motor shaft gear reducer input and the output ratio gear train is also connected. Then it is connected to the cam mechanism in order to move the pulley sheaves. Every one-degree movement of the axial position on the cam mechanism is converted.

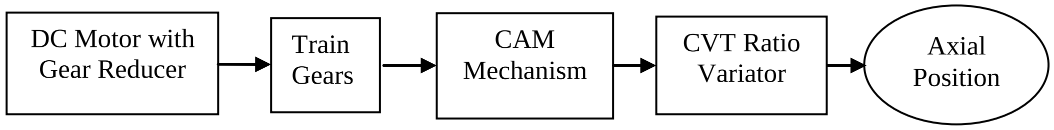

Figure 3.2: Block diagram of EMSAP

A detailed design of the Electro-Mechanical Single Acting Pulley Rubber V-Belt Continuously Variable Transmission (EMSAP RVB-CVT) is shown in Figure 3.3. The main criteria of the EMSAP RVB-CVT is that it was designed for a motorcycle with a 250 cc single cylinder engine, having a maximum torque of 53 Nm at 6,000 rpm. Friction between the V-Belt and the pulley is constant; also the tension of the belt remains constant. In the next sub-chapter, each part of the EMSAP RVB-CVT will be explained in more detail.

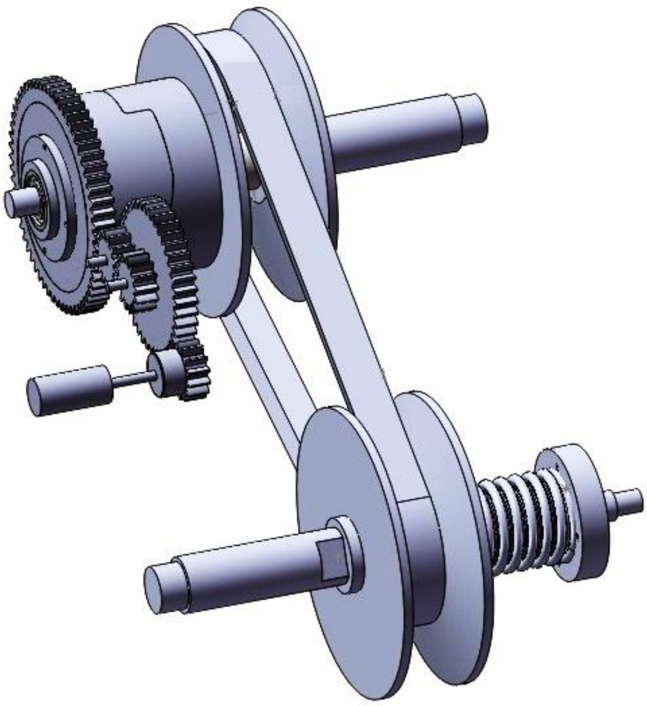

Figure 3.3: Detail of EMSAP RVB-CVT

3.3 THE EMSAP RVB-CVT COMPONENTS

3.3.1 The DC Motor

EMSAP CVT system utilizes DC motors as an actuator to move the sheaves of the primary pulleys axial through the cam mechanism. Utilizing DC motor has many advantages such as low voltage operation, easily to be controlled and linear performance (Killian and Thomas, 2000). Equivalent model between electrical and mechanical relationship is shown in Figure 3.4.