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ELCTRO-MECHANICALLY CONTROLLED CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM FOR PASSENGER CARS

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ABSTRACT

Electro-mechanically controlled continuously variable transmission (CVT) system is an automatic transmission system that can change the gear ratio to any arbitrary setting within the limits. This system includes an AC motor, set of power screw, an electromagnetic pick-up sensor, and two DC motors. Electromagnetic wheel speed sensor (WSS) generates the voltage with the travelling speed of the vehicle for operating the DC motor with a double acting magnetic pull-in solenoid switch. The function of power screw mechanism is for shifting movable sheaves axially along the shafts by the DC motor. Both the driving and driven pulleys' moving sheave move at the same time exactly the same linear distance but in opposite directions. The relationship between the DC motor speed and its response time to actuate the moveable sheave was studied. The response time is the time needed for the sheave to travel axially covering all of its stroke length. The response time was derived from motor rpm and its linear speed provided that the whole stroke length equals to 13.6 mm.

Keywords: Electromagnetic Sensor, Magnetic Pull-In Solenoid Switch, CVT.

1. INTRODUCTION

Predetermined gear ratio as is used in manual transmission obviously does not offer a good solution for all driving conditions of the vehicle [1]. Thus, CVT was introduced to replace the discrete gear ratio manual transmission system and it offers better fuel consumption [2]. The CVT is known as a transmission with literally infinite number of gear ratios which can work at optimal condition for different driving modes. In conventional hydraulic CVT, there is a slippage of the belt which causes loss of power and this behaviour is undesirable. The CVT requires constant force to clamp the belt and control the belt slippage. This results in continuous power consumption which contributes to the major loss to the hydraulic system and reducing its efficiency [3]. The present research is focused on the development of an electromagnetic pick-up sensor operated DC motor position control CVT to eliminate the problems faced by the existing CVT.

2. MATERIALS AND METHODS

This system includes an AC motor, set of power screw, an electromagnetic pick-up sensor, and two DC motors as shown in Figure 1. Each of the pulleys movable sheaves is operated by a DC motor in order to maintain the correct transmission ratio with the requirement of the driving torque of the car accompanied with electromagnetic pick-up sensor. Electromagnetic pick-up sensor produces the voltage with the travelling speed of the vehicle which operates the DC motor with a double acting magnetic pull-in solenoid switch. The function of power screw mechanisms is to shift movable sheaves axially along the shafts by the DC motor. Both movable pulley sheaves move at the same time exactly the same linear distance but in the opposite direction. The system activates only when the transmission ratio change occurs which consume less power compared to the conventional hydraulic CVT [4]. The power screw mechanism makes sure that the pulley is held at its place when there is no changing in gear ratio. No work is extracted from the DC motor during this time. Indeed, it is one of the ideal characteristics for a CVT system. In order to demonstrate the working principle of the proposed CVT system, several designs and components selection were made. The stroke length of the moveable sheave, the driving motor torque and power, torque required to move the moveable sheave were estimated by accounting the vehicle load, travelling speed, tires size, wheelbase, and the location of the CG. A simple pulse width modulation (PWM) was used to control the DC motor speed as it eliminates the heat and the wasted power of the motor and it drives the motor with short pulses. Figure 2 shows the 3-D model of the proposed CVT.

An AC motor is used to drive the system as it replaces the engine in the actual car. While selecting the motor, important characteristics such as the torque and the motor speed are taken into consideration. To find the minimum torque required by the AC motor to run the whole system, components that are linked through the motor up to the wheel are weighted. The secondary pulley shaft is connected with axle shaft through 3:1 straight bevel gear.

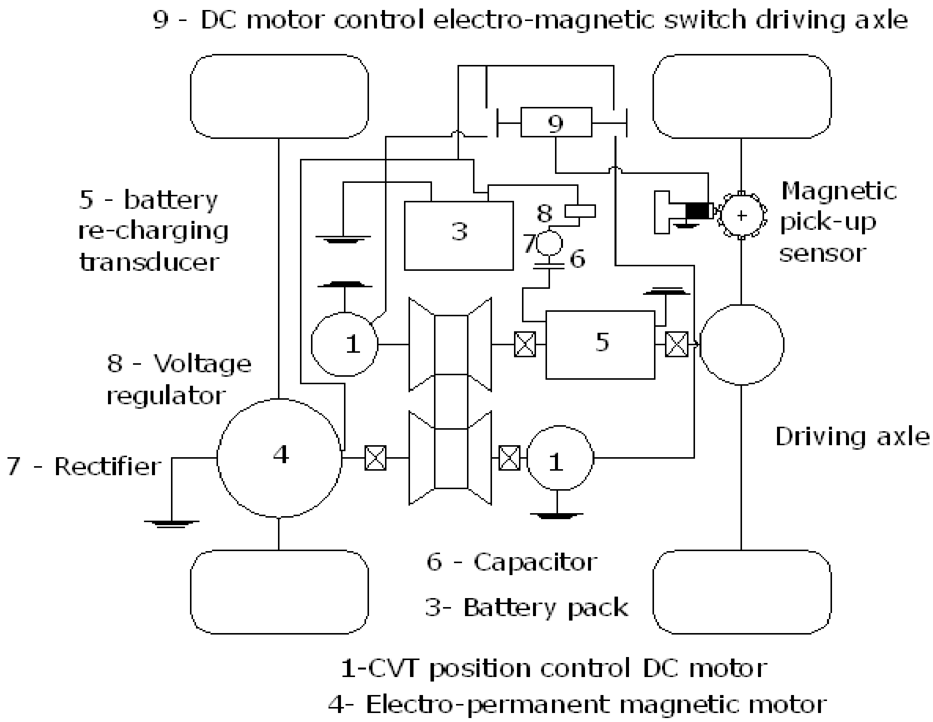

Fig 1. Schematic Diagram of the DC Motor Position Control CVT

Axle shaft's moment of inertia:

$$J_1 = \frac{m_1 R^2}{2} \tag{1}$$

Secondary pulley shaft's moment of inertia:

$$J_2 = \frac{m_2 R^2}{2} \tag{2}$$

Primary pulley shaft's moment of inertia:

$$J_3 = \frac{m_3 R^2}{2} \tag{3}$$

where, R is the radius of the shaft in m, m_1, m_2, m_3 are the masses of the shaft of driving axle, secondary pulley shaft, and primary pulley shaft in kN, respectively.
The motor torque can be computed by using the equation, $T = J_{total}\alpha$, where J_{total} is the total moment of inertia in kg.m^2[5]. Figure 3 shows the drive pulley. Axial movement of the pulley sheaves is controlled electromechanically. The centrifugal rollers or known as roller weight will be thrown outward by centrifugal force when the pulley is rotating. A roller back contact plane also known as the ramp plate guides the centrifugal rollers so that they will move toward the fixed sheave. As a result, an axial force derived from the centrifugal force pushes the moveable sheave and changes the gear ratio. The clamping force of the pulley can be computed by using the equation of Sheu *et al.*(1999) [6]:

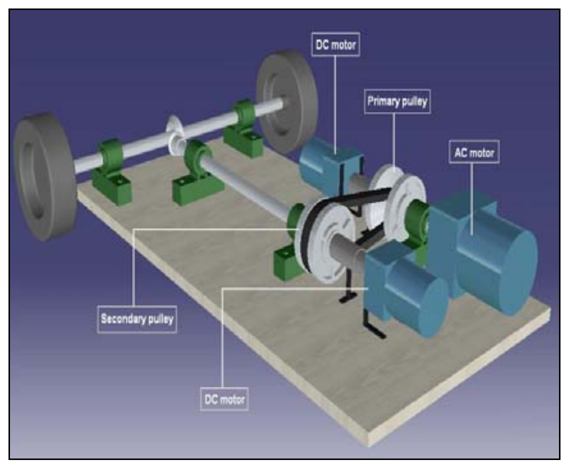

Fig 2. 3-D Model of the Proposed CVT

$$F_d = \frac{m y_m \omega^2}{\left(\frac{\cos\gamma + \mu_c \sin\gamma}{\sin\gamma + \mu_c \cos\gamma}\right) + \left(\frac{\sin\delta + \mu_b \sin\delta}{\cos\delta + \mu_b \sin\delta}\right)} \tag{4}$$

where, F_d is the axial force of the moveable flange, R_c is the normal force exerted by the roller housing in kN, y_m distance between the center of the roller and shaft centerline, δ is the angle between the roller contact plate and a line perpendicular to the shaft center, ω is the input angular velocity, μ_b and μ_c are the coefficient of friction between the roller and roller contact plane, and between the roller and roller housing, respectively.

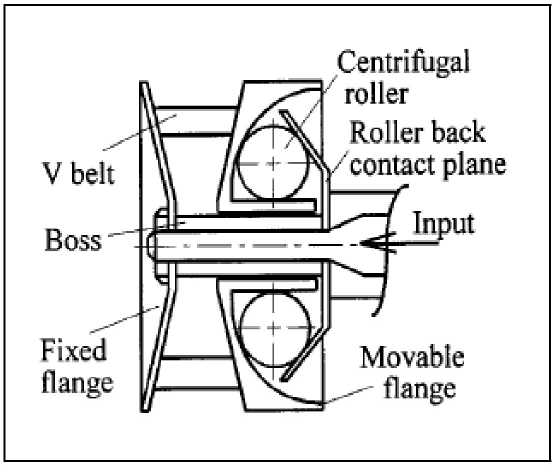

Fig 3. Drive Pulley [6]

Lead screw mechanism for each of the pulleys is developed with a set of nut and a DC motor which moves the movable sheaves of the pulley in correct time for maintaining the desired torque or transmission ration of the CVT. The diameter of the thread is selected based on the pulley's geometrical constraint. The minimum diameter of the sleeve must be slightly greater than the nut that secures the pulleys on the splined shaft. Torque required to drive the screw can be computed by using the equation of [6];

$$T_u = \frac{FD_p}{2}\left[\frac{\cos\phi\tan\lambda + f}{\cos\phi - f\tan\lambda}\right] \quad (5)$$

$$T_d = \frac{FD_p}{2}\left[\frac{f - \cos\phi\tan\lambda}{\cos\phi + f\tan\lambda}\right] \quad (6)$$

where, $\lambda = \tan^{-1}\frac{L}{\pi D_p}$, λ is the lead angle, f is the coefficient of friction, ϕ is the thread angle, L is the lead and D_p is the minimum pitch diameter, T_u and T_d are the raise and lower torque, respectively.

The simple pulse width modulation (PWM) was used to control the DC motor speed as it eliminates the heat and the wasted power of the motor and it drives the motor with short pulses. These pulses vary in duration to change the speed of the motor. The longer the pulses, the faster the motor turns, and vice versa. It is due to the fact that most of the available DC motor in the market already posses speed of more than 1000rpm. In this application, the DC motor speed should not be very high because it leads to the abrupt changing of the gear. It is undesirable as it can bring uncomfortable feeling for the driver and passengers of the vehicle. Lowering the DC motor speed is possible in many ways. Basic concept behind it is by varying the supply voltage. Since H-Bridge circuit have already been used, the common practice is to implement another method namely PWM (Pulse-Width Modulation) used to control the speed of DC motor.

The circuit consists of variable resistor, diode, resistor, capacitor and integrated circuit (IC). Figure 4 shows the completed circuit for controlling the speed of two DC motor. Using this circuit, speed in simply controlled by varying the resistance value through the variable resistor. This will only done once to make sure the speed of the DC motor is constant along the operation. Both DC motor should run at the same speed to maintain the belt tension. Any difference in speed may result in power loss and therefore the efficiency of the system might reduce.

Due to the positioning of the pulley, the rotation of the motors needs to be opposing each other so that if one pulley diameter is increasing, the other should be decreasing at the same rate and vice versa. By doing this

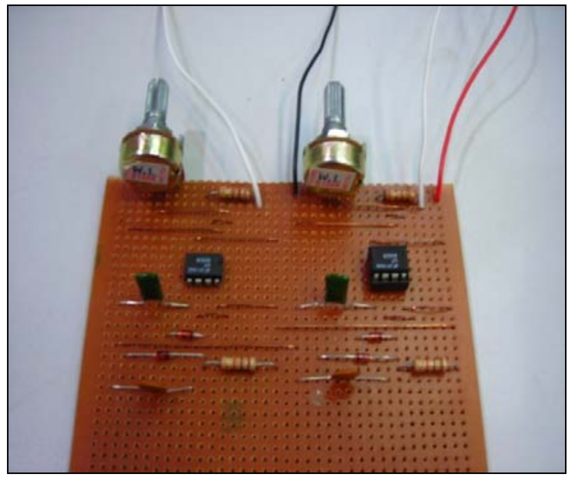

Fig 4. PWM Circuit for 2 DC Motors

gear ratio changing is made possible and belt tension can be maintained all the time. To achieve this, an integrated circuit H-bridge was used. Figure 5 shows the H-bridge circuit consists of only L293B integrated

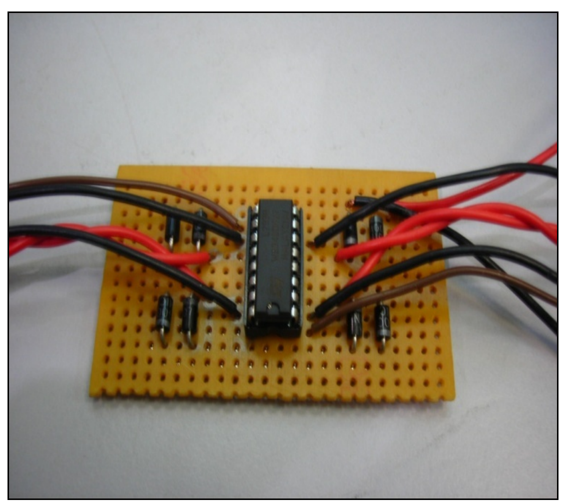

Fig 5. H-Bridge Circuit

circuit and diodes. Components on the right side of the diode are used to control one DC motor while the left side components are for another motor. This is the common method used in most of the automation strategy in controlling the direction of rotation of the motor. Both motors could either rotate in the same or in the opposite direction by changing the polarity.

Figure 6 shows the developed electromagnetic pick-up sensor operated DC motor position control CVT system. This system includes a pair of pulleys, DC motors, main AC motor, a DC battery, PWM circuit and H bridge circuit. After testing with different loading conditions it was found that the system is effective for transferring the power to the driving wheel in any operating condition of the vehicle.

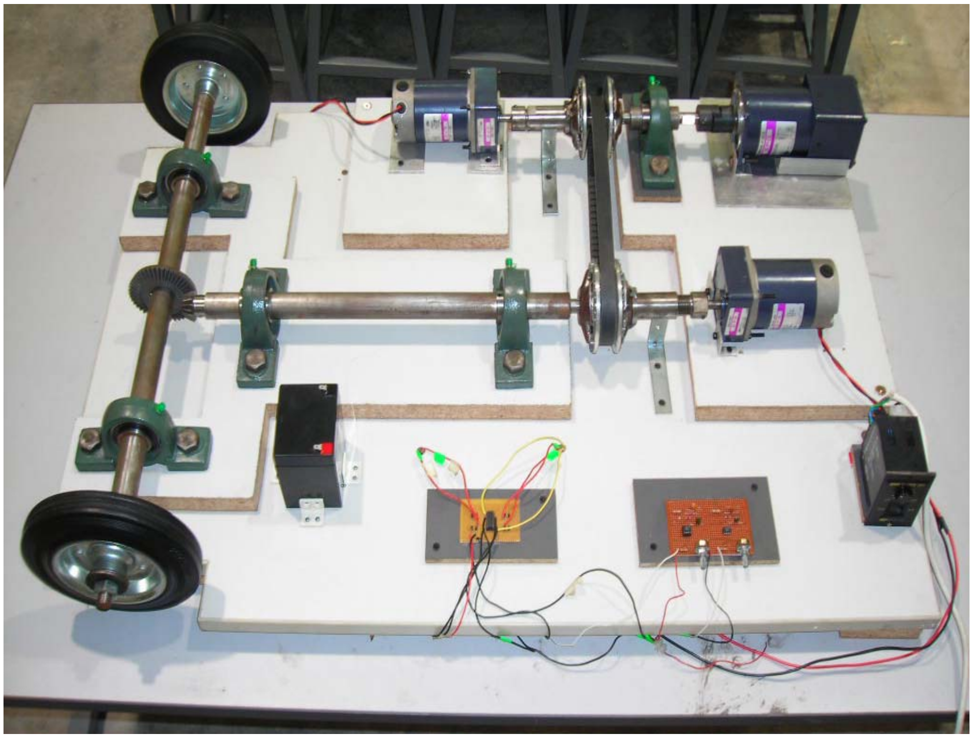

Fig 6. Developed CVT System

3. RESULTS AND DISCUSSION

Figure 7 shows the relationship of the linear speed of the sheave and the rotation speed of the DC motor with the developed IC control circuit.

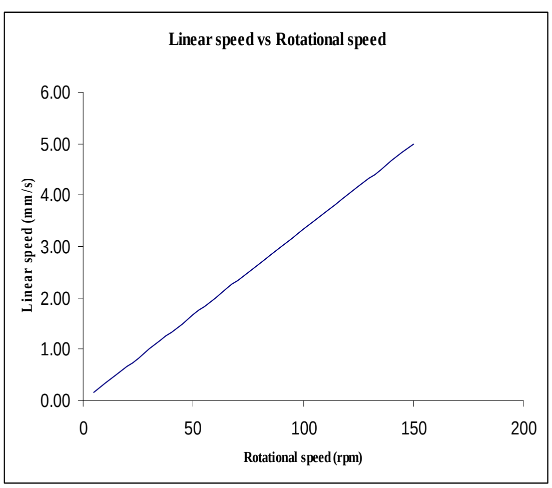

Fig 7. The Relationship Between Linear Speed of the Sheave and Rotational Speed of DC Motor

The speed of both driving and driven shaft is measured for every 2 mm increment of the stroke length which equals to one complete revolution of power screw. The gear ratio can be calculated by dividing the input speed by the output speed. The gear ratio varies from 1.29 up to 2.06 only. The result of the test is represented by Figure 8. All of the torque values are calculated based on gear ratio.

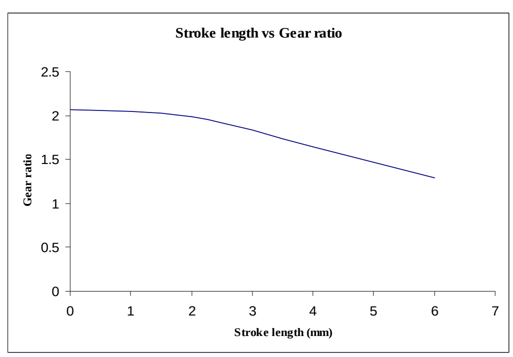

Fig 8. The relationship of the power screw stroke length and the transmission gear ratio.

The relationship between the DC motor speed and its response time to actuate the moveable sheave was studied. The response time here is the time needed for the sheave to travel axially covering all of its stroke length. Theoretically, high DC motor speed result in low response time. The response time was derived from motor rpm and its linear speed providing that the whole stroke length equals to 13.6mm.

Figure 9 shows the relationship between the torque of the shaft and the transmission gear ratio. Result showed that the small increment to the input torque will result in large decrement of the axle torque. This is because of the underpowered driving motor. It can be concluded that the graph of torque and gear ratio is linearly related unless the over clamping problem arise. Small adjustment is needed to be made to the primary pulley sheave which result in small difference in the stroke length of primary pulley and secondary pulley. Figure 10 shows the relationship of the AC motor speed and the actuator speed.

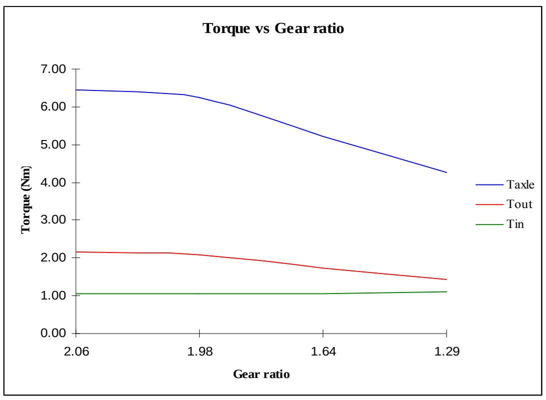

Fig 9. The Relationship Between Torque and Gear Ratio

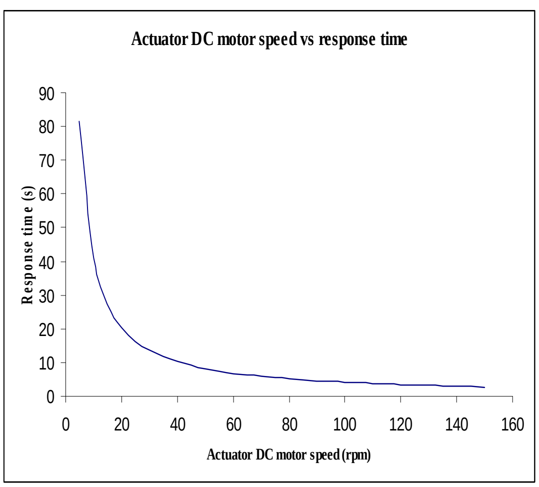

Fig 10. The Relationship of the DC Motor Speed and the Actuator Speed.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were made based on the content of this paper:

1. Transmission ratio of the CVT is changed to maintain the desired driving torque of the vehicle with the DC motor actuator and the developed power screw mechanism.
2. DC motor speed and rotation can be easily controlled using PWM and H-bridge circuit respectively.
3. The proposed electromechanical CVT system can eliminate the complexity of hydraulic system.

Several recommendations can be made to improve this electromechanical-actuated CVT. The DC motor could be replaced with stepper motor as it has the capability to move the moveable sheave precisely. Furthermore, it can hold torque better than the conventional DC motor. To continue the development of this project, the driving motor should be replaced with a higher powered motor so that CVT can demonstrate its full capability. In addition, the ratio controlling mechanism can be automatically controlled by employing fuzzy logic controlled PID with magnetic pick-up sensors.

5. REFERENCES

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6. NOMENCLATURE

Symbol	Meaning	Unit
J_1	Axle shaft's moment of inertia	$(kg.m^2)$
J_2	Secondary pulley shaft's moment of inertia	$(kg.m^2)$
J_3	Primary pulley shaft's moment of inertia	$(kg.m^2)$
m_1	Mass of drive axle shaft	(kN)
m_2	Mass of secondary pulley shaft	(kN)
m_3	Mass of primary pulley shaft	(kN)
R	Radius of the shaft	(m)
T	Torque	(kN.m)
F_d	Axial force of the movable flange	(kN)
μ_b	Coefficient of friction between the roller and roller contact	
μ_c	Coefficient of friction between the roller and roller contact plane	
R_c	Normal force	kN
λ	Lead angle	°degree
ϕ	Thread angle	°degree
L	Lead	m
D_p	Minimum pitch diameter	m
ω	Angular velocity	rad/s
y_m	Distance	m
δ	Angle	°degree

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