Development of an Efficient CVT using Electromecanical System

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***Abstract*—**Continuously variable transmission (CVT) is a type of automatic transmission that can change the gear ratio to any arbitrary setting within the limits. The most common type of CVT operates on a pulley system that allows an infinite variability between highest and lowest gears with no discrete steps. However, the current CVT system with hydraulic actuation method suffers from the power loss. It needs continuous force for the pulley to clamp the belt and hold the torque resulting in large amount of energy consumption. This study focused on the development of an electromechanical actuated control CVT to eliminate the problem that faced by the existing CVT. It is conducted with several steps; computing and selecting the appropriate sizing for stroke length, lead screw system and etc. From the visual observation it was found that the CVT system of this research is satisfactory.

***Keywords*—**CVT, Hydraulic Actuator, Discrete shifts, Electromechanical system, Lead screws.

I. Introduction

A continuously variable transmission (CVT) is a type of automatic transmission that can change the gear ratio to any arbitrary setting within the limits. The CVT is not constrained to a small number of gear ratios, such as the 4 to 6 forward ratios in typical automotive transmissions. The most common type of CVT operates on an ingenious pulley system that allows an infinite variability between highest and lowest gears with no discrete steps or shifts. CVT-automatic transmission system is desirable because it can eliminate few of the problem faces by the conventional CVT [1]. In this research we are focusing on developing a pulley-based CVT system where the ratio control is done by using electromechanical system. Researches and development of CVT has been done since 1940 searching for the best method of actuation. It is first conceptualized by Leonardo Da Vinci more than 500 years ago and is now it starts replacing planetary automatic transmissions in some automobiles. Indeed, ever since the first toroidal CVT patent was filed in 1886, the technology has been refined and improved. Today, several car manufacturers, including General Motors, Audi, Honda and Nissan, are designing their drivetrains around CVTs [3]

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II. Methodology

One approach of changing the CVT ratio is by using an electromechanical actuator. This includes a set of power screw and a DC motor for each pulley. The function of power screw mechanisms is for shifting movable sheaves axially along the shafts. For this system to function effectively the primary motor is responsible for changing transmission ratio and the secondary motor is for controlling the belt slippage. The system only operates during the transmission ratio changing which consume less power compared to the conventional hydraulic CVT. The power screw mechanism makes sure that the pulley is held at its place when there is no gear ratio changing.

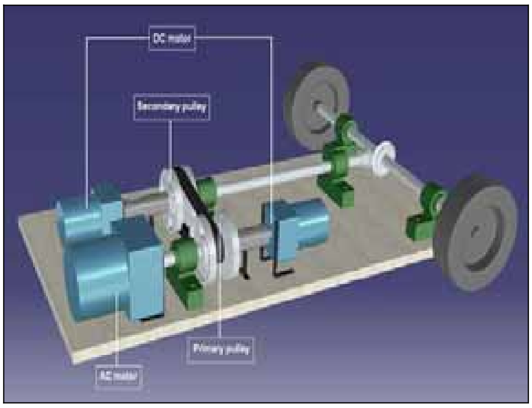

Fig. 1 Proposed CVT system

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 design and components selection were made. The main components of the system are AC motor to drive the whole system, DC motors and lead screws [2]. The calculations needed are stroke length of the moveable sheave, the driving motor specifications such as required torque and power, torque required to move the moveable sheave and lastly DC motor specifications to drive the power screw.

In this project, a set of pulleys were modified from a scooter. Therefore the stroke length is taken from the sheave dimension.

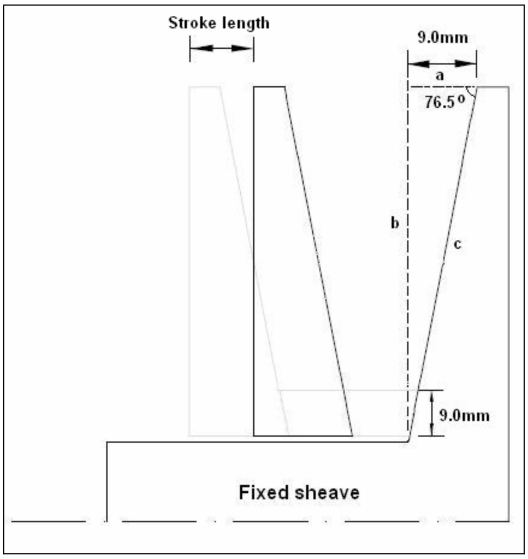

Fig. 2 Geometry of pulley

$$\tan 76.5° = \frac{b}{9.0}$$

$$b = 9.0(\tan 76.5°)$$

$$b = 37.5mm$$

The vertical distance traveled by the belt equals to 28.5mm.

$$\Delta x = \frac{28.5}{\tan 76.5°}$$

$$\Delta x = 6.8mm$$

Therefore the stroke length should be twice the Δx , which is 13.6mm.

III. Fabrication and Assembly

A simple model of rear wheel drive vehicle was built to visualize the working principle of the proposed CVT. The model is a simplified model since various components in actual vehicle is eliminated such as clutch, multi-stages gear reduction, differential and torque converter.

Instead of using steel frame, a flat wooden board was opted. It is a low cost material compared to the steel. Also, any adjustment can be easily made on this wooden board. For example, drilling through hole to secure the bolt and nut can be done faster and safer.

Assembly of the system was done stage by stage. Axle shaft together with the wheel was first attached to the pillow block and connected to the transmission shaft through straight-bevel gears with 3:1 gear ratio. Another end of the transmission output shaft is connected to the driven CVT pulley and DC motor which control the positioning of the movable sheave of the pulley. Both of the DC motors are placed crossing on each other as well as the moveable sheaves because it can minimize the belt misalignment. Instead of placing the DC motors adjacent to each other, they were placed opposing to one another. The same goes to their rotation in controlling the ratio. If one motor rotates clockwise, another motor should rotate the other way around in order for the ratio changing mechanism works properly.

AC motor was chosen over the DC motor to drive the whole system due to its higher rated torque. Meanwhile DC motor was chosen as the actuator because the direction of rotation can be simply switched by implementing H-bridge circuit. In actual driveline, multi-stages gear reduction is commonly used but in this project, only a reduction of 3:1 is being used to avoid the complexity and to decrease the loss of the system by means of mechanical loss. Solid steel shaft was being used rather than hollow shaft for simplification though it is generally known that hollow shaft can withstand high torsional load.

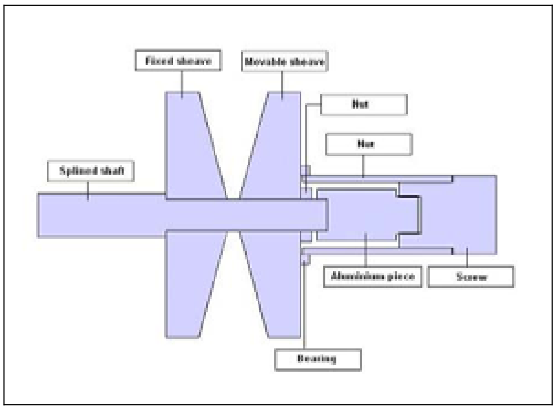

Fig. 3 Sectioned view of pulley assembly

Using the aluminum pulley means that force applied from the belt to the pulley should be minimize, therefore using rubber belt is the best choice for effective mechanical power transmission considering the limited allocated budget. However, it is important to mention that rubber belt is less effective than metal belt that is commonly used in commercial CVT application due to its slippage behavior[4]. The availability and higher price of both metal CVT pulley and belt become the limitation of the first conceptual design and therefore the only applicable choice is to do a modification to an existing set of CVT.

IV. Result Analysis

A few tests were done on the system to get some data to be analyzed. The best method for the testing is to use the test rig which includes the torque sensors and computerized sensors. However for this project, non-contact tachometer was used to measure the speed of the driving and driven shaft. A reflective tape was stick to the shaft while infrared pointer pointed to directly to the place where the tape was stick. The speed of the shaft is basically calculated by the device as every reflected infrared light toward its sensor. Fig. 4 demonstrates how the reading was taken on the rotating shaft.

Fig. 4 Using of tachometer to obtain shaft speed

Graphs were plotted from the test data. The speed of both driving and driven shaft is measured for every 2mm increment of the stroke length which equals to one complete revolution of power screw. The data is taken discretely because of the problem with actuator controller. The values fluctuate and the assumption for its average is taken as the data. However, the pattern of the gear ratio changing was obtained. 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.

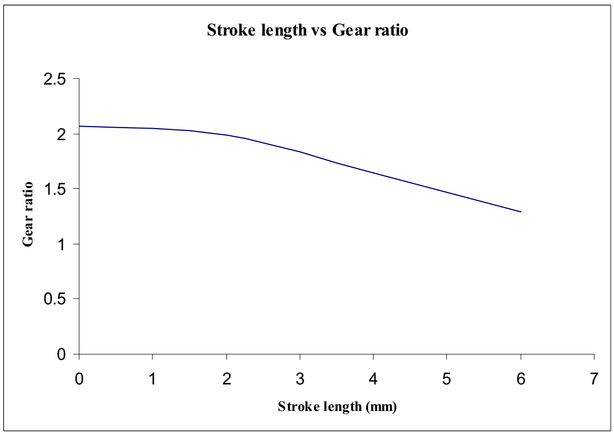

Fig. 5 Relation of the stroke length with the gear ratio

For the first 2mm of the stoke length, there is only a slight decrement in the gear ratio due to the over clamping behavior of the belt. The secondary actuator or lead screw has to be adjusted so that the belt is not too tight. In this stage, any stroke length of the primary actuator will not result in the same stroke length for secondary actuator. Then the graph behaves linearly starting from the stroke length of 3mm. Unfortunately, the data can be obtained up to 6mm of the stroke length. This is caused by the underpowered driving motor and some losses due to the misalignment of the components. Using higher power motor should overcome this problem but higher power motor will cost more. Therefore as long as the driving motor can demonstrate part of the operation, it should be sufficient enough to support the theory.

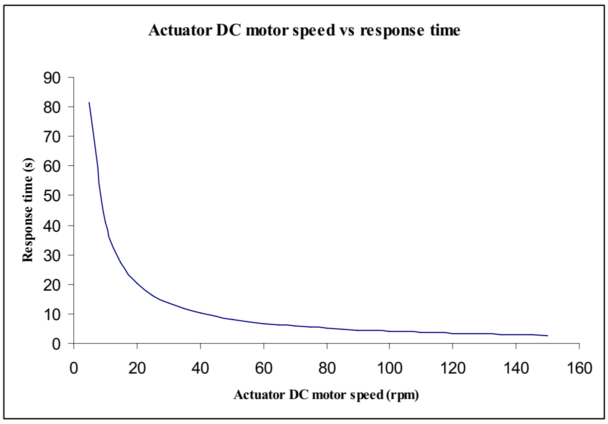

Fig. 6 Ratio changing response time with respect to DC motor speed

The relation 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 will result in low response time. The response time can be derived from motor rpm and its linear speed provided that the whole stroke length equals to 13.6mm

Response time should be controlled based on input such as the change in throttle position. High response time can be pictured in one of the driving conditions. A rapid change in throttle position will be translated as a need of acceleration by the driver. In this case, the gear ratio must be changed so that high torque can be developed. If the DC motor speed is low, it will take too long for pulleys to be positioned in the appropriate gear ratio. Thus the DC motor should be adjusted to a higher speed for this situation. Therefore high response time will give the desired output [5].

V. Recommendation

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.

VI. Conclusion

It can be truly said that the project were able to meet the objective that is to fabricate a CVT employing electromechanical system as the actuator or the ratio controlling mechanism. The result that obtains from the test is satisfactory. From the entire project, it can be concluded that;

1. Using DC motor to control the ratio changes of CVT is possible by implementation of power screw mechanism.
2. DC motor speed and rotation can be easily control using PWM and H-bridge circuit respectively.
3. The proposed electromechanical CVT system can eliminate the complexity of hydraulic system.

To make the project complete and impressive, further developments are needed to make sure that the system can run smoothly and finally it can be commercialized in today's competitive automotive market.

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