Experimental study of transmission ratio changing mechanism for motorcycle applications

B Supriyo¹*, S Ariyono², S Sihono³, B Sumiyarso² and B Tjahyono³

¹ Magister Terapan Teknik, Politeknik Negeri Semarang, Semarang, Indonesia
² Program Studi Teknik Mesin, Politeknik Negeri Semarang, Semarang, Indonesia
³ Program Studi Teknik Elektronika, Politeknik Negeri Semarang, Semarang, Indonesia

*bsupriyo2015@polines.ac.id

Abstract. Transmission ratio change in today’s motor cycle rubber belt Continuously Variable Transmission (CVT) are based on centrifugal forces resulted from engine revolution. Compare to manual transmission, this kind of CVT needs higher engine revolution to start engaging the transmission ratio which in turn requiring more fuel consumption. A transmission ratio change concept based on an Electro-mechanical actuator consisting of cam, actuator gears and DC motor has been developed to eliminate the dependency of transmission ratio on engine revolution. The DC motor rotates the cam through actuator gears. The rotation of the cam causes the primary movable pulley sheave to move in axial direction, which in turn changing the belt-pulley pitch radius and changing the transmission ratio. This research aims to design and implement an electronic measurement system based on Arduino Uno as a data acquisition system and Matlab/Simulink as a controller program to obtain the measurement data of primary pulley and secondary pulley speeds and primary pulley axial position. Based on these data, the transmission ratio can be determined and the relationship between transmission ratio and primary pulley position can then be obtained. For future development, these measurement data will be used as important references when developing and testing the transmission ratio controller programs.

1. Introduction

Gear boxes, also called automotive transmissions, play an important role in motorcycles or cars because they regulate both speed and torque on the drive wheels. One form of transmission that is now favored both on motorcycles and cars is Continuously Variable Transmission (CVT). The basic CVT system mainly consists of primary pulley (input), secondary pulley (output) and belt connecting both pulleys to transfer speed and torque from input to output pulley. A common CVT system has one movable pulley sheave in one side and one fixed pulley sheave in the other side, forming V-shape pulley. CVT has a good drivability, smooth gear shifting without jerking and easy to drive. But in general CVT still less efficient than manual transmission, because of some losses inherent in the CVT itself, such as transmission loss [1,2] and speed loss [3].

In the early period many CVTs used rubber belts in the form of simple bracelets and cone systems, such as those developed by the Dutch company, DAF, in 1958 [4]. However, DAF’s CVT was only able to be used on 0.6 L engines because heavy problems, noise and rough noise finally dropped its reputation [5]. In 1954, the Honda company introduced a mass production of Scooter to the market under the name Juno, a 0.175 liter engine scooter produced 8.8 kW [6]. Honda continued to produce small motorbikes with V-matic in 1977. Starting 1987 CVT system has been introduced for the first time in the market.
The current concepts of using centrifugal force systems on motorbikes and hydraulic force on sedan vehicles have not been able to adjust the transmission ratios accordingly so that the engine load is not at the optimum line [7-10]. In the centrifugal system, the transmission ratio of the CVT is governed by the centrifugal force caused by the engine rotation, while in the hydraulic system the ratio is regulated by control pattern through the hydraulic system. Another disadvantage in the hydraulic system is that the pulley moves to regulate the ratio of CVT which results in belt misalignment [11,12]. Both of these losses cause a decrease in efficiency of CVT hydraulics.

CVT is a transmission that is easy to operate both in a car and on a motorcycle. This transmission system is a very good transmission in improving fuel efficiency [13], since it is able to adjust the engine load on the optimum line if the transmission ratio is set properly. Several studies have been conducted to improve CVT efficiency, such as improving transmission mechanism and belt slip control [14], speed [3] and eliminating belt misalignment [15-17].

The transmission ratio changing mechanism for motorcycle application still uses the single actuated pulley movement concept, because the system still uses a flexible rubber belt, so that the rubber belt misalignment position in the middle of the two pulleys does not cause belt to easily break. This research will focus on the CVT transmission for motorcycle applications. It uses an electro-mechanical system consisting of DC motor as an actuator combined with a gear train set (called actuator gears) to move a cam mechanism attached to the primary moveable pulley sheave. This system is called Electro-Mechanical Single Actuated Rubber Belt CVT (EMSARB-CVT). The use of this cam is intended to axially move the primary movable pulley sheave such that the position of the belt contact point can move up or down on the surface of the pulley, changing the effective belt-pulley radius contact, hence changing the transmission ratio. In addition, the belt is clamped on the secondary pulley surface based on the spring force acting on the secondary movable pulley sheave, so that the belt can transfer speed and torque from the input pulley to the output pulley with no slip, then finally to the driving wheel of the motor cycle via the final gear drive.

This research will utilize Arduino Uno as a data acquisition system and Matlab/Simulink as a controller program to measure both primary and secondary pulley speeds, primary movable pulley position and compute the transmission ratio. Based on this data the relationship between transmission ratio and primary pulley position can be obtained.

2. Research materials and methods

2.1. Research materials

Research materials for this research consists of a mechanical set of electro-mechanical single actuated rubber belt CVT (EMSARB-CVT), primary pulley speed sensor, secondary pulley speed sensor, primary pulley position sensor, H-bridge DC motor driver, DC motor, Arduino Uno, 3 phase AC motor, 3-phase variable speed drive, computer with Matlab/Simulink program.

2.1.1. Mechanical set of EMSARB-CVT. The main parts of this mechanical of EMSARB-CVT consist of primary fixed pulley sheave, primary movable pulley sheave, primary shaft, secondary fixed pulley sheave, secondary movable pulley sheave, secondary shaft, secondary spring, rubber belt and cam mechanism with 4-gear train-set. The belt is placed and clamped inside the V-shape primary and secondary pulleys to transfer the speed and torque from the input (engine) to the output (wheel). The secondary spring makes sure that the belt always tights. For a basic CVT with fixed belt length and no belt-pulley slip, then the tangential velocity of both primary and secondary pulleys and belt are the same, such that the following (1) and (2) holds.

\[
\omega_p R_p = \omega_s R_s \quad (1)
\]

\[
\frac{\omega_p}{\omega_s} = \frac{R_s}{R_p} \quad (2)
\]

Where \( \omega_p \) is primary pulley angular speed, \( \omega_s \) secondary pulley angular speed, \( R_p \) primary belt-pulley contact radius and \( R_s \) secondary belt-pulley contact radius. If the transmission ratio \( (r_{cvt}) \) is determined based on primary and secondary pulley radii then it can be represented by (3). But if the transmission
ratio is determined based on primary and secondary pulley speeds then it can be represented as geometrical speed ratio \( r_{gs} \) by (4).

\[
rcvt = \frac{Rs}{Rp} \\
rgs = \frac{\omega_p}{\omega_s}
\]  

(3) 

(4)

When the primary pulley gap increases, the primary belt-pulley contact radius will decrease, then the secondary spring will push the secondary movable pulley sheave such that the secondary pulley gap will decrease, the secondary belt-pulley contact radius will increase, hence increasing transmission ratio and decreasing the speed of the secondary pulley shaft. Inversely, when the primary pulley gap decreases, the primary belt-pulley contact radius will increase, then the belt on the secondary pulley sheaves will slide inward and push the secondary movable pulley sheave away and push back the secondary spring such that the secondary pulley gap will increase, the secondary belt-pulley contact radius will decrease, hence decreasing transmission ratio and increasing the speed of the secondary pulley shaft.

In this test rig the engine is represented by 3-phase AC motor which drives the primary pulley via a standard belt-pulley mechanism and the secondary shaft (output) does not have any load. The transmission ratio of this CVT can be varied by changing the cam position which in turn changing the effective radius of belt-pulley contact of the primary pulley.

2.1.2. 3-Phase AC motor and Variable speed drive. The 3-phase AC motor represents the engine for this system rig. The shaft of this motor is connected to the primary shaft using a standard belt-pulley mechanism. The speed of this motor is regulated using a variable speed drive. In this experiment, the speed of the primary pulley shaft is maintained to about 1000 rpm.

2.1.3. DC motor and driver. This DC motor is used to rotate the actuator gears which turn the cam mechanism to axially move the primary movable pulley sheave, then changing the belt-pulley contact radius and finally changing the transmission ratio. This DC motor is controlled by PWM signal from a PWM pin Arduino Uno via the H-bridge DC motor driver.

2.1.4. Primary pulley position sensor. The primary pulley position sensor uses a 10-turn potentiometer to detect the rotational position of cam which also detects the axial position of the movable pulley and indirectly measures the primary belt-pulley effective contact radius. This primary pulley position measurement data is then correlated to the transmission ratio measurements derived from the speed measurements of both primary and secondary pulleys, using geometrical speed ratio equation in (4).

2.1.5. Speed sensors. There are two speed sensors based on 360 pulse/revolution (ppr) incremental encoders, namely the primary and the secondary speed sensors to detect the speeds (in rpm) of the primary and secondary pulley shafts. The number of pulse produced by each encoder for every one second time is converted to its respective angular speed in rpm. Based on these speeds, the real transmission ratio can be derived, in which using geometrical speed ratio equation in (4).

2.1.6. Arduino Uno. Arduino Uno is a very popular microcontroller board with inexpensive price and has good controller performance, especially for less complicated applications. The Arduino Uno is based on ATMega328, with 6 pins configurable for analog inputs and 14 digital input/output pins, in which 6 pins are configurable for pulse width modulation (PWM) outputs. Arduino Uno is used as a data acquisition system controlled by Matlab Simulink program via USB port to read the primary pulley position, to read primary and secondary shaft speeds and to drive the DC motor actuator for controlling the primary pulley position.

2.1.7. Computer. Computer is used as a main controller which is programmed using Matlab/Simulink to command the Arduino Uno via USB port to do the tasks of reading the primary pulley position,
reading both primary and secondary shaft speeds and driving the DC motor actuator for controlling the primary pulley position. Data from the readings are then processed and displayed as graphs.

![Electronic hardware diagram of EMSARB-CVT.](image)

**Figure 1.** Electronic hardware diagram of EMSARB-CVT.

(a) (b)

![Test rig (a). Top view (b). Side view.](image)

**Figure 2.** Test rig (a). Top view (b). Side view.

### 3. Research methods

The overall research method will cover:

- Literature study related to the basic concept of how to control the transmission ratios in CVT.
- Design and develop electronic circuits for speed sensors, position sensor, and DC motor Driver.
- Design and develop measurement program using Arduino and Matlab/Simulink programs.
- Testing of an electronic circuit consisting of an input pulley and output pulley speed sensors, as well as primary pulley position sensor.
- Software testing involves the Arduino Uno microcontroller hardware, as well as the Matlab/Simulink software installed on the computer to program the measurement process of the transmission ratio.
- Testing the system as a whole to do the simple task of achieving the actual transmission ratio according to the transmission ratio set point.
- Data collection of test results and discuss its performances related to primary and secondary pulley speeds, primary pulley position, and transmission ratio.
4. Results and discussion

4.1. Results

The results of these experiments consist of data measurements of primary pulley position, primary and secondary pulley angular speeds.

4.1.2. Relationship between transmission ratio and output voltage of primary pulley position sensor. The number of the DC motor shaft revolution is sensed using a multiturn potentiometer (10-rotation) acting as a position sensor which produces output voltage proportional to that of its respective number of revolutions. This motor shaft rotates the actuator gears which turn the cam and axially shift the movable primary pulley sheave, changing the belt-pulley contact radius hence changing transmission ratio. The actual transmission ratio is calculated based on the ratio between primary and secondary pulley speeds. The measurements of both primary and secondary pulley speeds are done using two rotary encoders attached on both pulley shafts. The graph of transmission ratio as a function of output voltage of position sensor can be seen in Fig. 3.

\[ y = 0.133x^2 - 1.275x + 4.13 \]

![Figure 3. Transmission ratio as a function of position sensor voltage.](image)

4.1.3. Relationship between secondary shaft speed and transmission ratio changes. If the transmission ratio is changed from about 3.0 (under drive) to 1.0 (1-to-1 ratio), as shown in Fig 4.a, then the output speed response from CVT gearbox (rpm out) with engine speed (rpm in) constant about 1000 rpm, can be seen in Fig 4.b.

![Figure 4. CVT gearbox response: a) changes in transmission ratio and b) changes in output speed.](image)
4.2. Discussions

Based on the graph in Fig 3, it can be seen that the relationship between the transmission ratio and the position sensor voltage is not linear but tends to be a second order polynomial. By using this polynomial equation, the actual value of the transmission ratio can be obtained by measuring the output voltage of the primary pulley position sensor. By monitoring this output voltage of the position sensor, the transmission ratio controller then can be developed to indirectly control the primary pulley position by actuating the DC motor as cam actuator, accordingly.

By setting a constant input speed of about 1000 rpm, the response speed of the output shaft of the CVT gearbox will change in accordance with the value of the transmission ratio. From Fig. 4. (a) and (b), it can be seen that for the lowest transmission ratio of 3.1, with an engine speed of 968 rpm, the output speed drops to 312 rpm. As for the highest transmission ratio of 1.1, with an engine speed of 935 rpm, the output speed drops to 860 rpm. From Fig. 4. (a), it can also be seen that the input speed (rpm in) which ideally should be constant for all values of the transmission ratio, it turns out that in practice it has gradually decreased slightly from 968 rpm (transmission ratio of 3.1) to 935 rpm (transmission ratio of 1.1). This is due to the increasing loading effect resulted from the increasing spring force exerted on output pulley sheaves, hence increasing the friction between rubber belt and both input and output pulley sheaves, especially when the output speed achieves its biggest value (transmission ratio of 1.1). In this case the AC motor used for power source representing engine does not have enough power to maintain a constant speed of 1000 rpm especially for transmission ratios of 1.1 which produces the highest output speed.

5. Conclusion

Experimental study of transmission ratio changing mechanism based on electro-mechanical rubber belt Continuously Variable Transmission on motorcycle has been carried out properly. The results show that the value of the transmission ratio can be indirectly obtained using a position sensor that uses a multiturn potentiometer (10-turn). The effective transmission ratio that can be detected is between 3.1 (lowest speed) to 1.1 (highest speed). The relationship between the transmission ratio and the position sensor output voltage is not linear, but it follows a second order polynomial equation. This equation is used to determine the value of the transmission ratio based on the output voltage of the primary pulley position sensor. The input speed (rpm in) of the CVT gearbox decreases gradually when the transmission ratio changes from 3.1 to 1.1 due to the increasing spring force exerted on the secondary pulley sheaves to clamp the rubber belt.

References

[1] Ide T 2000 Effect of belt loss and oil pump loss on the fuel economy of a vehicle with a metal V-belt CVT (No 2000-05-0130) (SAE Technical Paper)
[2] Akehurst S, Vaughan N D, Parker D A and Simner D 2004 Modelling of loss mechanisms in a pushing metal V-belt continuously variable transmission Part 1: torque losses due to band friction Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 218 1269-1281
[3] Balta B, Sonmez F O and Cengiz A 2015 Speed losses in V-ribbed belt drives Mechanism and Machine Theory 86 1-14
[4] Diepstraten J F P B 2007 Modeling of pulley based CVT systems: extension of the CMM model with bands-segment interaction
[5] Birch S 2000 Audi takes CVT from 15th century to 21st century Automotive Engineering International 1
[6] Casadesus-Masanell R and Heilbron J 2016 Decision-Making by Precedent and the Founding of American Honda (1948-1974) Harvard Business School Strategy Unit Working Paper (17-016)
[7] Song M, Oh J, Choi S, Kim Y and Kim H 2014 Optimal line pressure control for an automatic transmission-based parallel hybrid electric vehicle considering mode change and gear
Advances in Mechanical Engineering 6 216098

[8] Kazemi R and Raf’at M 2014 Nonlinear Optimal Control of Continuously Variable Transmission Powertrain International Scholarly Research Notices

[9] Jha S and Gandhi R A 2015 Continuously Variable Transmission Control Strategy Review International Journal of Engineering Research and Technology (IJERT) 4 1030-1034, 2015

[10] Alzuwayer B, Singh A, Muralidharan P and Han Z 2016 Model Based Pressure Control of a Push Belt Continuously Variable Transmission Modern Mechanical Engineering 6 99-112

[11] Tawi K B 1997 Investigation of belt misalignment effects on metal pushing v-belt continuously variable transmission (Doctoral dissertation, Cranfield University)

[12] Faye Z and Zhihong W 2009 Control study on the CVT metal V-belt's axial-misalignment of car In 2009 IEEE Intelligent Vehicles Symposium (pp 1389-1393) IEEE

[13] Tsuji T and Takeoka M 1996 Study of Fuel Consumption Improvement of the Car with the Dry Hybrid Belt CVT Society of Automotive Engineers of Japan JSAE Review 17 381-385

[14] Bonsen B 2006 Efficiency optimization of the push-belt CVT by variator slip control Dissertation Abstracts International 68

[15] Tawi K B, Husain N A, Kob M C, Supriyono B and Ariyono S 2012 Development of electro-mechanical actuation system for continuously variable transmissions in automotive applications In Prosiding Industrial Research Workshop and National Seminar 3 62-68

[16] Supriyo B, Tawi K B and Jamaluddin H 2013 Experimental study of an electro-mechanical CVT ratio controller International Journal of Automotive Technology 14 313-323

[17] Supriyo B, Tawi K B, Jamaluddin H and Hussein M 2014 Experimental Study of Electro-Mechanical Dual Acting Pulley Continuously Variable Transmission Ratio Calibration Jurnal Teknologi 71