To Optimise the Performance of Electric Powertrain by Tuning the CVT

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Abstract. There is desperate need to find an alternate power source to run the vehicles. This reasons leads to work on electric vehicles. In India, it has been noticed major part of urban air pollution is caused by auto rickshaw emissions as they are not maintained properly. So switching from conventional rickshaw to electric will significantly reduce this problem in urban areas. Continuously variable transmission (CVT) transfers power uninterrupted due to its infinite gear ratios. Moreover, it allows the motor to run at its optimum speed which ultimately reduces the current consumption. CVT available in current market is design to work efficiently with internal combustion engines. This CVT can be made compatible with pure electric power train by CVT tuning. This paper aims to study and analyses the effect on performance of CVT by varying the mass of flyweights. The driver and driven pulley RPM are measured using DAQ system. This data is then use to obtain gear ratio. The iterations are performed using two different mass of flyweights. The gear ratio verses pulley rpm graphs are compared. The result infers that as the flyweight mass is increase the engagement rpm decreases and up-shift rate increases. This enhances performance of CVT.

1. Introduction

One of the major reasons for urban pollution is vehicle emissions. Simultaneously the fossil fuel resources are also depleting at faster rate. This leads to the rise in fuel prices. In addition, Indian government is imposing stringent norms on engine emissions. Hence there is desperate need to find an alternate power source to run the vehicles. In urban areas of India, it has been noticed that major part of air pollution is caused by auto rickshaw emissions as they are a common man’s daily commute medium and are not properly maintained. So switching from conventional auto rickshaw to electric will significantly reduce the problem. This gave motivation to optimize the performance of an electrical three wheeler power train.

In this paper a simplified CVT transmission is selected over single reduction transmission for electric vehicle. A simplified CVT transmission improves vehicle dynamic performance, also significantly reduces daily usage cost. The installation cost difference for a single reduction transmission and CVT transmission is not large as a less power motor is used. Motor can work more efficiently and save energy in daily use with the help of larger gear ratio range in CVT. This will benefit the end user.

2. Vehicle specifications
The vehicle selected is BAJAJ RE. The conventional powertrain of Bajaj RE is converted to an electric power train.

Table 1. Conventional auto rickshaw data.

| Sr no | Description                              | Values       |
|-------|------------------------------------------|--------------|
| 1     | Mass of empty vehicle                    | 262.32 kg    |
| 2     | Mass of vehicle with driver               | 332.32 kg    |
| 3     | Mass of vehicle with driver and two passengers | 400 kg       |
| 4     | Mass of vehicle with driver and three passengers | 542.32 kg   |
| 5     | Radius of front tyre                      | 0.2 m        |
| 6     | Radius of rear tyre                       | 0.2 m        |
| 7     | Frontal area                              | 1.5414 m²    |
| 8     | Coefficient of drag                       | 0.385        |
| 9     | Coefficient of rolling resistance          | 0.015        |
| 10    | Transmission efficiency                    | 0.85         |
| 11    | Maximum gradient angle                    | 5°           |
| 12    | Density of air                            | 1.2          |

3. Power calculation and motor selection
The crucial component of electric rickshaw is its motor. Unless the proper motor is selected, vehicle will not run at all load conditions and there are chances of failure during extreme loads. So, for selection of motor minimum required power has to be calculated, which is actually the power required to overcome all the dynamic forces acting on vehicle. The calculation of these dynamic forces requires the geometric data and coefficient of drag of vehicle which has to be converted to electric vehicle, which are obtained from the dissertation work of Mogili Babu. [1]. Power requirement at wheel is determined by driving resistance. The calculations are done for one driver plus three passengers (W = 542.32 kg). It consist of 3 main components

Rolling resistance (F_r):
\[ F_r = \mu \times W \times g = 0.015 \times 542.32 \times 9.81 = 79.80 \text{N} \]  \tag{1}

Where, \( \mu \) = coefficient of friction ; \( W \) = mass of vehicle (kg); g= Acceleration due to gravity = 9.81 (m/sec²).

Air resistance (F_d):
\[ F_d = 0.5 \times \rho \times C_d \times A \times V^2 = 0.5 \times 1.2 \times 0.38 \times 1.5414 \times 1.92 = 1.1172 \text{ N} \]  \tag{2}

Where - density of air; \( C_d \) - coefficient of drag; \( A \) - frontal Area; \( V \) - velocity of vehicle in m/s.

Gradient resistance (F_g):
\[ F_g = W \times g \times \sin \alpha = 542.32 \times 9.81 \times \sin 5^\circ = 463.68 \text{ N} \]  \tag{3}

Where, \( W \) = mass of vehicle (kg); g= Acceleration due to gravity = 9.81 (m/sec²).

Tractive effort: \( F_t = F_r + F_d + F_g = 79.80 + 1.1172 + 463.68 = 544.59 \text{ N} \).  \tag{4}

Torque at wheels: \( T = F_t \times radius \ of \ wheel = 544.59 \times 0.2 = 108.91 \text{ Nm} \).  \tag{5}

Power: \( P = F_t \times V = 544.59 \times 1.9 = 1034 \text{ W} = 1.034 \text{ kW} \).  \tag{6}

The motor available selected has following specification.
Table 2. Motor specification

| Make     | Compage |
|----------|---------|
| Type     | BLDC motor |
| Output Power | 1 KW |
| Required input voltage | 48 V \text{rms} |
| Rated rpm | 3000 |
| Rated torque | 3.2 Nm at 22 Amps |
| Peak torque | 8 Nm at 30 Amps |

4. CVT tuning

In order to start vehicle moving, the motor must be engaged at a speed that has sufficient power to start accelerating the vehicle. To obtain low engagement speed the flyweights have to overcome the pretension in the driving clutch and start moving the sheaves together, until enough force is exerted on the belt to start the vehicle moving.[2] As the force increases, the belt pressure will go from 0 to 100%. All shift force is generated by the flyweight system. Flyweight works on the principle of centrifugal force.

\[ F = M \times R \times \omega^2 \]  

(7)

where, \( M \) = mass of flyweights in kg

Hence centrifugal force increases proportionally with flyweight mass. The overall effect of increasing the flyweights even slightly will increase centrifugal force. That is the CVT will engage at lower speed than earlier due to increased centrifugal force. This makes it possible to tune the CVT at lower engagement speed.

By lowering the engagement speed it is made sure that the shift speed increases during lower ratio acceleration phase.

5. Experimental setup

The complete experimental setup consists of BLDC motor, CVT, motor controller, 48V lead acid battery, LMS SCADA DAQ system, non-contact type laser tachometer and clamp meter. By changing the mass of flyweights multiple iterations of experiments are carried out for tuning CVT for electric vehicle. In this setup, 1kW BLDC motor is connected to CVT by using curved jaw coupling. Both the shaft of CVT and motor are aligned with precision. Motor speed is controlled through throttle which actually varies the input current to motor, keeping voltage constant. RPM of input and output pulley of CVT is measured with the help of non-contact LASER tachometer. Clamp meter with help of shunt resistance is used to measure voltage and current drawn by motor.

5.1. Test Procedure

- Initially flyweight of mass 120 gm is used.
- 25% throttle is given to motor.
- RPM of output and input pulley are measured using tachometer and LMS SCADA DAQ system.
- Voltage and current drawn by motor are noted from clamp meter.
- Similar process is repeated by in increasing the mass of flyweights and varying percentage of throttle input.
- During the process, speed ratios at various throttle position is calculated by measuring the angular speed of primary and secondary pulley.
6. Results
The mass is varied in two iterations and the results are plotted by measuring the angular velocities of primary and secondary pulley (rpm).

6.1. Iteration 1:

Table 3. Total mass of flyweights = 120 grams

| Throttle | Primary pulley rpm | Secondary pulley rpm | Voltage | Current |
|----------|--------------------|----------------------|---------|---------|
| 25%      | 372                | 52                   | 48      | 0.7     |
| 50%      | 1367               | 453                  | 48      | 4.9     |
| 100%     | 2460               | 970                  | 48      | 6.76    |

Figure 3. Primary pulley speed (rpm) verses time (seconds) [red-dotted line] and secondary pulley speed (rpm) verses time (seconds)[green-continuous line].
6.2. Iteration 2:

Table 4. Total mass of flyweights = 260 grams

| Throttle | Primary pulley rpm | Secondary pulley rpm | Voltage | Current |
|----------|--------------------|----------------------|---------|---------|
| 25%      | 1629               | 206                  | 48      | 3.32    |
| 50%      | 2253               | 2309                 | 48      | 5.9     |
| 100%     | 2757.85            | 3726.45              | 48      | 8.7     |

Figure 4. Primary pulley speed (rpm) versus time (seconds) [red-dotted line] and secondary pulley speed (rpm) versus time (seconds) [green-continuous line].

Figure 5. Primary pulley speed (rpm) versus time (seconds) [red-dotted line] and secondary pulley speed (rpm) versus time (seconds) [green-continuous line]. [a] Under drive, [b] speed ratio ≈ 1, [c] Over drive.
The highest speed ratio of 3.433 is obtained at 8 seconds which remains constant till 12 seconds. This is the time at which shifting of pulleys starts. Hereafter speed ratio decreases and hence the speed of output pulley increases and eventually reaches a point where speed of both pulleys is equal. This occurs at time equal to 16 seconds and at this point speed ratio reaches to 1. From here onwards speed ratio decreases and attains over drive.

7. Conclusions
Speed ratio is one of the important parameters considered for designing powertrain of any vehicle. Hence more attention is paid towards obtaining various speed ratio from CVT. Initially when the mass of flyweights was equal to 120 grams, different speed ratios were not obtained. CVT was operating at its highest speed ratio for every throttle position. But when the mass of flyweights was changed to 260 grams, all the speed ratios were obtained ranging from 0.733 to 3.433. It can be concluded that the CVT designed for internal combustion engine can be made compatible with electric motor of 1 kW in a simple and cheaper way. It has been noticed that urban city air pollution can be reduced by electrification of auto rickshaw. The electrification can be made cheaper using a CVT available in market and tune it according to the selected motor power. The results obtained from this study are useful for electrification of auto rickshaw.

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