Tuning of CVT for an Electric Vehicle

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Abstract

The current market highlights the need for better performance cars in limited budget. We aim to incorporate a CVT and to tune it well to increase the efficiency of the vehicle without any drastic surge in the price. A Continuous Variable Transmission (CVT) also called as step less transmission is an automatic transmission that can shift seamlessly through a continuous range of effective gear ratios. The purpose of using a CVT is to enable the motor to run at its most optimum speed for a range of output speeds.

This paper strives to study and analyze the effect of variation in different parameters such as mass of flyweights, stiffness of springs, mass of clutch shoes of centrifugal clutch on the performance of the CVT. For the above mentioned purpose a set of springs of different stiffness, a set of flyweights having different mass were incorporated. The data regarding engagement RPM, adjustment of drive ratios with change of load and speed was recorded and analyzed. The results revealed that there was a positive correlation between stiffness of springs and the torque carrying capacity which impacted the vehicle's performance to improve thus creating an energy efficient system that have better ability to sustain for more time at the average speed.

The paper examines the research carried out on the performance of the vehicle by varying various factors that could affect the efficiency and on the basis of the findings we conclude that the addition of a well tuned CVT can highly improve the performance of Electric Vehicles thus achieving the goal of the industry as well as end users.

Keywords — *Continuous Variable Transmission, spring stiffness, tuning, optimize, torque, speed*

I. INTRODUCTION

Leonardo da Vinci, in 1490, conceptualized a stepless continuously variable transmission. Today, CVT continues to emerge as a key technology for improving the fuel efficiency of automobiles. CVTs use infinitely adjustable drive ratios instead of discrete gears to attain optimal performance. CVT-equipped vehicles attain better gas mileage and acceleration than cars with traditional transmissions. CVTs are not new to the automotive world, but their torque transmission capabilities and reliability have been limited. New developments in gear reduction and manufacturing have led to ever more robust CVTs, which in turn allows them to be used in more diverse automotive applications. As CVT development continues, costs will be reduced further and performance will continue to increase, which in turn makes further development and application of CVT technology desirable.

Contrary to a manual or a conventional automatic transmission, with the CVT no torque interruption occurs during gear change. Since the continuously variable transmission has no explicit gears, it accelerates smoothly, without any jerky motion. During slow-moving situations like stop-and-go urban traffic or in a traffic jam, the CVT comfort factor is especially noticeable and low engine rpm keeps noise levels inside the car down to a pleasant minimum. The CVT control unit automatically selects the best ratio between rpm, and the torque required for vehicle performance. The engine thus operates within an optimum power range, lowering fuel consumption. When the driver steps on the gas pedal, the CVT lowers the transmission ratio and maintains a consistently high engine rpm for optimal torque and acceleration. At a uniform driving speed it switches to the fuel-saving overdrive mode. Non-slip traction between the belt and pulleys enables the CVT to deliver high dynamics and power from the engine to the road.

II. INITIAL DESIGN OF CVT

A. Components of CVT:

1. Variable Diameter Pulleys

The variable-diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. A belt rides in the groove between the two cones.

2. Belt

V-belts are preferred if the belt is made of rubber. V-belts get their name from the fact that the belts bear a V-shaped cross section, which increases the frictional grip of the belt.

3. Centrifugal Clutch

A centrifugal clutch helps avoid the belt to transmit the torque to the tires at lower rpms to reduce slip due to low tension in the belt and increase the life of the belts.

III. VEHICLE SPECIFICATIONS

Sr No.	Parameter	Value
1	Vehicle weight	200 kg
2	Average Speed	33 kmph
3	Wheel Radius	218 mm
4	Top Speed	45 kmph
5	Friction coeff for wheels	0.5-0.65

IV. SPECIFICATIONS OF MOTOR USED

Sr No.	Parameter	Value
1	Power Rating	2000 W
2	Voltage	48 V
3	RPM Rated	3000
4	Continuous Torque	7.2 Nm
5	Peak Torque	24 Nm
6	Current Rating	45 Ah
7	Max Current	120 Ah

Fig 1: CVT Render (https://www.turbosquid.com/3d-models/small-cvt-continuously-variable-fbx/511510)

V. CUSTOMIZATION OF THE CVT

A. Driven Pulley

The adjustment of the driven pulley determines the power loss of the transmission. Good efficiency is obtained when the side forces on the belt are large enough to transfer the power at any belt position without slipping the belt. Since the torque is multiplied in low gear, most side force is required when the belt rides at the largest radius of the driven pulley and least side force is required when the belt is at the smallest radius.

B. Spring of Driven pulley or Pressure Spring

The spring in the driven unit is installed in order to give a pre-tension so that the necessary side force is available to transfer enough power in low gear. Increasing the pre-tension will bring the speed up before the drive starts shifting whereas decreasing the pre-tension will permit the drive to shift at a lower speed. Too little pre-tension causes belt slip and too high causes belt wear.

C. Driving Pulley

The driving pulley must control the motor speed and keep it running on the power curve through the entire shift range. The moment of the pulley and the belt is controlled by flyweights. The system has to overcome the force of pressure spring and then match the side pressure requirements of the driven plus the torque lost in transmission between the driver and the driven system. Thus the net force required is larger on the driver than on the driven.

D. Flyweights

Movement of the belt is controlled by the weight and shape of the flyweights. The distance of its center of gravity from the center line of the drive shaft and speed of motor produces a centrifugal force on the flyweights. A heavier weight will bring the shift speed down on the contrary a lighter weight will bring the shift speed up.

E. Friction clutch

The clutch permits a free running condition that is when the motor speed is below the engagement speed, in this condition force from the pressure spring is stronger than the force from the centrifugal weight. At the engagement speed the force from the centrifugal weight will overcome the spring pressure and the movable pulley will close in on the belt and start to engage it. The vehicle will start moving as the pulley closes harder around the belt until it is fully engaged and no more slip occurs. This is called the clutching action. In a correctly tuned clutch the shift speed is at the power peak of the motor and the motor now maintains a constant speed while the belt changes position to increase the vehicle speed.

We can define the engagement RPM of the CVT clutch to the highest efficiency of the motor so that the motor performs or activates only at the efficient phase of its operating graph. The best efficiency of a motor is achieved when the motor runs between 80% to 120% of its rated speed. Thus, we select a motor of rated 3000 RPM that achieves the highest efficiency range between 2500-3500RPM.

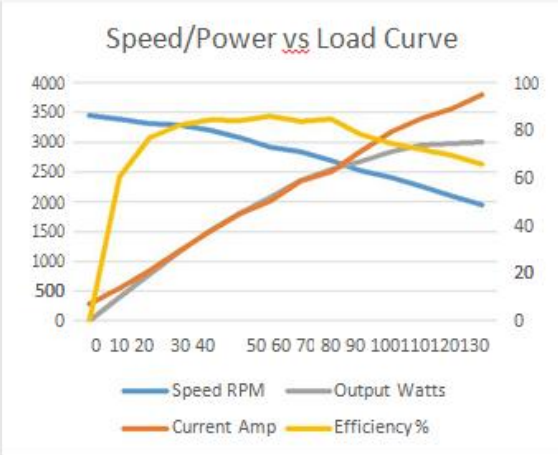

Fig 2: Motor Test Report available as per motor tests done by the manufacturer of the BLDC motor

Notations	Parameter	Unit
M	Mass of vehicle	Kg
m	Mass of flyweights	Kg
a	Acceleration	m/s
μ_r	Co-efficient of rolling friction	-
µ	Co-efficient of Clutch shoe friction pads	-
ω	Angular Velocity clutch pulley	Rad/s
R	Distance CG of Clutch shoe from centre of clutch	m
T_w	Torque on wheels	Nm
K	Stiffness of Pressure Spring	N/mm

Engagement RPM = 2500 RPM (for highest efficiency of Motor)

Engagement RPM of Clutch = 2500/initial gear ratio = 2500/2.259 = 1106.6~ 1100RPM

Acceleration Force = M * a
= 210* 1m/s^2
= 210 N

Frictional Resistance = µ*M*g
=0.05*210 *9.812
=213 N

Grade resistance = M*g*sinΘ
= 210*9.81*sin(4^0)
= 143.73 N

Total Force on Wheels = 456.73 N

Torque on Wheels T_w = 456.73* 0.217 = 99.11 Nm

Torque transmitted at the clutch = 99.11 /3.66 = 27.07 Nm

Torque transmitting capacity = Centrifugal Force at engagement RPM * coefficient of friction

$\therefore$ 27 = µ(3m*r*ω^2)*r

$\therefore$ 27 /(0.7*0.075*0.075*(1100*2π/60)^2 = 3 m

= 172.2 gms.

Taking stock mass of clutch, (standard weights)

m = 175 gms

The CVT system used is equipped with three clutch pad weights. Each weight is of stock 175 grams each.

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Design of Pressure Springs for Test:

The springs were designed so as to have an initial tension of the belt constant in all the cases. The required data of the test springs used in the research are as follows:

Spring No	Deflection (mm)	Length in clutch (mm)	Length of Spring (mm)	Stiffness of Spring (N/mm)
Pilot	46	50	96	6.54
1	60	50	110	5
2	75	50	125	4
3	85.77	50	135.71	3.5
4	100	50	150	3
5	150	50	200	2

VI. EXPERIMENTAL DATA

Testing of the vehicle was done on a straight concrete road. The time was measured, for the vehicle to cover a stretch of 100m from a standstill position. The top speed was measured using the speedometer mounted on the vehicle. The data regarding power consumption was logged in the battery management system for each and every run. The battery wasattached to a BMS which could store the data using an inverter connected via a CAN interface.

The set of springs having different values of stiffness were employed for each of the flyweights. The data given below are the practical test data which was conducted on concrete road. The data was recorded and the best combination of pressure spring and flyweights were selected analysing the data.

- M1= 15 grams

Sr. no.	Stiffness	Current	Top Speed	Time
1	6.54	23.2	30	25:33
2	5	25.8	30	25:29
3	4	26.1	31	25:05
4	3.5	26.2	32	24:91
5	3	27.8	34	24
6	2	31.1	35	23:56

Comments:

1. The side force generated by the weights were too low to handle the torque of the vehicle. The high slippage of the belt on the pulleys creating losses and heating issues.

2. The low side force created low torque carrying capacity and low torque on the motor. Thus current consumed was low.

3. The shifting RPM was too high and the gear ratios never changed.

- M2= 25 grams

Sr. no.	Stiffness	Current	Top Speed	Time
1	6.54	30.2	37.8	21:32
2	5	31.8	39	20:82
3	4	35.4	41.6	19:93
4	3.5	34.8	42.7	19:49
5	3	38.2	43.4	19:16
6	2	40.1	45	18:27

Comments:

1. The side force on an average increased. The slip was reduced.
2. The current consumption was more efficient as the output

increased more than the current consumption. 3. The gear ratio changed at a later stage but the side force lacked the capacity to transfer the torque. 4. This setup was close to optimum so weights were only slightly increased in the next setup.

- M3= 30 grams

Sr. no.	Stiffness	Current	Top Speed	Time
1	6.54	34.2	47	17:72
2	5	38.7	49	16:35
3	4	42.9	53.2	14:31
4	3.5	46.1	55.5	13:69
5	3	46.8	51	15:19
6	2	45.2	45	18:78

Comments:

1. Slip of belt was reduced and performance of the vehicle drastically increased having better response to the driver.
Current consumed was efficient as the output increased more than current consumed by the motor.

- M4= 40 grams

Sr. no.	Stiffness	Current	Top Speed	Time
1	6.54	65.4	48.4	16:71
2	5	69.8	52	15:20
3	4	63.2	50.7	16:12
4	3.5	68.1	48.9	17:34
5	3	70.2	45.1	18:08
6	2	79.8	40	23

Comments:

1. The side force generated caused the shift in gear ratio too soon and the torque on the motor was too high to handle. The shifting RPM of the CVT was not correct and the testing stopped.
The motor got an unnecessary heating and sparking at input terminals was observed. This setup was too risky so further setups after this were assumed worse.

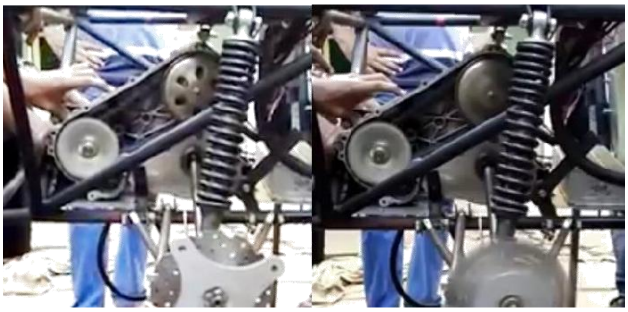

Fig 3: CVT disengaged state (Left) and engaged state (Right)

Fig 4: CVT at highest gear (lowest gear ratio – 0.85:1)

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