

Design and Performance Study of Continuously Variable Transmission (CVT)

Prakash Chandra Shukla^{*}, Prashant Kumar Tiwari^{*}, Yashwant Kumar Singh^{*},
Vikash Singh^{*}, Mr. Rakesh Kumar Yadav^{**}
^{*}Bachelor of Technology, ^{**}Assistant Professor
Mechanical Engineering Department,
United College of Engineering and Management, Allahabad, India

Abstract - Nowadays, automakers have invested in new technologies in order to improve the efficiency of their products. A Continuously variable transmission (CVT) offers a continuum of gear ratios between desired limits, which consequently enhances the fuel economy and dynamic performance of a vehicle by better matching the engine operating conditions to the variable driving scenarios. Automakers have taken an important step toward achieving the objective by designing continuously variable transmission systems (CVT) to continuously adapt the power of the engine with the external load according to the optimum efficiency curve of engine and reducing fuel consumption besides making smooth start up and removing the shock caused by changing the gear ratio and making more pleasurable driving.

Keywords- CVT, Metal Belt, Control, Pulley, Ride with CVT Design

1. INTRODUCTION

With the environmental concern, automobile energy consumption has become a key element in the current debate on global warming. Over the past few decades, vehicle fuel economy plays a important role in determining the emission of greenhouse gases from the automotive vehicles. There are three fundamental ways to reduce

greenhouse gas emissions from the transportation sector [1]:

- (a) Increase the energy efficiency of transportation vehicles.
- (b) Substitute energy sources that are low in carbon for carbon -intensive sources (i.e. the use of alternative fuel technologies).
- (c) Reduce transportation activity.

A continuously variable transmission (CVT) is a transmission which can change sleeplessly through an infinite number of effective gear ratios between maximum and minimum values. The flexibility of a CVT allows the driving shaft to maintain a constant angular velocity over a range of output velocities. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient revolutions per minute (RPM) for a range of vehicle speeds. Basically there are many types of CVTs as: Belt CVT, Spherical CVT, Chain CVT, Hydrostatic CVT etc. Belt type CVT is common and have gained targets for better fuel economy and improved vehicle performance.

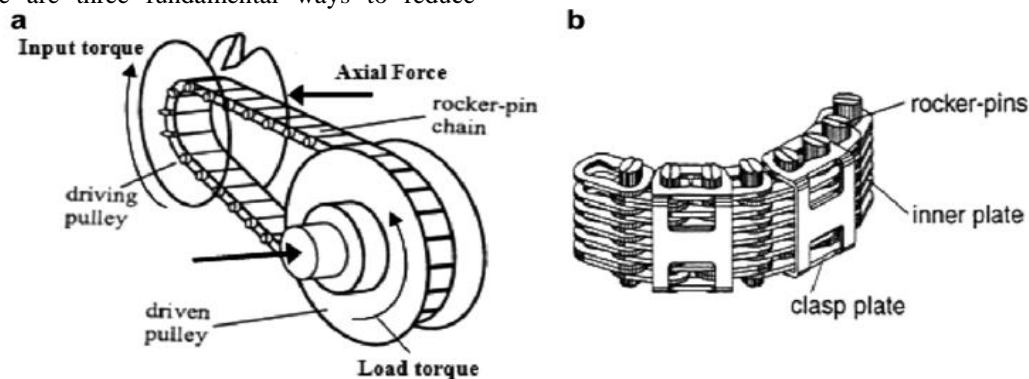


Fig.1 Basic configuration of Belt CVT Drive

2. BACKGROUND AND BRIEF HISTORY

In the year 1490 Leonardo da Vinci had sketched his idea of a CVT. In early 1930s, General Motors had developed a fully toroidal CVT and conducted extensive testing before eventually deciding to implement a conventional stepped-gear automatic transmission due to cost concerns. General Motors did research on CVTs in the 1960s, but none ever saw their production. British manufacturer Austin used a CVT for several years in one of its smaller cars, but it was

dropped due to its high cost, poor reliability, and inadequate torque transmission [3]. Many CVTs in the early stage used a simple rubber band, like the one developed by a Dutch firm, Daf, in 1958. However, the Dafs CVT could only handle a 0.6L engine, and severe problem with rough start and noise eventually began to spoil its reputation [4]. In early 90's electromechanical CVT based on dry hybrid rubber belt was applied for motor cycle [5]. Today almost all CVTs in the market use the Van

Doorne Company's steel push belt as the transmission element. In 1987 the first steel pushing belt was introduced.

3. USING HYDRAULICS TO CONTROL THE PULLEYS

The basic configuration of a CVT comprises two variable diameter pulleys kept at a fixed distance apart and connected by a power transmitting device like belt. The pulley on the engine side is called the driver pulley and the one on the final drive side is called the driven pulley.

In the push belt type CVT, belt and pulleys are the main parts of the power transmission. Belt CVT, torque is transmitted from the driver to the driven pulley by the pushing action of belt elements. Since the half pulleys are subject to a large amount of force from the belt and need high accuracy in creating a smooth and constant movement in the change of the rotation ratio using the hydraulic system is the best option. It is also possible to use solenoid valves, which have the possibility of being under an accurate control from the electrical section of the vehicle, to control the pulleys and power transmission system automatically.



Fig.2 Belt type Continuously Variable Transmission (CVT)

4. BELT

In the continuous variable transmissions, it is possible to create an infinite number of torque ratios. But it should be noted that the belt may slip or stretch in a deforming way which reduces the efficiency. Now a days, with the use of new materials (such as rubber, steel, thin & high strength metals) in making belt. One of the important advances in this field is utilizing the steel belts. These flexible belts

comprise a set of thin steel bands (9 to 12) which have passed through the metal blocks and are placed on one another to increase their strength. The aforementioned steel bands do not slip and have a high resistance and are capable of transmitting larger torque. These belts also produce fewer noises comparing to the rubber belts and work under pressure.

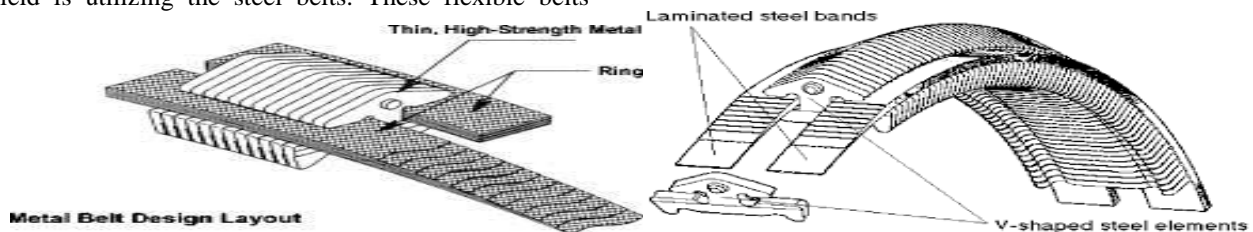


Fig.3 Belt structure

5. MECHANISM OF PULLEYS

Planetary automatic transmission and you'll see a complex world of gears, brakes, clutches and governing devices. By comparison, a continuously variable transmission is a study in simplicity. Most CVTs only have three basic components:

- A high-power metal or rubber belt
- A variable-input "driving" pulley.
- An output "driven" pulley.

The variable diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. 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. When the two cones of the pulley are far apart (when the diameter increases), the belt rides lower in the groove, and the radius of the belt loop going around the pulley gets smaller.

When one pulley increases its radius, the other decreases its radius to keep the belt tight. As the two pulleys change their radii relative to one another, they create an infinite number of gear ratios from low to high and everything in between. For example when the pitch radius is small on the driving pulley and large on the driven pulley then the rotational speed of the driven pulley decreases, resulting in a lower "gear." When the pitch radius large on the driving pulley and small on the driven pulley, then the rotational speed of the

driven pulley increases, resulting in a higher “gear.” Thus, in theory, a CVT has an infinite number of "gears" that it can run through at any time, at any engine or vehicle speed. The

simplicity and step less nature of CVTs make them an ideal transmission.

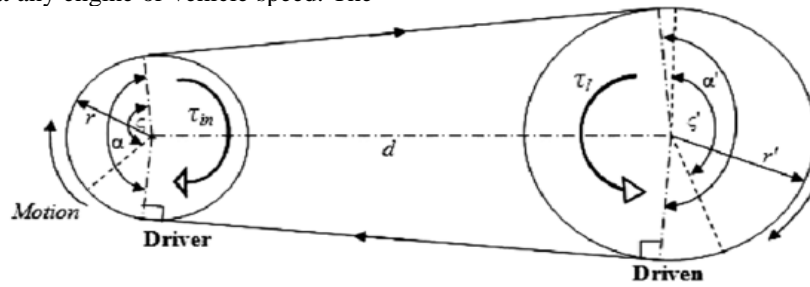


Fig.4 Mechanism of Pulleys

$$T = T_{max} \times R_{CT} \times R_{CVT} \text{ at } N = 2500\text{rpm}$$

These kinds of belts are produced just in limited classes and for special cars. Thus, after plenty of researches eventually the metal belt No. P811 is chosen considering the car specification. The only problem is its Low Ratio which is less than required rate. As it is explained in the following sections, for solving this Problem, some reduction gears are used before differentia.

6. COMPONENTS DESIGN

Having the necessary capacity for the required torque as well as create a required range of torque variation according to the specification of the target car are the most important factors in the selection of CVT belt. The capacity of transmitted torque by metal belt must be at least:

Center Distance[mm]	155
Belt Length[mm]	649.7
Element Width[mm]	24
Number of ring per set	09
Ratio coverage[-]	5.55
Lubrication fluid type	ESSO EZL799
LOW Ratio[-]	2.47
Primary running radius in LOW[mm]	30.0
Secondary running radius in LOW[mm]	74.1
TOP Ratio[-]	0.6
Primary running radius in TOP[mm]	66.6
Secondary running radius in TOP[mm]	40.7
OD Ratio[-]	0.445
Primary running radius in OD[mm]	72.5
Secondary running radius in OD[mm]	32.3

Table.1 Parameters Used in Design of CVT

The clunking sound of an engaging clutch in transmission system is familiar to all drivers. In contrast to that a CVT is perfectly smooth and naturally changes its ratio such that the driver/passenger only feels steady acceleration. The harshness of shifts and discrete gears cause the engine to run lesser than optimal speed. On the other hand a CVT

7. ADVANTAGES AND BENEFITS

proves to be more reliable as it gives better performance and improved efficiency. Due to the ability to change the ratios continuously, a CVT helps to keep the engine in its optimum rpm range, thereby increasing the fuel efficiency.

Gear	Efficiency Range (%)
1	60-80
2	60-90
3	85-95
4	90-95
5	85-93

Table 2: Efficiency versus gear ratio for automatic transmission

CVT Mechanism	Efficiency Range (%)
Rubber belts	90-95
Steel belts	90-97
Toroidal traction	70-94
Nutating traction	75-96
Variable geometry	85-93

Table 3: Efficiency of various CVT designs

8. CVT CONTROL STRATEGY

Although CVTs are currently in production, many control issues still need to be addressed. Generally CVT control strategy can be classified into two major divisions;

- Classical control
- Advance control.

Classical Control

PID (Proportional, Integral and Derivative) controller has been the basis in simple linear control systems. The PID controller is a well known and well established technique for various industrial control applications. This is mainly due to its simple design, straightforward parameters tuning, and robust performance. In the early development of metal pushing V-belt some researchers use PID to control CVT.

Advanced Control

Advanced control approach was used to improve the drive train control simulation. The results from which showed that the proposed control scheme was robust and that the closed-loop performance was acceptable despite the presence of disturbance, but their simulation was based on a wide open throttle opening (WTO). There were certain issues to be resolved when the control scheme was simulated at different throttle opening and in the presence of disturbances.

9. THE FUTURE DEVELOPMENT OF CVT

The ratio coverage and torque capacity were the main problems, but nowadays, Toyota Corolla has the ratio coverage of 6.26 (0.396-2.48) in its new model (CVT i-S) [4] and the new JATCO CVT in Nissan (2.0 L-class, FWD Vehicles) has the ratio coverage of 7.0. [2] This development in ratio coverage has been achieved by smaller minimum diameter of metal belt and adding an auxiliary transmission. Furthermore, torque capacity could increase from about 100 Nm to 380 Nm with a torque converter and to 400 Nm without it in the third generation, e.g. in tropic CVT in Nissan. This improvement was achieved by increasing the belt size [2]. The other challenge is evolution of CVT technology is improving fuel consumption. This issue has already been followed by the capability of adaptation of engine power with the exact required torque for diverse driving situation which is followed by increasing the torque ratio and torque capacity and also improving control methods. In addition to these factors, the focus of researchers is on the enhancement of mechanical efficiency, too. Accordingly, reducing the mechanical friction (internal belt friction between bands and block and also external friction between block and pulleys) is one of the best subjects for

improvement which is obtained by modification of metal belt and improving the efficiency of oil pump.

10. CONCLUSIONS

In this paper step by step stage of designing a CVT proposed to be used for an Iranian automaker manual transmission (MT) automobile is presented. As it is shown the required torque ratio for each vehicle can be obtained by designing an auxiliary planetary gearbox, selecting the proper belt, designing an output and idle gear and with no need to change any other components of the vehicle. In order to lubricate different parts, the new formula for designing a perforated shaft has been derived from DE-ASME Elliptic theory. The results confirm the require space needed for replacing the old transmission system with CVT with considerable fewer weight. The designed CVT considerably reduces the fuel consumption while causing a pleasure driving

REFERENCES

- [1] Bonsen, B. 2006. Efficiency Optimization of the Push-Belt CVT by Variator Slip Control. Technische Universiteit Eindhoven: PhD. Thesis.
- [2] Hongyan, W., Yunshan, Z., Boying, Z. and Xiding, Q. 1999. Research on Integrated Control Strategy of CVT for Passenger Cars. Proceedings of the American Control Conference. 6-9 September. Arlington, 401-405.
- [3] Xudong, W., Meilan, Z. and Yongqin, Z. 2006. Research on Electronic Control System of a New-type CVT. Proceeding on The 1st.
- [4] J.D. Micklem, D.K. Longmore, C.R. Burrows. 1994. Modelling of the steel pushing V-belt continuously variable transmission, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 208 () 13-27.
- [5] N. Srivastava, I. Haque, 2008. Clearance and friction induced dynamics of chain CVT drives, Multibody System Dynamics 19 (3) 255-280.
- [6] Kluger, M. A. and Fussner, D. R. 1997. An Overview of Current CVT Mechanisms, Forces and Efficiencies,
- [7] Transmission and Driveline Systems Symposium. SAE Paper No. 970688, in SAE SP-1241: 81-88
- [8] Chen, T. F., Lee, D. W. and Sung, C. K. 1998. An Experimental Study on Transmission Efficiency of a Rubber V Belt CVT. Mech. Mach Theory. 33(4): 351-363.
- [9] Yamamoto, T., Matsudaa, K. and Hibib, T. 2001. Analysis of the Efficiency of a Half-Toroidal CVT, Society of Automotive Engineers of Japan, JSAE Review 22: 565-570.
- [10] Boos, M. and Mozer, H. 1997. ECOTRONIC - The Continuously Variable ZF Transmission (CVT). Transmission and Driveline Systems Symposium SAE Paper No. 970685. in SAE SP-1241: 61-67.
- [11] Yasuoka, M., Uchida, M., Katakura, S. and Yoshino, T. 1999. An Integrated Control Algorithm for an SI Engine and a CVT. Transmission and Driveline Systems Symposium. SAE Paper No. 1999-01-0752, in SAE SP-1440: 155-160.
- [12] Vroemen, B., Serrarens, A. and Veldpaus, F. 2001. Hierarchical Control of the Zero Inertia Powertrain. Society of Automotive Engineers of Japans Paper. 22: 519-526.