Continuous Variable Transmission

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Abstract: since last two decades ample amount of research work has been done in order to develop power train systems such that they reduce power losses in the vehicle. Comfort ride is one of the important concerns in a passenger car. Continuously variable transmission (CVT) is a solution for it. The CVT provides continuously varying combinations of gear ratios within fixed limits that save fuel and give a better performance of vehicle that comply with the operating conditions of engine. This paper deals with a research on the control of friction- limited CVT. As the growth in advancement of CVTs continues the car performances shall keep improving and the costs shall also depreciate. A few critical issues and difficulties in this system are also mentioned.

Keywords: CVT, control, belt, chain, friction-limited continuously variable transmission.

I. INTRODUCTION

Due to the growth in economy and environmental concerns, automotive fuel energy consumption (pointing at power transmission system in cars) has become an important aspect of discussions on global warming.

Vehicle fuel economy is important to depict greenhouse gas emissions from a vehicle. Three basic techniques are there to reduce greenhouse gas emissions:

1) Improve energy efficiency of automobiles.

2) Use alternate fuel techniques.

3) Reduce unnecessary transport activity. But with growth in urbanization this is hardly possible. For achieving lower emissions and improved performance it is important to understand the working of CVT and its dynamic interactions so as to design efficient controllers thereby reducing existing losses and enhancing the fuel economy of the vehicle.

There are many varieties of CVTs each with their own unique characteristics for e.g.

Belt CVT, Spherical CVT, Chain CVT, E-CVT, Hydrostatic CVT, Toroidal CVT, etc. Of these the belt and chain type CVTs are common and have gained a hold in context of achieving targets of better fuel economy and improved vehicle performance.

Configuration of a CVT involves two variable diameter pulleys which are kept at a specific distance apart and connected by a power-transmitting device such as belt or chain.

The pulley fixed to the engine shaft is called the driver pulley/ primary pulley while the one on the final drive connected to shaft of the FNR gear box is called the driven/ secondary pulley. Figure A and Figure B represent the basic layout of metal V-belt CVT and a chain CVT [1, 2].

In a metal V-belt CVT the torque is transmitted from primary to secondary pulley due to continuous movement of belt. As there is friction between band surface and belt elements, the bands, like flat rubber belts, also participate in torque transmission. Thus we have a combined push pull action in the belt which enables transfer of torque in the V-belt CVT.
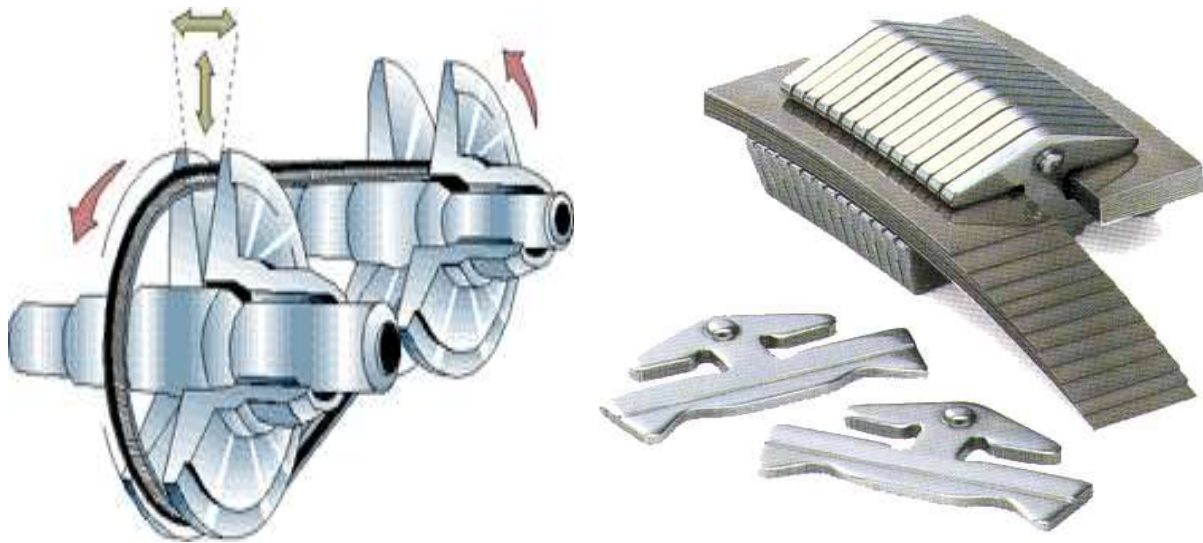
Figure-A

In a chain CVT system, the plates and rocker pins as depicted in Fig.2b, transmit tractive effort from the primary to secondary pulley finally leading to wheels. The contact forces between the chain and the pulleys are distributed discreetly in a chain CVT drive. This leads to impacts like- the chain links enter and leave the pulley groove. Therefore excitation mechanisms occur, that are strongly related to polygonal action of chain links. This leads to vibrations in the entire chain CVT system, which further hampers its dynamic performance. Belt and chain CVT systems come under friction-limited drives as their dynamic performance and torque capacity depend largely on the friction characteristic of contact patch between the belt/chain and the pulley.

II. 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 Daf's 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.

III. ADVANTAGES AND BENEFITS

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 proves to be more reliable as it gives better performance and improved efficiency.

The power efficiency of a typical five speeds automatic transmission system is shown in Table I; v.i.z. the percentage of engine power transferred through the transmission. Compared to a typical manual transmission with 97% this yields an average efficiency of 86% [6]. On comparison the Table II shows efficiency range of different CVT designs.

Table 1: Automatic Transmission Efficiency versus gear ratio [6]

Gear	Efficiency Range
1	60~85%
2	60~90%
3	85~95%
4	90~95%
5	85~94%

Table 2: Efficiency of various CVT designs [6,7,8]

CVT	
Mechanism	**Efficiency Range Variable geometry**
Rubber belts	90~95%
Steel belts	90~97%
Toroidal traction	70~94%
Nutating traction	75~96%

IV. CHALLENGES AND LIMITATIONS

The slow progress in development of CVT accounts to various reasons such as lack of demand, satisfaction with sufficient performance of manual and auto transmission systems. Also difficulties in designing and manufacturing of CVTs adhering to the required torque capacity, efficiency, size, weight, and manufacturing cost of step-ratio transmission.

One of the major problems faced in previous CVTs was the slipping in drive belt or rollers. This was caused due to lack of discrete gear teeth that form a rigid mechanical connection between two gears, the friction drivers are prone to slip, especially at high torque. For many years, the simple solution to this problem was limiting the usage of CVTs, only in cars with relatively low torque engine. Another solution was by installing a torque converter, but efficiency of the CVT gets reduced [3]. With the growth in technology and advancement in engineering CVTs have been made available for cars with high torque engines as well. For CVTs to operate at optimal ratios in any speed, the selection ratios have to be addressed. Manual transmissions are controlled manually, where the desired gear ratio totally depends upon the driver to shift it and automatic transmissions have relatively simple shifting algorithms between three to five gears. However a more complex algorithm is required for CVTs to accommodate an infinite division of speed and gear ratios.

New CVT Research:

Until 1997, research on CVT was focused on the basic issues of drive belt design and power transmission. But today as belts have developed and produced by Van Doome's Transmission (VDT) and other companies which are better and reliable CVT becomes sufficiently efficient. Further research is now mostly focused on control and implementation of CVT. CVT control has recently come to the forefront of research.

Although mechanically efficient CVT can be designed but a control algorithm is needed for optimal performance which demands integrated control, such as the system developed by Nissan to obtain demand drive torque with optimum fuel economy [10]. A control system determines the desired CVT ratio related to vehicle speed, fuel economy, torque value targeted. Considering not only the thermal efficiency of the engine but also power loss from drive train and its accessories Honda has developed an integrated control algorithm for its CVTs. On testing a prototype vehicle for Honda's algorithm resulted in an increase in 1% fuel economy in comparison to the conventional algorithm. Though not a very remarkable increase, it was claimed by Honda that the algorithm would become one of the basis of development for next generation control system.

V. TYPE OF CVT CONTROL

CVT Ratio Control:

The CVT ratio control is a growing research domain at present. Ratio control algorithms are usually being developed for better fuel efficiency and performance.

There are four different types of control operations such as

- Shift ratio control

- Lock up control

- Static shift control

- Line pressure control

Shift ratio control provides a map data on the basis of throttle opening as well as vehicle speed. Lock-up control provides the connection or release state of torque converter on the basis of throttle opening angle and engine speed. A static shift control takes care of the forward and reverse direction according to change in shift lever position. The effective line pressure between primary and secondary pulley for a given shift ratio without any belt slip is determined by the Line pressure control. Even though CVTs are currently in production, many control issues still have to be addressed.

VI. CVT CONTROL STRATEGY

CVT control strategy may be classified into two major categories-classical control and advance control.

Classical Control:

PID (Proportional, Integral and Derivative) controller is useful in simple linear control systems. The PID controller is a renowned and well-established technique for various industrial control applications. This is majorly because of its simplicity in design, straight-forward parameters tuning, and robust performance. During the early development of metal pushing V-belt some researchers used PID to control CVT by using some information on the gear ratio or on the transmitted torque which is then fed back by the PID-type controller. But this was not sufficient as drive train is a nonlinear system. It was claimed by them that this approach would work if a gain scheduled controller with typically more than 80 different gain points was used.

Later, linearization control approach was used to improve the drivetrain 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. Reference from [11] suggest that they had considered a powertrain having a CVT and flywheel to be divided into a number of system layers with descending response time. In between these layers there were electronic circuits supplying control currents, solenoids controlling CVT pulley pressures, the engine throttle valve, the CVT, the engine, and finally the vehicle.

VII. CONCLUSION

A CVT is a promising automotive technology that can further provide improved vehicle performance with restricted emissions.

New research frontiers must be analyzed in context to CVT design and configuration. A few configurations of CVT designs have been reported to achieve lower losses, but the range of applicability of such CVTs for high torque requirements is yet to be verified. This paper not only addresses the research accomplished towards understanding CVT control and dynamics but also tries to highlight the difficulties or directions for future research that might lead to better development of such systems and their controllers.

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