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Continuously Variable Transmission Control Strategy Review

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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:

- Improve energy efficiency of automobiles.
- Use alternate fuel techniques.
- 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, Torroidal CVT, etc.

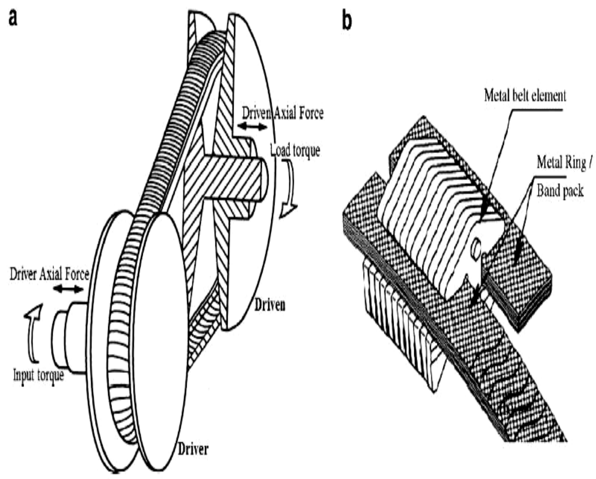
Of these the belt and chain type CVTs are common and have gained a hold in context of achieving targets of better fuel economy and improved vehicle performance.

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 system.

FigureA:



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. Figure

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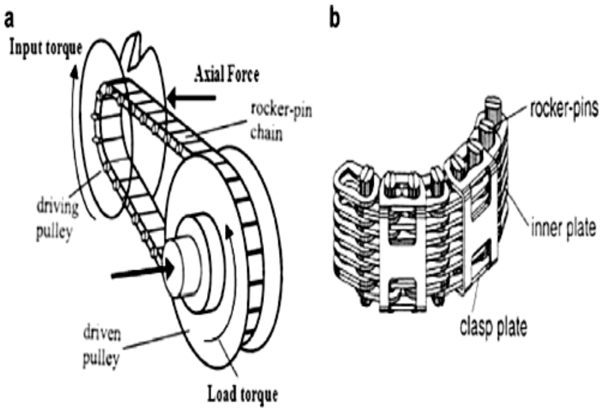
B:



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.

II. 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	85~93%
Rubber belts	90~95%
Steel belts	90~97%
Toroidal traction	70~94%
Nutating traction	75~96%

The efficiency of these CVTs depend less upon driving habit unlike manual transmission. As CVT allows the engine to run at its most efficient point being virtually independent of the speed of vehicle so a vehicle equipped with CVT saves more fuel compared t a conventional transmission. A testing by ZF Getrie be GmbH for U.S. Environmental Protection Agency City and Highway Cycles many years ago found that the CVT uses about 10% less fuel than a 4 speed automatic transmission. Also the testing showed that CVT was more than one second faster in the 0 to 100 Km/hr acceleration test [9].

III.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 Transmissie (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.

IV. 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 pulleyfor 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.

V. CVT CONTROL STRATEGY

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

Classical Control

PID (Proportional, Intergral 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.

Two PI controllers were used to regulate the pulley pressures by manipulating current provided to the solenoids [34]. While experimenting acceleration that change the speed from 60 to 80kmphwas performed with and without the flywheel. The results showed satisfactory performance of control system in the tested vehicle.

In accordance to [12, 13] if the clamping forces in a variator were decreased; the efficiency of CVT would increase immensely. Lower clamping forces lead to increasein risk of excessive belt slip that can damage the system. So a method was introduced to measure and also control slip in a CVT inorder to reduce the clamping forces while preventing destructive slip of belt. Inorder to ensure vigorous performance of the system against peak torque values a controller was designed with an optimal load disturbance response mechanism. For maximizing the integral gain a synthesis method was applied to the PID controller and it was made sure that the closed loop system stayed stable. The application of this algorithm in a test vehicle has been studied.

It was based on a constrained optimization problem for ensuring that the maximum sensitivity was less than specified value.

Considering maximum sensitivity as the main design parameter a trade-off can be designed between robustness and load disturbance response w.r.t model uncertainties. The other resulting controller parameters of this optimization process can be achieved graphically for a PID controller [13]. The self adjusting PID which is one of the latest systems, is not a pure PID but it is combined with a PID. The results from simulation indicated that the speed ratio controller produce reasonable match between CVT ratio and engine torque.

Advance Control

Advance Control involves modified LQR (Linear Quadratic Controller) strategy by adding an integrator to each input. In reference to a study [14]

the engine-CVT-load model was developed based on fuel optimization and vehicle dynamic were assumed linear. Good result was obtained but, it was shown that the engine power should be included in the cost function.

A fuzzy controller was introduced to keep engine speed at its target by regulating the ratio and varying the throttle opening. The engine speed is important to be maintained at an optimum working condition according to the car's moving resistance.

This may be done by using synthesized control. As the characteristics of power train vary with different conditions, it is tough to throttle opening and ratios inorder to meet such demands. Hence fuzzy control strategy was studies to solve the issue. The results from simulation depicted that synthesized controller by fuzzy strategy could maintain speed of the engine operating at its peak efficiency point for any demand level of power.

Reference paper [14] proposed a fuzzy controller for controlling a tractor consisting CVT. In a conventional control system fuel economy and efficient performance concerns only reflect the working state of the tractor and the driver's demand is ignored leading to limited applications. For solving this problem a rule based fuzzy inference of driver's demand was proposed using a fuzzy inference engine which would help to indicate the driver's demand for tractor performance based on rate of change of accelerator pedal and so the tractor dynamic factor was obtained. After this process the transition control rule is adopted for attaining smooth transition from the intelligent transient dynamic rule to steady fuel economy rule. Results from simulation showed that intelligent control rule enabled tractors to reach the appropriate comprehensive performance levels.

Thus came a new method for developing an intelligent tractor equipped with CVT.

In reference to[15] fuzzy-PID controller was introduced for an engine equipped with a CVT. It was realized that a conventional proportional control strategy could not satisfy the control demand for engaging the clutch; as a result a fuzzy controller for the clutch control was designed and self-adjusting PID for the ratio control was provided to it followed by simulation of setup. The results showed that the speed ratio controller has good control effect and gives a reasonable match between engine and CVT. It illustrates that the simulation model established is acceptable and reasonable, which offers theoretical help to construct and develop CVT system. Article [16] analysed an integrated powertrain and CVT controller inorder to improve fuel consumption and emission. Two different network controllers had been used to control torque demand and engine speed demand. In this the measured engine speed was passed to engine operating point optimiser, that was used to set the corresponding ideal engine torque which was the first torque demand. The output of the network controller (I) was the second torque demand.

The two torque demands are used to drive the vehicle through CVT. The network controller (2) controls engine speed demand.

So by the two network controllers we can get improved fuel consumption and restricted vehicular exhaust emissions.

Neural networks or rather Artificial Neural Networks (ANN) can be reliable for such purposes. This network consists of non-linear neuron-like computing elements. The property of non-linearity permits non-linear mapping; as the drive train and vehicle dynamics are highly non-linear ANN is an optimum control system.

A system consisting of outer loop with neural network and inner loop with the help of PD controller is to be implemented onto the drive train having electromechanical CVT.

In order to fulfill the objective v.i.z to design an develop electromechanical CVT pulley controller for automotive application, we require intelligent and efficient controllers.

Using this controller, by adjusting the CVT ratios engine rpm can be kept at desired speed. The adaptive ANN will select proper CVT ratio hence acting as a skilled driver.

Even though CVT plays an important role in the agenda of maintaining high performance and fuel economy of a vehicle, in mass production vehicles expected increase in acceleration and reduction of fuel consumption have not been achieved.

This could be blamed upon the low efficiency of control logic which was inaccurate to deliver desired shifting.

As chain and belt type CVTs are majorly used transmission systems this paper reviews some of the detailed researc that has been made to understand the control of such CVT systems. Also, the theory reviewed shows significant opportunities of further research that could be done in order to gain a better insight into the dynamics of such CVT systems for designing more efficient controllers, identify losses, and optimize operating ranges for maximum torque transmissibility or efficiency.

VI. 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.

VII. REFERENCES

(1) 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.

(2) N. Srivastava, I. Haque, 2008. Clearance and friction induced dynamics of chain CVT drives, Multibody System Dynamics 19 (3) 255–280.

(3) Yamaguchi, J. 2000 Nissan's Extroid CVT, Automotive Engineering International Online, SAE International, February

(4) Birch, S. 2000. Audi Takes CVT From 15th Century to 21st Century. Automotive Engineering International Online. SAE International, January, 3. SAE International.

(5) 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.
Da Wen Ge, Sugeng Ariyono and Daw Thet Thet Mon 553

(6) Kluger, M. A. and Fussner, D. R. 1997. An Overview of Current CVT Mechanisms, Forces and Efficiencies, Transmission and Driveline Systems Symposium. SAE Paper No. 970688, in SAE SP-1241: 81-88

(7) 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.

(8) 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.

(9) 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.

(10) 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.

(11) 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.

(12) Pulles, R. J., Bonsen, B., Steinbuch, M. and Veenhuizen, P. A. 2005. Slip controller design and implementation in a Continuously Variable Transmission, American Control Conference. 8-10 June. Portland, USA, 1625-1630

(13) Bonsen, B. 2006. Efficiency Optimization of the Push-Belt CVT by Variator Slip Control. Technische Universiteit Eindhoven: PhD. Thesis.

(14) 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.

(15) Xudong, W., Meilan, Z. and Yongqin, Z. 2006. Research on Electronic Control System of a New-type CVT. Proceeding on The 1st International Forum on Strategic Technology, IFOST2006, IEEE. 18-20 October. Uslan,Korea, 289-292.

(16) Deacon, M., Brace, C. J., Vaughan, N. D., Burrows, C. R. and Horrocks R. W. 1999. Impact of Alternative Controller Strategies on Exhaust Emission from an Integrated Diesel/Continuously Variable Transmission. Proceeding of the Institution of Mechanical Engineers. 213(2):95-107.

(17) Zhang, Y., Zhou, Z. and Zhou, X. 2006. Intelligent Control Rule for Tractor with Continuously Variable Transmission. Proceedings of the 2006 IEEE International Conference on Mechatronics and Automation. 25–28 June, Luoyang, China, 1712-1716.