Clamping Force Adjustment System for a Continuously Variable Transmission

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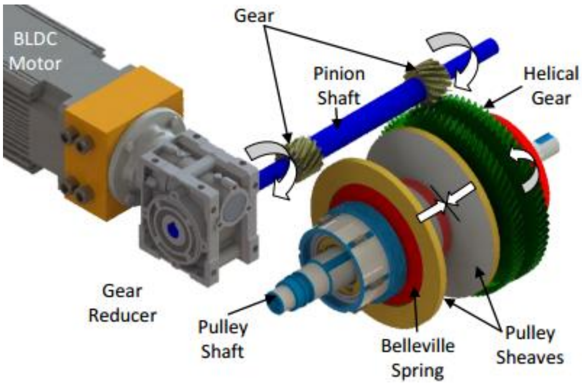
Graphical Abstract



Abstract

In a continuously variable transmission (CVT), engine torque is transferred to the vehicle's wheels using traction between the metal pushing V-belt (MPVB) and the CVT's pulleys. As a result, sufficient clamping force from the pulleys to MPVB is required. Conventionally, the clamping force is generated by extracting some of the engine power through an oil pump in a hydraulic actuation system. The oil pump converts the engine power into hydraulic pressure exerted on the CVT pulleys so that MPVB can be clamped accordingly. This process, nevertheless, causes inefficiency in the vehicle's powertrain system since less power is transmitted to the wheels. To address this issue, this paper describes a design of clamping force adjustment system using screw-thread mechanism.

Keywords

Screw-thread; DC motor; metal pushing V-belt; electro-mechanical; automotive

Introduction

Producing an efficient transmission for applications in automotive is one of the biggest challenges currently faced by the automotive manufacturers. Hence, many types of automotive transmissions are introduced to address this challenge, with continuously variable transmission (CVT) using a metal pushing V-belt (MPVB) being one of the most popular solution. CVT with MPVB offers continuous ratio change, wide ratio coverage and also potential in weight reduction due to the application of MPVB instead of a number of discrete gears.

In a CVT, the ratio (r_{CVT}) is varied by simultaneously adjusting the openings of the primary pulley and the secondary pulley (Figure 1). During operation, sufficient clamping force on the MPVB is required so that it is always taut, thus allowing the engine torque to be transferred from the primary pulley, which is connected to the engine, to the secondary pulley that is coupled to the vehicle's wheels. To produce the clamping force, a hydraulic actuation system is embedded in the conventional CVTs. This system consists of, among others, an oil pump that is powered by the vehicle's engine. The purpose of the oil pump is to generate high hydraulic pressure, typically at around 50 to 70 bar, so that the pressure can be transferred to the pulleys to clamp the MPVB accordingly (Naunheimer et al., 2011). For safety purposes, the clamping force on the MPVB is usually set at about 30% higher than the normal requirement (Bonsen, 2005). This setting, unfortunately, leads to significant losses in the MPVB and the hydraulic actuation system, which is estimated at about 100W to 1kW, depending on the capacity of the engine (Kirchner, 2007).

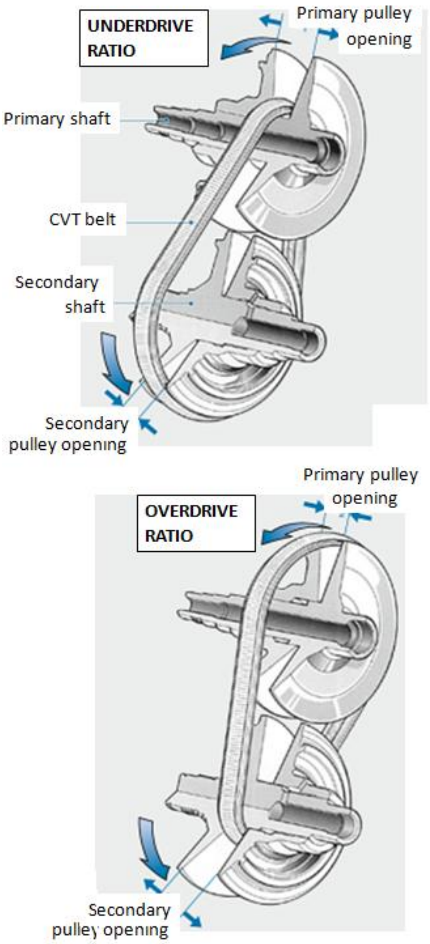


Figure 1: Changing r_{CVT} in a CVT with MPVB (Reif, 2014)

To reduce the losses in a CVT due to the excessively high clamping force on the MPVB, numerous researchers have applied controls on the clamping force. For instance, Pulles *et al*. (2005) controls the clamping force control by adjusting the hydraulic pressure on the secondary pulley based on the relationship between the desired speed of the secondary pulley and the required clamping force on the same pulley. Another example is described in Rothenbuehler (2009) whereby a servopump is used to control the hydraulic pressure on the secondary pulley. Here, the clamping force is controlled so that the slipping between the MPVB and the pulleys can be capped at below 2%.

While the aforementioned efforts on clamping force control lead to the reduction of losses in MPVB, the requirement of high hydraulic pressure to clamp MPVB is still inevitable. As a result, significant engine power is still required for the operation of a CVT. Hence, a more efficient clamping force system for a CVT is desired.

THE PROPOSED CLAMPING FORCE ADJUSTMENT SYSTEM

In early 2000s, researchers in Universiti Teknologi Malaysia have produced the prototype of electro-mechanical CVT (EM CVT) applying screw-thread systems and two brushless DC (BLDC) motors (Tawi *et al*., 2014 and Supriyo, Tawi and Jamaluddin, 2012). One of these motors is used to adjust the opening of the primary pulley through the primary screw-thread system while another motor is tasked for the same purpose in the secondary pulley. The application of the screw-thread system eliminates the requirement of high hydraulic pressure in a conventional CVT, thus no engine power is required to operate the CVT. Nevertheless, the prospect to implement clamping force control in the prototype is challenging since the prototype is not developed with a dedicated clamping force adjustment system. Therefore, this paper proposes a clamping force adjustment system to be embedded in the design of the prototype.

The clamping force adjustment system is designed as part of the secondary pulley assembly. In the system, a BLDC motor is used to rotate two helical gears on the opposite sides of the secondary pulleys (Figure 2). These helical gears are meshed with two power screws that are designed to move axially in the opposing direction. Two disc springs (Belleville springs) are positioned between the power screws and the secondary pulley, and the axial movement of the power screws leads to the adjustment of the disc springs' deflection. Figure 3 shows the simplified diagrams to relate the axial position of the power screw and the deflection of the disc springs. As a result, the clamping force on MPVB can be changed accordingly by using the BLDC motor.

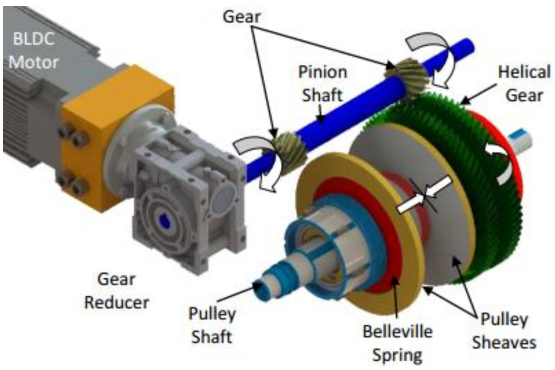


Figure 2: The proposed clamping force adjustment system

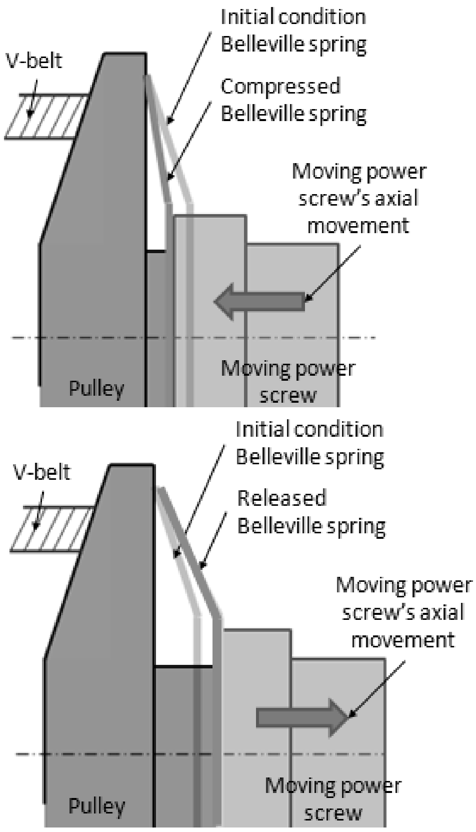


Figure 3: The relationship between the power screw movement and the disc spring's deflection

To prepare for the experimental evaluation of the clamping force adjustment system, a test rig for the system is designed. In the test rig, two position sensors are assembled at both ends of the pinion shafts (Figure 4). One position sensor is designated as the minimum position (MP) sensor, and its main objective is to set zero position where the disc springs have zero deflection. Another position sensor is responsible to measure the deflection of the disc springs based on the rotation of the pinion shaft. As a result, the relationship between the deflection of the disc springs, which represents the clamping force exerted on the MPVB, and the position of the power screws can be established. A force sensor, on the other hand, is positioned between the pulley sheaves so that the relationship between the power screw's movement and the clamping force can be established. This relationship is crucial for the next step to develop a control on the MPVB's clamping force.

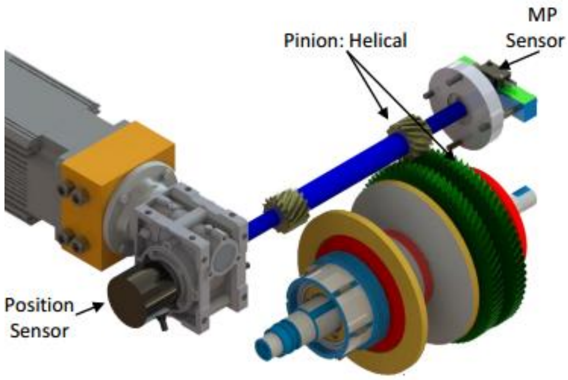


Figure 4: Position sensor for the test rig

Discussion

The proposed clamping force adjustment system, generally, presents the opportunity to further explore the area of clamping force control in an EM CVT. However, to integrate the system into the existing prototype of UTM's EM CVT is a little bit challenging since it requires major modifications on the prototype's secondary pulley assembly. Not only that, the process to vary r_{CVT} in the prototype must also be re-examined since originally, the prototype requires two DC motor to change r_{CVT}. With the clamping force adjustment system, however, one motor is already designated for clamping force adjustment, thus modifications on the prototype are required to allow the process to change r_{CVT} to be carried out with only one BLDC motor.

Furthermore, according to the works by Tawi et al. (2014), during the process to change r_{CVT}, the relationship between the opening of the primary pulley and the opening of the secondary pulley is not linear. This means that by including the proposed clamping force adjustment system in the existing prototype, the deflection of the disc spring will not be a constant and it is instead dependent on r_{CVT}. This condition, therefore, must be taken into consideration so that the process to control clamping force in the prototype of EM CVT can be performed effectively. Besides, further researches especially in the area of disc spring's deflection are still required so that the proper understanding on the disc springs' characteristics can be developed as the fundamentals for the implementation of the clamping force control.

Conclusion

The clamping force adjustment system, proposed in this paper, allows the possibility to adjust the clamping force on the MPVB in the prototype of EM CVT developed earlier by UTM's researchers. This possibility opens up the prospect to implement clamping force control in the prototype. Nevertheless, further works need to be done particularly concerning the characteristics of the disc springs during the process of varying r_{CVT} since these characteristics are very crucial to achieve effective and practical clamping force control for the prototype.

References

[1] Nauheimer, H., Bertsche, B., Ryborz, J. and Novak, W., 2011. Automotive Transmission; Fundamentals, Selection, Design and Application, Second Edition. Springer. Berlin-Heidelberg.

[2] Bonsen, B., Pulles, R. J., Simons, S. W. H., Steinbuch, M. and Veenhuizen, P. A., 2005. Implementation of a slip controlled CVT in a production vehicle, IEEE Conference on Control Applications 2005, Toronto, Canada. 1212-1217.

[3] Reif, K., 2014. Fundamental of Automotive and Engine Technology; Standard Drives, Hybrid Drives, Brakes, Safety Systems. Springer Vieweg, Wiesbaden.

[4] Kirchner, E., 2007. Leistungsübertragung in Fahrzeuggetrieben; Grundlagen der Auslegung, Entwicklung und Validierung von Fahrzeuggetrieben und deren Komponente. Springer. Heidelberg.

[5] Pulles, R. J., Bonsen, B., Steinbuch, M. and Veenhuizen, P. A., 2005. Slip controller design and implementation in a continuously variable transmission. Proc. 2005 American Control Conference., Oregon, USA.

[6] Rothenbuehler, Y., 2009. New Slip Synthesis and Theoretical Approach of CVT Slip Control. Phd. Thesis: École Polytechnique Fédérale de Lausanne, Switzerland.

[7] Tawi, K. B., Mazali, I. I., Supriyo, B., Husain, N. A., Kob, M. S. C., Abidin, Y. Z., 2014. Pulleys' axial movement mechanism for electro-mechanical continuously variable transmission. Applied Mechanics and Materials. Automotive Engineering and Mobility Research, 633:185-192.

[8] Supriyo, B., Tawi, K. B. and H. Jamaluddin., 2012. Experimental study of an electro-mechanical CVT ratio controller. International Journal of Automotive Technology, 14(2):13-323.