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TEMPERATURE AND TORQUE VARIATIONS ANALYSIS OF THE CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM OF A VEHICLE BAJA SAE

Murilo Patreze, murilopatreze@gmail.com
Bruno César de Carvalho Tavares,bruno.c.tavares@hotmail.com
Geice Paula Villibor, geice.villibor@ufv.br
Universidade Federal de Viçosa – Campus Universitário – CEP 36570-900 – Viçosa – Minas Gerais

Abstract. *The continuously variable transmission (CVT) brings some changes relative to the gears transmission system, as better use of the torque and power range of the engine. Possible factors that affect the CVT behavior are a temperature increase, belt slip and preload in pulleys. Thus, the aim of the work, check the influence of CVT protection in increasing the surrounding temperature and preload of CVT pulleys on the vehicle output torque. The vehicle was coupled to a dynamometer measurement the torque on the powertrain output shaft and CVT temperature was monitored at six points by means of thermocouples. The tests were conducted with CVT opened and closed; and six CVT preload conditions. By means of variance analysis it was found that the protection increases the temperature of the interaction between the CVT and condition protection and preload influence the output torque. The average temperature in the open and closed CVT was 26.2°C and 55.9°C, respectively. The higher torque 439.64 Nm was observed for the combination of spring work pulley driven with minimum preload and the same protection cover closed. The results made it possible to better understand the CVT behavior and identify the best working ranges, supporting the design of a new protection for the system.*

Keywords: *dynamometer,off-road vehicles, experimentation.*

1. INTRODUCTION

The Continuously Variable Transmission (CVT) with rubber belts have long been used in low-power vehicles because of its significant advantages over other conventional transmissions, including simple construction, smooth operation, easy handling, low cost and easy maintenance (Zuh et al, 2010). CVT’s has been used in passenger cars, in all terrains vehicles (ATVs) and currently in off-road vehicles like baja.

Other advantages of CVT are related to better utilization of torque and engine power, which improves performance, saving fuel and reducing environmental impacts due to the emission of pollutants. Another factor is the transmission power without discontinuities typical of a common gear box, since the system has a continuously changing ratio speed in its working range, which results in riding comfort. These advantages have attracted the attention of engineers, who are in constant studies and improvements of the properties and dynamic behavior of the CVT. Of course, always seeking the possibility and the development of new projects.

The study object was the CVT of the vehicle off-road type baja, developed by UFVbaja team. The Baja SAE project is a challenge for engineering students that offers the chance to put into practice the knowledge acquired in the classroom to enhance their preparation for the labor market (Sae, 2014). Among the problems with loss of quality performance in past competitions it is supposed that these factors were generated by a temperature rise in the transmission system used CVT type. Aimed at safety and the rules of the competition, the CVT should be protected. This way aimed to work with, check the influence of CVT protection in increasing the surrounding temperature and also on the vehicle output torque.

However, in some competitions and past tests were various problems exposed by the team with qualitative performance losses and change in prototype behavior. It was supposed that these factors were generated by a temperature rise in the transmission system used CVT type and also when type used in the CVT preload system. Furthermore, when a rubber belt operates with very high internal temperatures, rubber properties begin to change resulting in a premature failure in relation to life that has been designed (Gates, 2014).

The CVT power losses include torque and velocity losses. The belt torque loss results primarily from the hysteresis materials loss when the belt is compressed and tensioned on pulleys; and radial slipping when the belt is inserted and removed from the pulleys (Zuh et al, 2010). For mechanisms with rubber belts "V", a unified theory of slipping was proposed and considers four factors that may affect the belt slipping, they are: elasticity along the belt, radial compliance, radial and axial deflection and stiffness flexure during operation (Chen et al, 1999). The adequate traction on the belts is of crucial importance for the performance of the CVT in all operational condition. The preload in pulleys spring can influence the behavior of belts.

Following the rules of the SAE and to avoid possible unintended safely component and the public, the team must maintain the protected CVT which causes the increase in system temperature. Thus, the aim of the work, check the influence of CVT protection and preloads conditions in increasing the surrounding temperature and also on the vehicle output torque.

2. MATERIAL AND METHODS

The UFVbaja prototype uses a single cylinder engine, Briggs & Stratton, with 10 Hp at 4000 rpm and 18.6 N m at 2600 rpm, as its theoretical maximum power and torque, respectively (Briggs & Stratton, 2012). The engine is coupled to the CVT Polaris P90, which was analyzed in this work, and finally a secondary gear reduction and fixed gear ratio of 6.4:1. This type of CVT is generally used in ATV's and snowmobiles vehicles. The pulleys are part of a wheelbase of 10 inches, and variable reduction of between 0.76:1 and 3.83:1. To protect the CVT external agents such as mud, water, rocks and other, uses a protective cover when the vehicle is operating. The protective cover built by UFVbaja team, using fiberglass with reinforced resin. In the Figure 1, the CVT without and with protective cover is presented.

(a) (b)

Figure 1. CVT Polaris P90 mounted UFVbaja vehicle without protective cover (a) and with protective cover.

The tests were realized to verify the influence of CVT temperature and preload spring on powertrain performance, in terms of output torque of baja vehicle. Initially, the maximum torque at the powertrain output secondary reduction was measured by means of a dynamometer "Prony brake" type. This procedure took place with the vehicle suspended for stands and secured by safety belts and weights. A flange was used to connect the output shaft of the vehicle secondary reduction to the dynamometer, which eliminated losses by sliding observed in belts and pulleys systems.

For the torque analysis, the accelerator was set at maximum load application. Gradually, the resistive torque on the dynamometer drum was increased and this is the value that the powertrain must exceed. This analysis was realized throughout the dynamometer resistance control points. This torque was measured using a load cell with nominal capacity of 2 kN, HBM®, S9M model, associated with a data acquisition system of the National Instruments® and Labview® software. The load cell was attached to the dynamometer drum, replacing the conventional counterweights system, improving the data reliability (Figure 2). The output torque on the powertrain shaft (T, N m) was determine multiplying the radius of drum (R, m), by force on the load cell (F, N). That is, the torque exerted by the vehicle transmission assembly.

(a) (b)

Figure 2. Load cell (a) and lateral view of dynamometer (b) used in torque tests of vehicle of UFVbaja.

Simultaneously at the maximum torque analysis, it evaluated the operating temperature of CVT on predetermined points. It was initially examined the vehicle without protection in CVT (the same in open air) and after, with a completely sealed protection. For temperature measurement have been used type K thermocouples with data acquisition system describe above. These thermocouples were fixed by the back of the pulleys, as close as possible to each of them, but without touching them (Figure 3). Three thermocouples for pulley were used, equally spaced, to confirm if the temperature was stable. The average value of temperature in six measurement points was used for this analysis. For temperature measuring, the vehicle remained on until the temperature stabilization in both cases, with and without protection.

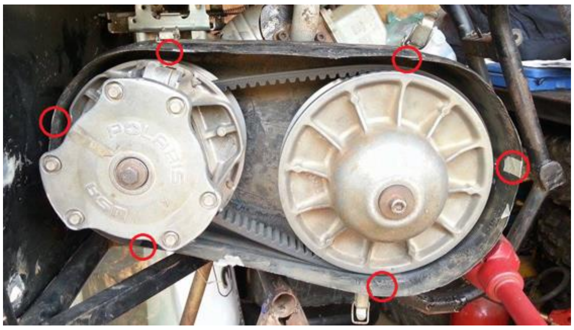

Figure 3 - Thermocouples positions using to measure the temperature in the CVT pulleys

The CVT has a coil spring in its driven pulley and another spring in your motor pulley. Otherwise, within each pulley it is a total of six possible combinations of preload on the springs. These positions, when varied, makes the pulleys to change their response effort to centrifugal force, which makes them to expand or close at different speeds, modifying vehicle response. In the Figure 4, the possible combinations of positions of the spring is presented. For the (3x1) position, it has the lowest preload applied to the spring, and the (1x2) position have the greatest.

Figure 4. Setting the pulley spring positions moved from CVT Polaris P90

The experiment was conducted in a factorial scheme 6 x 2 (six CVT preload and two CVT protection conditions), in completely randomized design, with three replications, totaling 36 experimental units. The influence of preload and CVT protection on output torque was verified by variance analysis. The factors with significant effect was evaluated by Tukey mean test, at 5% of significance level. It was utilized the software SISVAR to realized every statistical analysis.

3. RESULTS AND DISCUSSION

In the Table 1 the results of analysis of variance relative to the maximum temperature measured for each treatment are presented. The configuration of the protection (open and closed) was the only significant effect about the CVT temperature. When the CVT was closed, the airflow was limited, reducing the heat exchange with the environment and increasing the measured temperature. It was found that there was an increase of about 53% in temperature when the CVT worked with the protection which reinforces the need for improved system cooling. The average temperatures were 26.16°C and 55.86 °C, to CVT open and closed, respectively. The changes in the spring stiffness was not sufficient to interfere in working temperatures.

Table 1. Analysis of variance to the maximum temperature measured in the CVT used in baja vehicle

Source	Degrees of Freedom	Sum of Square	Mean Square	F
Preload	5	2.65	0.53	$1.51^{n.s.}$
CVT protection	1	7935.84	7935.84	22673.84^{*}
Preload x CVT protection	5	3.70	0.74	$2.11^{n.s.}$
Residue	24	8.40	0.35	
TOTAL	35	7950.59		

$^{n.s.}$. – not significant at 5%; * Significant at 5%. F (5, 24) = 2.62; F (1, 24) = 4.26

It is verified that the interaction between the CVT preload and the protection condition was significant on the maximum torque in the powertrain output shaft (Table 2). As expected, the spring configuration had significant difference in the average, since changes the dynamics of the opening of the driven pulleys, as well as the setting of protection. What can be explained by the significant variation of the torque exerted by setting the preload of the springs, standing still even at the purely temperature changes caused by the configuration of the covers.

Table 2. Analysis of variance to maximum torque measured in powertrain of baja vehicle

Source	Degrees of Freedom	Sum of Square	Mean Square	F
Preload	5	7361.02	1472.20	473.84*
CVT protection	1	4102.40	4102.40	1320.40*
Preload x CVT protection	5	6904.07	1380.81	444.43*
Residue	24	74.57	3.11	
TOTAL	35	18442.06		

n.s. – not significant at 5%; * Significant at 5%. F (5, 24) = 2.62; F (1, 24) = 4.26

The general average output shaft torque was 397.37 N m, ranging from 359.73 to 438.55 N m, with coefficient of variation 0.44%. The higher torque was observed in the spring configuration 3x1 and closed, i.e., to lower preload and higher working temperatures of the CVT. The lowest torque was observed in the spring configuration 2x1 and open, i.e., to intermediate preload and lowest working temperatures of the CVT. In Table 4 are presented the results Tukey, test at 5% significance, only to interaction between the preload and the setting of the CVT protection.

Table 4. Results of Tukey test to maximum torque (N m) for the interaction of mean settings Preload X Protection

Preload/ Protection	Open	Closed
Combination 1x1	398.69 Aa	396.02 Aa
Combination 1x2	390.73 Ba	393.84 Ab
Combination 2x1	359.73 Ca	386.78 Bb
Combination 2x2	379.55 Da	414.97 Cb
Combination 3x1	365.88 Ea	438.55 Db
Combination 3x2	425.52 Fa	418.08 Cb

Means followed by the same letter (upper case in column and lower case in line) not differ statistically among themselves by Tukey test 5%.
Combination 1x2 – highest preload; Combination 3x1– lowest preload.

As previously mentioned, the maximum temperature measured was 56.80°C. However, due to the movement of pulleys and belt, it is not possible to measure the temperature exactly on the surface of these at the time of the operation, but with little distance. According to Gates Rubber Company®, for rubber belts, is usually accepts an operating temperature range between -35° C and 71° C, and the golden rule is that an increase of 8 °C inside the belt reduces the lifetime of the 50% (Gates, 2014). As soon as the surface temperature must be higher than the measured, wanted to design a protection that kept the CVT working with the lowest possible temperature for the greater component life of the transmission.

4. CONCLUSIONS

The use of protecting CVT increased working temperatures in the region around the pulleys, however at higher temperatures the highest values were observed for torque;

The maximum torque is influenced by the interaction between protection and preload condition in which major changes were observed for combinations wherein the temperature was low, showing that influence of preload can have more effect on the output torque observed.

Even though the increase in temperature has not reduced the maximum available torque, improve cooling can contribute to the maintenance of life of the mechanical components and minimize negative effects due to high temperatures;

5. ACKNOWLEDGEMENT

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