Experimental Study of CVT for Improving Belt Life by Analyzing the Thermal properties of Sheave Material

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Abstract

The CVT or Continuously Variable Transmission is a power transmission device used as a mode of Automatic transmission system with a continuum range of gearing ratios due to its cam-ed sheave design. There are several different design other than conically sloped pulley system, but all of them work on same principle. Previous studies and applications have looked into the problem of heating of the CVT sheaves and belt which has led to reduction of transmission efficiency and reduction of belt life as well as life of sheaves and other parts. Mainly two reasons behind this phenomenon - first, the practical and commercial CVT is far from ideal and has belt slippage in general working environment and then second from this dynamic friction, higher temperatures are observed which in return causes more slippage especially in case of rubber belt which is the most widely used type. After software analysis, choose a thermally best material for the sheaves as a result of the analysis and manufacture a custom CVT and a test rig for it. Thus, finally the testing of such practical apparatus would suggest true results and confirmation to the hypothesis as well as compiling data about the test, equipment working and hurdles in practicality and commercial transformation of the project. In closure, the objective is improvement of CVT belt life by customizing the sheave material of the CVT.

Keywords: CVT, Sheave, Thermal Analysis, ANSYS

1. Introduction

Continuously Variable transmission as the name suggests are meant to be advantageous over a conventional selector or sequential transmission systems by varying the gear ratios continuously over the ride so as to achieve a smoother transition of torque. This system hence achieves a greater overall efficiency of the vehicle and supports the modern move towards creating efficient vehicle for better performance and above all a greater reduction in Automotive emissions. But then the suggested upper hand of system is much an exaggeration of theoretical concepts and the practical prototypes and commercial products of such sorts have seen a greater transmission losses in contrast to the improved torque characteristics. One such problem was encountered by the authors, excessive heating in belt-pulley type
transmission which is the most common and commercial model of CVT. The problem is one of the most trending topics of discussion over number of online forums relating to young engineers facing this problem in particular with baja off-road vehicle challenge specifically. Which was the ulterior motivation for the project and the content further is another attempt to fundamentally answer the problem. [1] The work describes the use of a DAQ on a BAJA SAE vehicle CVT to acquire its real time gear ratio and later optimize it using the data. It establishes a relationship between the temperature of sheaves and performance as well as material dependence of heat dissipation in the device. This study is quite relevant reference to this project as the study suggest higher heat dissipation using Aluminium MMC and design features such as fins. An Experimental research on transmission efficiency of metal belt continuously variable transmission is based around the derivation of CVT efficiency at different gear ratios and assigning a viable reason to the observation but focuses on the former. [2] Experimental Study on cooling of Continuously Variable Transmission (CVT) in Scooter describes the solution employed in commercial scooters with respect to cooling of CVT. Though it does not explore different solutions but the content is focused on the commercial scooters with certain modifications to the CVT housing. They used a commercial 110cc scooter for the project in affiliation with Mahindra two wheelers ltd

1.1. Compact design

One benefit of CVT is that it is lighter and simpler in comparison to conventional automatic transmission and manual transmission. Remember that there are no physical gears or a set of planetary gears within a typical CVT box. The design and components are remarkably simpler. Nonetheless, this compact design makes CVT an ideal transmission choice for compact vehicles.

1.2. Stepless acceleration

Both traditional automatic transmission and manual transmission use different physical gears to go through different gear ratios in a step by step trend. Shifting between the ratios can create shift shocks or sudden jerks. On the other hand, CVT varies gear ratio continuously and smoothly as opposed to a stepped manner. This allows for a smoother operation and quicker drive. Another advantage of CVT is that it allows the engine to rev almost immediately, therefore handing over peak torque. Remember that torque is a measure of how much force is needed to cause an object to rotate. A CVT also eliminates gear hunting as the vehicle decelerates, such as when it is ascending a hill. In extension, a conventional automatic transmission normally struggles while the vehicle is under heavy load. Under the exact plot, a CVT can almost immediately find the precise gear ratio, thus providing seamless power

1.3. Fuel efficiency

The ratio between engine shaft speed and driveshaft speed is continually changing in a CVT. In addition, apart from mechanical components, a CVT also has sensors to keep an engine within its optimal power range regardless of how fast or slow the vehicle is moving. This means that a CVT is more fuel economical than a traditional automatic transmission or manual transmission, especially in the course of a stop-start traffic situation or when the vehicle is continually changing speed. Sensors built inside a CVT allow better fuel efficiency, especially by balancing fuel economy and power requirement. The engine essentially runs at the optimum speed regardless of the wheel speed. In other words, by continuously altering
and balancing the gear ratio, or the ratio of engine shaft speed to driveshaft speed, a CVT ensures that the most relevant amount of energy from fuel combustion is used.

2. Methodology

The methodology in this study is concentrated about the material of the CVT sheaves. As the objective of the study is thermal improvement of the CVT, the first likely step is always literature survey to know more about the machine and the roots of the problem around which the project is based. Though, after doing so the process guidance must be specific and here it is the study of theory behind the problem. Here it is hypothesized that the problem of belt slippage and wear which gives many other problems downstream, actually arises due to heating. Thus, the logical solution must lie in the theory of heat transfer. The study must then lead to a number of candidate materials that have better thermal characteristics compared to the material that is already being used. Further filtration is required to reach to a final best, which would be done by comparing the thermal properties and mechanical properties as well to apply the selected material practically. After selection of one or more candidate materials, computer simulations are required for further filtration as well as for some confirmation of the hypothesis for the least. The results from the thermal analysis then would lead to a single best material. Fabrication of Continuously Variable Transmission (CVT) sheaves from that material is to be done after which the testing is done so that an experimental proof is obtained. This leads to the last stage where all the observations are used to derive a brief and meaningful conclusion.

3. Material Selection

According to Fourier’s law, the rate of heat flow $q$, through a homogeneous solid is directly proportional to the area $A$, of the cross-section perpendicular to the direction of the heat flow, and to the temperature difference $\Delta T$ along the path of heat flow. Mathematically, it can be written as $q = -k \Delta T$

where $k$ is the thermal conductivity tensor.

Hence, higher thermal conductivity would mean higher heat dissipation due to its direct proportion relationship to heat dissipation. But material selection is to be limited to practical materials since the end product is of nature of transmission of power nd hence mechanical properties of candidate materials must at least match the material in use i.e. stainless steel 301.
4. Computational Thermal Analysis

The steps to get into the second phase of the project i.e. the method of computer simulations employed to select a final material from a filtered set of materials selected by the standard data from matweb references. The reason for this further filtration process is to manufacture the end CVT from only the best material instead of fabricating and testing all the candidate materials. The candidate materials selected were aluminium 6061 and aluminium 7075. Therefore, by the method of computer simulations two tasks are ruled out. One, the confirmation of hypothesis that higher coefficient of heat conductivity and specific heat capacity would lead to lower sheave temperatures, this is to be done by comparing the results of the candidate materials against the conventional material. Second, the selection of the best material from the candidate materials.

Since the prospects of an undergraduate degree projects are limited much of the work has assumed certain factors. The computer simulations were completed with following assumptions:

4.1. Absence of ventilation

since many commercial mopeds and vehicles do not have any ventilation and the limitations of the project scope and computational hardware and skill requirements, no air flow is taken into account.

4.2. Steady state evaluation

It is assumed that there is only the stagnant air block surrounding the assembly and the result is to be obtained after the system reaches a steady state using heat transfer processes of radiation, convection and conduction.

4.3. Symmetry

It is assumed that the parts other than the sheaves are identical in heat transfer or all CVT models and hence can be eliminated by symmetry. Also, All CVT models are symmetrical apart from the sheave material. The literature survey suggested that it is not nearly practical or possible to estimate the internal heat generation of such a complex device. The parameters of hysteresis, peculiar frictional contact and non-ideal real world environment prevents the
project from giving even a rough estimate of the heat flux values. Instead, to somehow derive a working heat transfer model, the results obtained from a test of a commercial CVT were used. The test aimed to get the temperature values of Honda Activa moped’s CVT. This allowed the project to take the assumption (1) and the input sheave slope temperature of $150 \, ^{\circ}\text{C}$. Thus, inhibiting from adding further complexity into the system and considering the assumption (3) in play, the simulations were completed.
Figure 1. Stainless steel 301

Figure 2. Aluminium 6061

Figure 3. Aluminium 7075
5. Experimentation

After fabricating and assembling the CVT is the final Testing of the CVT. The test rig used a briggs & stratton model 20 engine used in lawn movers and off-road buggies such as the baja SAE vehicles. The engine specification are:

- Make: Briggs & Stratton; Displacement: 305 cc; Fuel: petrol; Brake power: 10 hp; Peak Torque: 19 ft.lb; Compression ratio: 8:1

The test environment was to be made such that the working conditions are ideal to an idling commercial CVT. It is worth noting that the test on the honda activa 110cc commercial CVT was performed at idle rpm when the belt id slipping. Thus to match that testing environment the custom CVT was also tested similarly.

The test statistics are as follows: 10hp, 21.7 N.m torque engine directly connected to the primary pulley allowed to run at 1750 rpm in both cases until a stagnation of temperature was observed.

| Sheave material         | Primary Sheave | Secondary Sheave |
|-------------------------|----------------|------------------|
| Stainless Steel 301     | 151            | 135              |
| Aluminium 7075          | 136            | 123              |

6. Results and Discussion

The observations suggest that there is an actual reduction in temperature of the sheaves and hence the complete system. The results confirm the hypothesis that higher heat dissipation is offered by aluminium 7075. The temperature reduction observed is 9.9% on the primary sheave and 8.9% on the secondary sheave when the material is changed from conventional stainless steel to aluminium 7071. Since the belt life and transmission efficiency is inversely proportional to the sheave temperature, the belt life is increased by the same estimate. It is also of further notice that the cost of the suggested material Aluminium 7075 is about twice the conventional material. It was also observed that there was only insignificant wearing of the belt during the testing period. On the side lines, the mechanical properties of the aluminium 7075 is much better than the stainless steel and though it is not in the scope of this project, it is certainly a significant advantage.
7. Conclusions

From the above observations, it can be concluded that the suggested material Aluminium 7075 is better thermally than the conventional Stainless steel 301 material. The temperature reduction found was about 10%. Though there is no statistical or mathematical model available to estimate the improvement in belt life, it can be said that it does improve and roughly by the same margin. This conclusion is derived from the fact that the heat reduction will certainly reduce the wear of the rubber belt which is observed due to softening of rubber at higher temperatures. The trade-off between the cost parameter and thermal performance is disadvantageous to the cost side but when looked from the perspective of the advantageous mechanical properties, it can be surely suggested that the material must be used in commercial CVTs as the weight of the aluminium 7075 is marginally low while the tensile strength is about two and a half times the stainless steel.

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