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An Approach to Improvement in Heat Flow Analysis of Continuously Variable Transmission (CVT)

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ABSTRACT

Continuous Variable Transmissions (CVTs) are one of the most widely used automatic transmissions in light vehicles, and yet CVT cooling remains a major issue in high load and high torque conditions. CVTs operate at very high rpm which poses a threat under the OSHA criteria for 'Hazardous Energy Control' which necceciates shielding of rotating components. Guards shall be protected against the hazardous release of energy. The purpose of this research is to find an efficient way to cool a CVT, implementing various aspects of fluid Mechanics, heat Transfer, and CAE. This study includes a improvement in standard CVT with its casing and various modification, like fins, ducts, and fans. The tests and analyses show the effectiveness of up to three different combinations and result in about 7 °C reductions in the CVT temperature using Computational Fluid Dynamics (CFD) software. The results would help understand and overcome the current limitations of a CVT and implement the improvements efficiently in light to medium weight vehicles.

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1. INTRODUCTION

Continuous Variable Transmission (CVT) is an automatic transmission that can change seamlessly through a continuous range of effective gear ratios. It has three major components comprising the primary and secondary pulleys and the belt. The pulleys are made of two conical sheaves each. The primary pulley is the one connected to the engine, also called the driving pulley. The secondary pulley also called the driven pulley is attached to the drive shaft. The belt moves about these sheaves and transmits the work from the driving pulley to the driven pulley. The major advantage of the CVT system is that the transmission ratio can be changed without interrupting the torque output. CVTs are used in the vehicle industry like all terrain-vehicles or snowmobiles, also scooters, and even some cars that work with a continuously variable transmission.

The CVT works on the principle of centrifugal force, hence there is a certain minimum engagement speed to compensate for the idling of the engine. Slippage occurs either when engine speed is nearly equal to engagement speed or at very high engine speed, because of which, friction is generated, factors such as these are responsible for heat generation.

Heat generation is not desirable for the components inside CVT housing. The material properties of the components depend on temperature. The temperature has an impact on the strength /elasticity of the drive belt. Belts tend to lose their elastic property at a higher temperature. More slippage will occur due to less

tension in the belt, giving rise to loss in transmission efficiency. Due to an increase in temperature, thermal stresses develop in the components which reduces its service life.
In this paper, a CVT of an All-Terrain vehicle is taken and the simulation of the heat distribution from the component is done using CFD software.

2. BACKGROUND
In the research study presented by Johannes Wurm and Mathias [2], the thermal effects within an enclosed CVT is studied. The design of a commercially available CVT system was taken and measurements were conducted on an engine test stand. Computational Fluid Dynamics (CFD) is used to compute heat transfer and the flow conditions resulting from the pulley rotation and the belt movement. STARCCM+, a state-of-the-art commercial software code. CFD codes were used to execute all simulations. A similar study conducted by Patil *et al.* [1] wherein using Fourier's law, the heat dissipation from the CVT increased by increasing the heat transfer area. The total increase in area is 27.41%. Thermal conductivity of the sheaves was increased by changing the material from steel to aluminium (Al MMC). These alterations resulted in a drop of 10.4% in the temperature for the primary pulley and a drop of 8.55% in case of the secondary pulley. B. Xiao *et al.* [3] conducted a study on change in heat transfer during forced air convection, in their study they concluded that heat transfer coefficient increases with increase in air velocity.

3. METHODOLOGY
Design optimization of any component includes certain processes which ensure the successful working of the setup. It always begins with physical testing of the previous design using experimental techniques to find out the flaws. Then the setup is designed virtually and then the analyzing software is calibrated according to the real-life setup. Optimization of the model begins from the next step,trying out various design optimizations like fins, axial fan, and material alteration in this particular case. This new design is then virtually analyzed to find out the exact improvement we were able to achieve. The process we are following through in this case can be seen in Fig. 1.

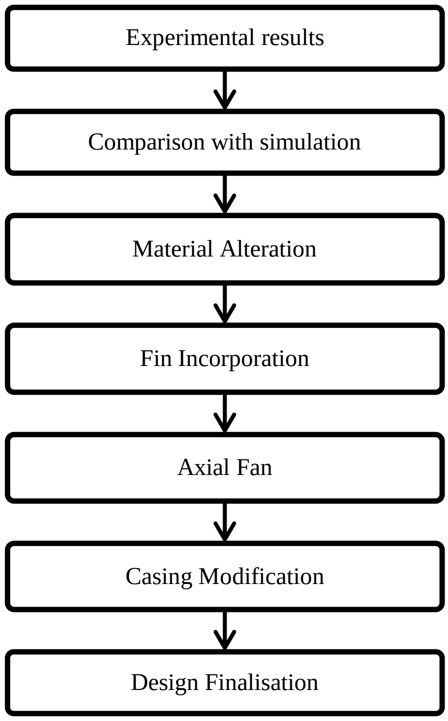

Figure 1. Methodology

3.1. Experimental Analysis
Infrared thermometers have been used to measure the temperature of all parts of CVT with respect to changing time and temperature. The CVT is run for an hour and the data is measured in this time interval

using a Tachometer and an infrared thermometer. The readings were taken when the engine reaches maximum rotations. Average temperatures value was considered as the baseline sheave and belt temperatures.

3.2. Reference Design

The reference design used for a heat flow analysis of CVT is Gaged GX9 CVT with Enduro 100 belt on it. A detailed CAD model of the CVT is shown in Fig. 2.

The material for the belt and pulleys is considered to be Silicon Rubber and Aluminium 7075-T6 respectively. Belt failure occurs from200°F to 220°F according to the manufacturer.
Following are the specifications of CVT used:

- Primary pulley diameter: 6in (152.4mm)
- Secondary pulley diameter: 8in (203.2mm)
- V-Belt centre to centre distance: 10in (254mm)
- Total belt length: 33.85in (859.8mm)

3.3. Modifications

With increasing engine performance, loads on the CVT components rise as well. The power loss of the transmission leads to high thermal loads and the resulting peak temperatures drastically reduce the life span of the belt. To overcome this issue new designs which focus on improving the heat transfer and reducing high-temperature zones need to be found.

Figure 2. Gaged GX9 CVT

The cooling of CVT can be achieved by modification of both CVT and the CVT casing. The modifications made are then compared to the reference model (without any modifications).

1) CVT Modification: Heat is transferred predominantly by conduction and convection. As the belt is continuously running between the drive and driven pulley, the temperature is generated due to friction between surfaces. This leads to an increase in the surface temperature at pulleys and belts. An axial fan is incorporated on the Primary pulley and various iterations of fin designs are done on the primary and secondary pulleys. Simulations are conducted on thermal analysis of CFD software to understand which is most efficient. The flow of air which is forced by the fan carries heat along with it as air flows along with the CVT components, in this way forced convection takes place inside the housing. Material is changed to Aluminium MMC T5 as it is known to have a very good thermal conductivity with comparable strength to 7075-T6.
2) Casing Modification: A completely closed Casing is initially analysed using Flow Simulation and

then using the flow results, required inlets and outlets for air to flow are provided to stimulate forced convection in the system leading to further cooling.

4. ANALYSIS AND RESULTS

4.1. Reference Study

In order to conduct the study and obtain a feasible/tangible/palpable result, an experiment was conducted on a model of Briggs and Stratton engine and the Gaged GX9 CVT currently being used by the SAEINDIA BAJA, Team Turbocrafters, SIES Graduate School of Technology. The setup of the experiment is as shown in Fig. 3.

Figure 3. Setup

Wherein with the help of an infrared temperature sensor, baseline temperatures were observed and further used in this research.The experiment indicated the maximum belt temperature to be 103.4 °C and the corresponding maximum sheave temperature at around 94.2°C. The same design was analyzed on CFD software.

4.2. Comparison Study

The experimentally observed temperatures and a standard GX9 CVT were analyzed on ANSYS steady-state thermal analysis. The entire setup was finely meshed and then was solved using the experimentally obtained temperatures as boundary conditions. This yielded a similar pattern of temperature distribution as that of the experiment. A detailed image of this analysis can be observed in Fig. 4. Analytically the maximum temperature was 103.7°C and the sheave temperature of 96.6°C. This indicates the reliability of simulations and analysis on CFD software.

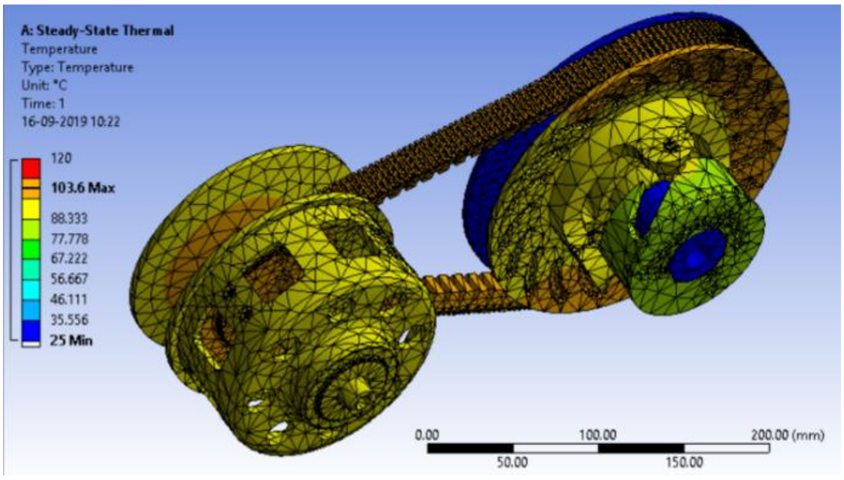

Figure 4. Thermsl Analysis of OEM CVT

Here the material of sheaves being Al 7075-T6, with its coefficient of thermal conductivity as 130 W/mK [4] and coefficient of thermal convection as 91.75 W/m^2K.

4.3. Stage I

According to Fourier's law,

$$Q = -kA\left(\frac{dT}{dx}\right)$$

Material of the CVT was altered from Al 7075-T6 to Aluminium MMC-T5. Al MMC was chosen considering its coefficient of thermal conductivity (k), coefficient of thermal convection (h) as well as the yield strength of the material in comparison to Al 7075. This increased the value of the coefficient of thermal conductivity from 130 W/mK to 147 W/mK [1] [3][6][7][9][10].The setup was again fine meshed and solved in same manner as before.

In this step the results from ANSYS yields a decrease of approximately 5ºC and 10ºC for the sheaves and the belt respectively. Observe Fig. 5.

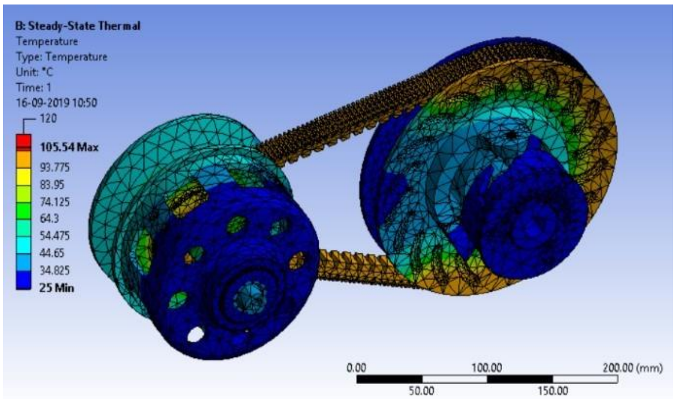

Figure 5. Thermal analysis of Al 7075 T6 CVT

The next step to consider is the physical property of the new material Aluminium MMC. The detailed physical properties of both Al7075 T6 and Al MMC T5 can be observed in table 1. The elastic modulus of Al MMC T5 is much higher than that of Al 7075 T6 which means that Al MMC has a higher rigidity, which means higher force is required to deform than 7075 T6. Also, as it can be observed, the UTS of MMC is lower than 7075 T6. But as the setup is a belt drive, the UTS value is well over the required margin.

Table 1. Mechanical and Thermal Properties of materials

Property	MMC	7075 T6
Elastic Modulus	108.2 GPa	71.7 GPa
Ultimate Tensile Strength	320.6 MPa	572MPa
Thermal Conductivity	147 W/m-k	130 W/m-K
Specific Heat Capacity	0.798 J/g-°C	0.96 J/g-°C
Mass Density	2.75 g/cc	2.81 g/cc
Poisson's ratio	0.33	0.33

4.4. Stage II

Integrating fin to accelerate the rate of heat transfer is a widely used method in the industry, hence using fin calculation, fin effectiveness for 20 fins per sheave was incorporated. Al MMC was selected for its excellent properties of thermal convection.

Fin length: 8.379×10-3m

Fin Effectiveness: 2.14

The updated design of the CVT is as shown in Fig. 6.

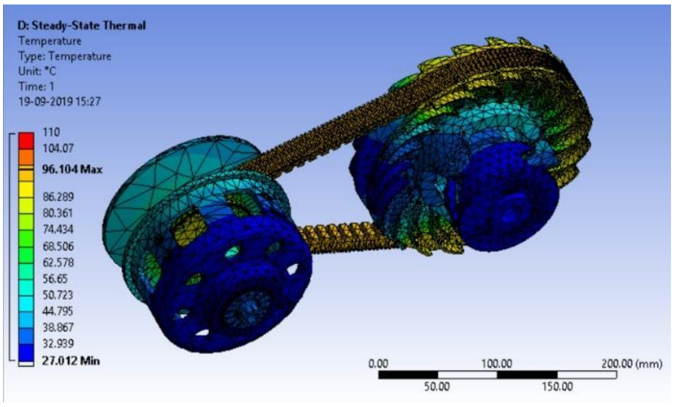

Figure 6. Thermal analysis after incorporating fins

Similar CFD software simulations were conducted, the results for this study indicated 85.8°C and 86.7°C as the average temperature for the sheaves and the belt respectively.

4.5. Stage III

The addition of a fan would introduce the phenomenon of forced convection to the study which was originally limited, hindered, despite the vehicle running at high speeds, due to the CVT casing. An Axial fan is installed which sucks in air from outside of the casing and circulates it throughout the casing. Flow analysis using Solidworks flow simulation and a finely meshed assembly setup yielded temperatures of 80.3°C and 82.47°C for the sheaves and the belt respectively.

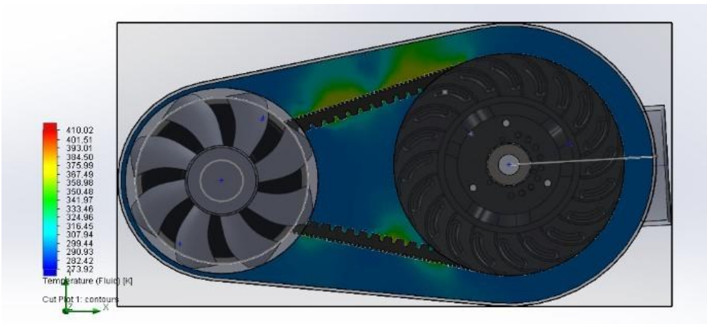

Figure 7. CFD Analysis conducted in SolidWorks flow simulation

The above figure shows the cut plot of temperature varia- tion along the cross-section of the belt, the belt's temperature ranges between 85°C to 94°C.

4.6. Final Assembly

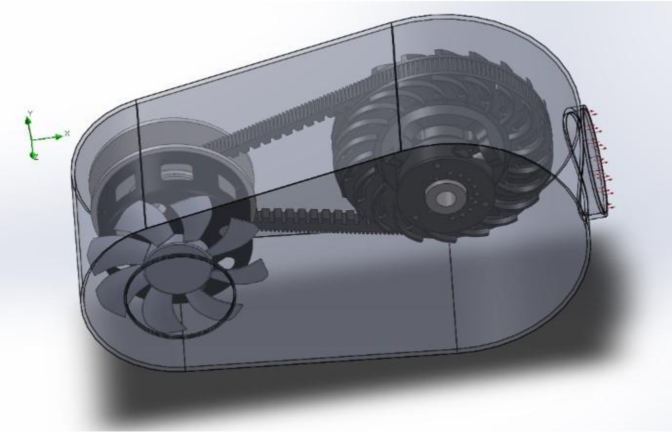

Figure 8. Final Assembly of the CVT with impeller and CVT Casing

The final assembly setup we achieved after extensive re- search and analysis can be observed in Fig. 8.This final setup consists of fins on the CVT sheaves, and an axial fan attached to the primary pulley. This setup along with the casing created to provide perfect airflow makes our design the best.

4.7. Result

Table 2 shows all the temperature readings obtained from each stage of analysis. The first column consists of the average temperature reading s obtained from practically running the vehicle for an hour and then taking the readings using a temperature gun. Then similar conditions were created virtually on ANSYS Workbench and was analysed to ensure the calibration of baseline data in virtual medium. Almost similar results were obtained on ANSYS workbench ensuring that fact. Next step was to analyse by changing only the material of the CVT of which the results can be observed in the third column. Converting material to MMC caused a reduction of about 6ºC from basline temperature. Further reduction of about 10 degrees can be observed in the temperature when fins are added into the sheaves. Next step includes the addition of an impeller into the setup and modifying the CVT casing to induce forced convection. This again brought about 4-to-5-degree reduction in the temperature.

Table 2. Results

	Experimentally (ºC)	Analytically (ºC)	7075 to Al MMC (ºC)	Fins (ºC)	Forced Convection (ºC)
Belt	103.4	103.7	97.8	86.7	82.47
Sheaves	94.2	96.6	87.4	85.8	80.3

5. IMPLEMENTATION

A well-analyzed and better model of forced convection has been implemented on our Ares 2.0 ATV CVT casing which consists of meshed aluminum sheet in the front providing proper inlet and specific holes in the backplate along with the sheaves as an outlet. It has successfully provided us with a reduction of about 2 to 3 degrees. Implementations of further methods like fins on sheaves and impeller are currently being conducted to obtain practical results.

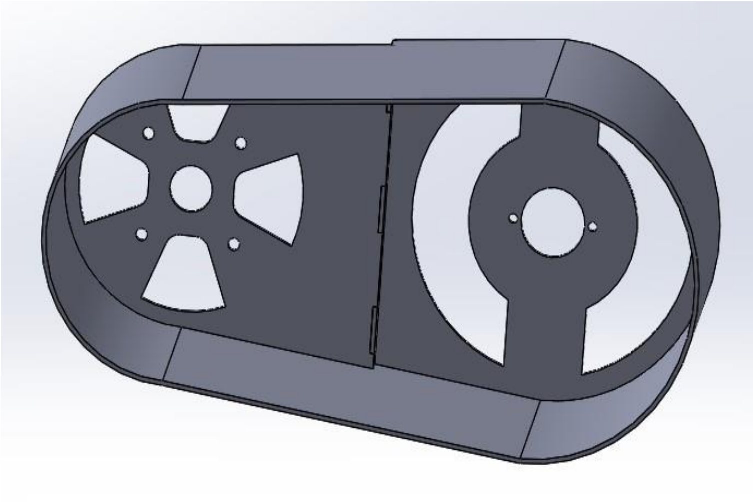

Figure 9. CVT Casing 2020 Ares 2.0

Figure 10. 2020 Ares 2.0

6. CONCLUSION

The step-by-step analysis of temperature variation of CVT and its improvisation techniques yielded the best iteration of CVT along with its casing which will act as a thermally efficient substitute for Gaged CVT GX9. Change of material to Al MMC-T5 led to about 7 °C reductions in the CVT temperature. Total reduction of about 18°C was observed when the idea of fins was implemented on the secondary pulley. The temperature reduction wouldn't be as listed if the analysis were to be conducted with the CVT enclosed in its casing. The fan introduces forced convection which maintains a cool temperature and yields consistent results. Overall using all these setups, we were able to bring the temperature of belt as well as the pulley sheaves well below the temperature of 200°F(93.3°C) suggested by the manufacturers.

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