STEADY STATE THERMAL ANALYSIS OF CONTINUOUS VARIABLE TRANSMISSION WITH EXTENDED SURFACES

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ABSTRACT

A Continuous Variable Transmission is an unconventional type of transmission which transmits torque/power from the crankshaft of the engine to the wheels that run on the ground. It is a single speed step- less transmission with the help of pulleys and a belt to obtain uninterrupted and continuous infinite gear ratios within a finite limit. Infinite gear ratios are obtained by varying belt diameter over pulleys. Due to continuous contact between the belt and the pulley, the friction between both the surfaces leads to the generation of heat over a period of time. At higher speed, instances and clutch slippage situations produce more amount of heat in CVT components. Studies show that CVT surface temperatures may reach up as high as 80°C to 120°C depending upon the various speeds of CVT, which affects the service life of components in long run and simultaneously its performance is reduced. So, necessary cooling is required to enhance the life of CVT. The main objective of this work is reducing the surface temperature from 80°C to 60°C in static condition around the pulleys of a CVT by increasing its surface area in the form of rectangular and cylindrical fins which is subjected to natural convection and by comparing the changes in temperature distribution and heat dissipated using both the fins. The temperature distribution is analyzed for different models using steady -state thermal analysis tool in Ansys. The fin material used is aluminum alloy of 3003 grade for its feasibility of machining, welding, and comparatively higher thermal conductivity.

KEYWORDS: Transmission, Fins, Temperature Distribution & Aluminium Alloy

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INTRODUCTION

An automobile transmission system is used to transfer the torque at end of crankshaft to the wheels. In conventional cases, it makes use of gear train where there would some power losses during the gear change, load acting, different driving conditions etc. To overcome these problems, CVT system was adopted to minimize the transmission losses and to enhance the ease of drivability. The first use of CVT dates back to 1890 and was found in lawn mowers and small tractors. Later on, developments led to its adoption to the field of the automobile.

RELATED REVIEW WORK

The major parts of CVT are a belt which is usually made of steel or rubber or some thin, high strength materials and a pair of conically tapered pulleys. Usually, heat is generated during dynamic conditions i.e due to friction between the contact surfaces of the CVT components. A CVT in special purpose vehicles like Go-kart

BAJA-SAE, Formula Student prototypes directly exposed to the atmosphere, While CVT in automobiles like motorcycles and cars having a special outer casing which protects the CVT. Usually, CVT's in scooters are equipped with a fan to accommodate the air flow on to the pulley surface as well as the belt. Many research works are still being carried out to optimize the performance of CVT. Major works are being carried on in the fields of design to increase the life of the belt as well as the power being transmitted from primary pulley to the secondary pulley. In the process of lowering the temperatures of CVT researchers have concentrated on design modification of inlet and outlet on the outer casing of CVT which plays a key role in varying the air flow rate on to the CVT. *Dhongde S. et al. [1]* raised CVT in let area by four times to existing area due to which temperature of the belt was reduced by 13.9 % and also raised the number of blades over the centrifugal fan to improve the quantity of air flow on a pulley which resulted in the decrease in temperature by 21 % respectively. Provision of convergent baffles to force air from fan also lowered the belt temperature significantly. *Vaishya A. et al. [2]* examined and studied air flow path and air flow rate inside CVT casing. Increase in air inlets and outlet areas was 4.2% and 22.6% respectively which led to reduce air inlet temperature by 15⁰C and 13% increase in air flow at outlet respectively. Modifications reduced maximum belt temperature by 20⁰C and pulley temperatures by 5⁰C. *Karthikeyan N. et al. [3]* executed a CFD analysis on CVT for modifying the air flow path to reduce the temperature of the clutch. Change in fan design, provision of a convergent guide and increasing outlet area by 184% improved clutch housing flow by 40%. Clutch surface temperature was reduced by 8⁰C. A belt is majorly an important component and its properties are useful in studying the thermal characteristics of a CVT. The power transmission lost at belt end is due to bending, compression, and shearing of the belt due to friction, belt hysteresis, belt disengagement, engagement losses [4]. *Lolli Sergio et al. [5]* improved the shape and material characteristics of the belt to develop a new belt called CVTH belt. It is composed of a continuous link polymeric rigid material, rubber stiffened by fiber cords. Good distribution of belt contact area increase belt lifetime of 200 hours at 90 Nm torque was obtained. *Johannes wurm et al. [6]* developed a numerical model predicting thermal conditions of a CVT. A novel and time effective model were developed to find out the temperature profile. The heat generated in CVT is dissipated through CVT liquid in high-end automobiles. Many researchers were being carried out to evaluate the properties of these fluids for better heat dissipation. *Murakami et al. [7]* developed a new CVT fluid and evaluated its traction coefficient with respect to contact pressure, fluid temperature, and slip ratio. A CVT fluid was developed called T-CVT fluid which was superior to conventional fluids. *Bert Pennings et al. [8]* performed a fluid test to find cooling and heat dissipation characteristics which obtained notable results.

Method of Approach

Modeling of CVT is done based on BAJA-SAE Continuous Variable Transmission setup. It is further modified by increasing the surface area by adding rectangular and cylindrical fins on secondary pulley's surface. Considering an average base temperature of CVT's driven pulley surface as 80⁰C it is aimed at lowering the temperature to 60⁰C. With help of heat transfer calculating the number of fins required using interpolation or iterative processes and then modeling the fins using Solid works and import the modeling into Ansys workbench. Utilizing the thermal module in ANSYS WORK BENCH, required steady-state thermal analysis is performed and its results are compared with theoretical calculations.

Theoretical Calculations

Consider the outer shell of the pulley made of steel

Consider the fins on the pulley made of Aluminium Metal Matrix Composite

A Coefficient of heat transfer of steel = 7.9 W/m^2

A Coefficient of Heat transfer of Al Alloy = 10 W/m^2

Consider the outer diameter of pulley = 250 mm

The Outer surface Area of the secondary pulley is = 0.049 m^2

Consider the base temperature = 80° C

Ambient temperature around the CVT = 60° C

A Thermal conductivity of Al Alloy = 97 W/m.k

Heat transfer from secondary pulley surface without any fins: $Q = h \cdot A \cdot (T_a - T_b) = 7.742 \text{ W}$

Where

h is coefficient of heat transfer

A is the area of the pulley

T_a is the base temperature

T_b is the ambient temperature

Consider Rectangle Fin Dimensions As Follows

Thickness (t) = 0.5 mm

Width (w) = 30 mm

Length (l) = 40 mm

Perimeter = 0.061 m

Area = $1.5 \cdot 10^{-5} \text{ m}^2$

Heat Transfer through Single Rectangle fin:

$$Q = \sqrt{(h \cdot P \cdot K \cdot A \cdot (T_b - T_a) \cdot \tanh mL)}$$

$$m = \sqrt{(hP/KA)} = 20.47$$

$$Q = 0.399 \text{ W}$$

$$Q_{\text{fins}} = n \cdot [m \cdot K \cdot A \cdot (T_b - T_a) \cdot \tanh mL]$$

Where n is the no. of fins required

$$n = 19.30 \sim 20 \text{ Fins}$$

A Weight of single rectangle fin = 1.69 grams

A Weight of 20 rectangle fins = 33.8 grams

A Weight of pulley without fins = 6.88 kg

A Weight of the pulley with fins = 6.913 kg

Heat Transfer without fin through effective fin area = $3 \times 10^{-3} w$

A Volume of the single fin = 600 mm^3

Surface area generated for one fin = 2470 mm^2

Consider Cylindrical Fin Dimensions as follows

Diameter(d) = 0.016mm

Length(l) = 0.04 m

Perimeter = 0.050398m

Area = $2.0106 \times 10^{-4} \text{ m}^2$

m = 5.076 kg

Q for single fin = 0.3966 W

Q without fin through particular area = 0.040212W

A Weight of single cylindrical fin = 22.6gms

A Weight of 20 cylindrical fins = 452grams

A Weight of pulley without fins = 6.880 kg

A Weight of the pulley with fins = 7.332 kg

A Volume of the single fin = 8042.48 mm^3

Surface area generated for one fin = 2412 mm^2

MODELING AND ANALYSIS

Drafting of CVT

Figure 1: Front and Side Views of Primary & Secondary Pulleys Respectively

MODELING

A 3D CAD model of a mechanical assembly. It features two circular components, one larger and one smaller, connected by a long, thin arm. The larger component has a green face with a radial pattern of colored segments (yellow, blue, red, green, etc.) and a central hub. The smaller component has a brown face with a similar radial pattern. The arm is a thin, curved structure with a series of small, evenly spaced holes along its length. The entire assembly is shown in a perspective view against a light blue background.

Figure 3: Modelling of CVT Setup in Solid Works

Steady State analysis is executed in ANSYS WORKBENCH 18.2. It calculates the effects of steady thermal loads on the system or component. Analysts utilize the data obtained by performing a steady-state analysis before doing a transient thermal analysis, in order to obtain initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished. The required input values like coefficients of conduction and convection values are provided to obtain required results.

Initially modelled individual parts are two primary pulleys, two secondary pulleys, two connecting shafts, rectangular fins, cylindrical fins and a v-groove belt in Solid works part drawing module and then assembled them using solid works assembly module to obtain required dimensions with rectangular and cylindrical fins on it as shown in figure 4 and figure 8. On meshing, it generated more than seven lakh nodes in fine meshing where it could not generate the required results as it is beyond the scope of analysis. So examining the assembly of the single secondary pulley with rectangular and cylindrical fins as a system respectively and performed analysis to get required results.

Figure 4: Modelling of Secondary Pulley with Rectangular Fins on its Surface

Figure 5: Meshing of Secondary Pulley with Rectangular Fins on its Surface

On performing coarse meshing it generates 10403 nodes and 4631 elements.

Figure 6: Analysis of Secondary Pulley with Rectangular Fins on its Surface

Figure 7: Temperature Analysis of Secondary Pulley with Rectangular Fins on its Surface

Figure 8: Modelling of Secondary Pulley with Cylindrical Fins on its Surface

Figure 9: Meshing of Secondary Pulley with Cylindrical Fins on its Surface

On performing coarse meshing it generated 10403 nodes and 4631 elements.

Figure 10: Temperature Analysis of Secondary Pulley with Cylindrical Fins on its Surface

Figure 11: Heat Flux of Secondary Pulley with Cylindrical Fins on its Surface

RESULTS

Table 1

Fin	Theoretical Temperatures($^{\circ}\text{C}$)		Analysis Temperatures($^{\circ}\text{C}$)	
	Initial	Final	Initial	Final
Rectangular	80	60	80	62.101
Cylindrical	80	60	80	76.002

Table 2

Fin	Surface Area(mm ²)		Mass(grams)	
	1 fin	20 fins	1 fin	20 fins
Rectangular	2470	49400	1.69	33.8
Cylindrical	2412	48240	22.6	452

A Weight of the secondary pulley with rectangular fins = 6.913 kg

A Weight of the secondary pulley with cylindrical fins = 7.332 kg.

CONCLUSIONS

From the obtained results, there is an increase of surface area by 33.47% using rectangular fins while there is an around 32.94% increase in surface area by using cylindrical fins. There is a decrease in temperature by 21.8% using rectangular fins, nearly 5.67% only by using cylindrical fins. With rectangular fins, the mass of the pulley increases by 0.47% only but cylindrical fins with 6.16%. This concludes that rectangular fins are more effective in terms of mass, heat transfer, effectiveness and feasibility of manufacturing as well as the economy.

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