Modeling and Thermal Analysis of Continuously Variable Transmission (CVT)

1Vijaya Raju Kommu, 2Parvataneni Venkata Jagan Mohan Rao
1PG Student, Andhra University College of Engineering, Visakhapatnam, Andhra Pradesh, India.
2Professor, Marine Engg Department, Andhra University College of Engineering, Visakhapatnam, Andhra Pradesh, India.
Email id. vijayaraju002@gmail.com, pvjmr567@gmail.com.

Abstract- Continuously variable transmission (CVT) is an automatic transmission used to obtain infinite gear ratios between driver and driven shafts. They are used in scooters, Baja vehicles etc. Engine power is transmitted from driver side to driven side (secondary) by means of a belt and pulleys. At higher speed instances and clutch slippage situations more heat is generated in CVT components and if it is operated for a long run it also affects the service life of components and simultaneously performance is reduced. So, cooling of CVT is necessary. The research aims at reducing the surface temperature around the pulleys of a CVT by changing material of the pulleys to increase heat flow rate and design modification of CVT. The temperature distribution and total heat flux is analyzed for different designs using steady state thermal analysis tool in Ansys.

Keywords: ANSYS; CATIA V5; FINS; GEAR RATIO.

Introduction
Transmission allows the variation of torque between engine crank and road wheels by using gearbox. Automobiles require different torque at various driving conditions. Transmission is mainly classified as manual transmission and automatic transmission. Manual transmission consists of changing gears manually by using a clutch and gearshift lever. So performance of transmission is dependent on skill of the driver. In automatic transmission gear change is done by sensing speed of the vehicle all automatically. There is no need of disengaging clutch and driver is free from gear changing efforts. Continuously variable transmission (CVT) is a step less automatic transmission which offers infinite number of gear ratios. A pulley based CVT is used for investigation in current work, which consists of two V belt pulleys which are split in between to accommodate the V belt. Primary pulley is connected to engine crank side and secondary pulley to wheel side. The gear ratio is changed by moving the two sheaves of one pulley closer together and the two sheaves of the other pulley farther apart, which changes effective diameter of both the pulleys. The contact between V belt sidewalls and pulley groove is the main source of heat generation in CVT. This temperature generation affects the service life of pulley and belt due to material degradation. Expansion of belt due to heat results in loss of transmission efficiency and less durability of CVT parts. Studies show that CVT temperature may reach up to 150 0C. Present paper deals with design modification and change in material of pulleys to achieve better heat dissipation properties. New material used is aluminium metal matrix composite (Al MMC) due to its high thermal conductivity and design modification involved provision of fins.

Continuously Variable Transmission
The continuously variable transmission (CVT) is a transmission in which the ratio of the rotational speeds of two shafts, as the input shaft and output shaft of a vehicle or other machine, can be varied continuously within a given range, providing an infinite number of possible ratios. A CVT need not be automatic, nor include zero or reverse output. Such features may be adapted to CVTs in certain specific applications. Other mechanical transmissions only allow a few different discrete gear ratios to be selected, but the continuously variable transmission essentially has an infinite number of ratios available within a finite range, so it enables the relationship between the speed of a vehicle, engine, and the driven speed of the wheels to be selected within a continuous range. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient speeds within a narrow range.

Fig 1. Continuously variable transmission
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CVT
How CVTs work and how they improve performance etc…. The purpose of CVT is to vary the transmission ratio continuously.

Working of CVT depends on the type of CVT
- Friction CVTs vary the radius of the contact point between two rotating objects, thus the tangential velocity;
- Hydrostatic CVTs vary the fluid flow with variable displacement pumps into hydrostatic motors;
- CVT improves efficiency by allowing the engine to operate always in its optimum R.P.M., whatever the vehicle's speed.
- What are the benefits of operating in the optimum R.P.M.?
  - Lower consumption;
  - Less greenhouse gas emissions;
  - Better performance;
- CVT is the ideal transmission, so why are there so few CVT cars? The existing inventions are based on
  - Friction, hydrostatic, Ratcheting which are all mechanical systems with inherent limitations, (compared to traditional transmissions).
- How to extract the full CVT potential?
  - A conceptual innovation is the only way out. Although, research continues improving the friction CVTs and ratcheting CVTs, these efforts are accomplished by expensive high tech materials and precision manufacturing. This is to overcome the inherent limitations of these concepts (friction and ratcheting).

Principle of CVT Transmission
As an ordinary gear box CVT also works on the same gearing principle that when we attached a big driving gear to one small driven gear we obtain high torque and vice versa. But the CVT does not used gear to obtain speed ratio of transfer power. The other power transmission system belt drive used in CVT can change its diameters. There are three main component of CVT which make is able to obtain infinite speed ratio transmission. These are a variable input driving pulley, a variable output driven pulley and a metallic belt.

Apart from these, there are also various microprocessors and sensors and even epicyclic gearing and clutch. Both the driving and driven pulleys are of variable diameter type. Each pulley is made of two 20 degree cones facing each other. A belt is there in the groove between the two cones. The belts are specially constructed to provide for the required flexibility.

The driving pulley is connected to the engine crankshaft while the driven pulley transfers motion to the drive shaft. When the two cones of the pulley are close together, the belt rides higher in the groove and the pulley diameter apparently increases, whereas the belt rides lower in the groove, making the effective diameter decrease, when the two cones of the pulley are far apart. These cones are moved closer or far apart using hydraulic pressure, centrifugal force or spring tension.

Literature Review
Design modification of belt is also a way to decrease heat generation. Bertini, L., L. Carmignani, and F. Frendo. "Analytical model for the power losses in rubber V-belt continuously variable transmission (CVT)", the power is lost to bending, compression and shearing of the belt from friction, belt hysteresis, belt engagement and disengagement. Losses depend upon properties of the belt [1]. Karthikeyan N. et al. [2] performed CFD analysis of CVT for air flow path modification to reduce clutch temperature. Change in fan design, provision of convergent guide and increasing outlet area by 184 % improved clutch housing flow by 40 % and clutch surface temperature reduced by 8⁰C. Vaishya A. et al. [3] studied air flow path and air flow rate inside CVT casing. Increase in air inlet and outlet area was 4 % and 22 % respectively. Corresponding changes were reduction in air inlet temperature by 15 ⁰C and 13% increase in air flow at outlet. Modifications reduced maximum belt temperature by 20 ⁰C, also driver and driven pulley temperature reduced by 5⁰C. Lolli Sergio et al. [4] improved shape and material characteristics of belt to develop a new belt called as CVTH belt. It composed of a continuity element, polymeric rigid material and rubber stiffened by fiber cords. Dhongde S. et al. [5] increased CVT outlet duct area by 4.2 times the existing area and number of blades of centrifugal fan was increased to improve air flow on pulley. Due to these changes belt temperature and driven pulley temperature reduced by 14 % and 20 % respectively. Provision of convergent baffles to force air from fan increased the belt temperature. Belt is a crucial component in thermal characteristics of a CVT.

Problem Identification
- The CVT is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the weight.
At higher speed instances more heat is generated in CVT components and if it is operated for a long run it also affects the service life of components and simultaneously performance is reduced. So, cooling of CVT is necessary. Improper design leads to failure, because without better heat transfer rate over heating occurs which cause materials to fail.

**Design Methodology**
Pulley based CVT model is created in CATIA V5 from the drawings of B&S engine with a capacity of 10hp which is used in BAJA vehicle Figure 1 and Fig.2 shows the dimensions of movable and fixed pulley on primary clutch side respectively. Figure 3 shows dimensions of fixed and movable pulleys on secondary clutch.

![Fig 2. Fixed pulley on the side of primary clutch](image)

![Fig 3. Fixed and movable pulleys on secondary clutch](image)

Three dimensional sketch of CVT drawn from given dimensions is showed in above Figure. Belt used for this type of CVT is made of cogged version of steel. Specifications of belt are mentioned below:
- Belt length: 1022.54 mm
- Belt dimensions: 18.66 mm x 10 mm
- Internal groove angle: 60°

**Objectives**
1. Analytical design of CVT using Baja Vehicle.
2. Obtaining design of CVT using CATIA v5 and then imported in Ansys 14.5.
3. Comparing the performance of two different designs with fin and without fins.
4. Analysis of CVT by STEADY-STATE THERMAL analysis.
5. To find which design gives better heat transfer rate and temperature distribution results.
6. Identification of the suitable design for CVT.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>108.2 Gpa</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>320.6 Mpa</td>
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<tr>
<td>Thermal Conductivity</td>
<td>97 W/m-k</td>
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<tr>
<td>Specific heat capacity</td>
<td>0.798 J/g-°C</td>
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<tr>
<td>Mass density</td>
<td>2.75 g/cc</td>
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<tr>
<td>Poisson’s ratio</td>
<td>0.33</td>
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<tr>
<td>Coefficient of friction</td>
<td>0.37</td>
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<tr>
<td>Tensile strength at upper yield point</td>
<td>260 Mpa</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>14 x 10-6°/C</td>
</tr>
</tbody>
</table>
Brief Overview of Structural Static Analysis

Static analysis is one in which the loads/boundary conditions are not the functions of time and the assumption here is that the load is applied gradually. The most common application of FEA is the solution of stress related design problems. Typically in a static analysis the kind of matrix solved is

\[
[K] \times [X] = [F]
\]

Where \( K \) is called the stiffness matrix, \( X \) is the displacement vector and \( F \) is the load matrix. This is a force balance equation. Sometimes, the \( K \) matrix is the function of \( X \). Such systems are called non-linear systems.

Nodal Displacements \( u_i, u_j \)
Nodal Forces \( f_i, f_j \)

Spring constant \( k \)

Spring force displacement relationship

\[ F = k \Delta \] with \( \Delta = u_j - u_i \)

\( K = F/\Delta (>0) \) is the force needed to produce a unit stretch

Consider the equilibrium forces for the spring. At node \( i \), we have

\[ f_i = -F = -k(u_j - u_i) = kui - kuj \]

And at node \( j \),

\[ f_j = F = k(u_j - u_i) = -kui + kuj \]

Element Quality Requirements

There are certain parameters that determine the quality of the results. The engineer has to ensure that these parameters maintained within the acceptable limits of the software for obtaining the good results. These are called mesh quality parameters.

Warp age Warp age occurs only on Quad and Hexa elements. Since three points define a plane, one of the four nodes being in different plane by an angle causes warp age. The perfect warp age value desired is zero.

Analysis Procedure

Create the geometry in catia workbench and save the file in IGS format and open Ansys workbench apply engineering data (material properties), create or import the geometry, apply model(meshing), apply boundary conditions(setup) shown the results(stress, deformation, heat flux) meshing figure

Steady state thermal analysis is used to find out the temperature distribution around the surface of pulleys of CVT in ANSYS work bench. Maximum heat is generated on belt surface where thermal analysis is done by applying temperature of 150°C. Base model and modified design model are analyzed. Surface temperatures around the surface of pulley of both the designs are compared.

The boundary conditions are:

- Initial temperature: 22°C
- Maximum Temperatures over the belt: 150°C
- Convection film coefficient between steel and air: 7.9 W/m²°C
- Convection film coefficient between Al MMC and air: 147 W/m²°C
Results and Discussions
Thermal analysis of base model CVT is done by applying given boundary conditions and temperature distribution solution is shown in Fig 5. It shows the maximum temperature reached on secondary pulley and temperature on primary pulley where as belt temperature is still near 150 °C.
Temperature distribution
The graph between the with fins and without fins
We can observe that in case of temperature distribution, CVT made of ALMMC, Belt is steel material and is found to have better temperature distribution as shown below graph.

Total heat flux
The graph between the with fins and without fins
We can observe that in case of total heat flux, CVT made of AL-MMC, Belt is steel material and is found to have better heat flux as shown below graph.

Conclusion
Providing fins and changing material of CVT pulleys caused a drop in temperature of CVT system. Temperature distribution is minimum 50.776°C with fins & without fins is 130.65°C. Total heat flux with fins 2.1104w/mm² & without fins is 1.9225w/mm² are noted and tabulated, With fins 5% better heat transfer rate compared to without fins. Finally 45 % of variation between these two CVT’s, finally fins design gives better heat transfer rate and temperature distribution results concluded arrange fins.

References