STUDY OF HEAT TRANSFER ANALYSIS OF CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

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ABTRACT: The heat generated in CVT during high load conditions is huge and leads to high thermal loads. Particularly, rubber belt suffers from high temperature peaks and their life span reduces significantly. Thus, expansion of belt due to heating results in loss of transmission efficiency and less durability of CVT parts. Thermal analysis had been carried out in the earlier researches which calculate the temperature of the belt and the pulley. During running condition, CVT temperature may exceed 150 °C which then reduces lifespan of the rubber belt. Thus, sufficient cooling must be provided to CVT. Being a delicate task for open CVT system, it becomes even worse for enclosed CVT system. But enclosing of CVT is required in order to protect the system from dust, mud and water to avoid belt slipping. Computational fluid dynamics (CFD) approach is used to analyze the temperature distribution of pulley and belt. The problem is being solved using steady-state method since transient approach is not feasible. Transient simulation increases the computational time as well as cost. In our work, our focus is on increasing the life span of belt by maintaining the belt temperature at or below 150 °C. Proper analysis were carried out to study the flow behavior of the air inside of CVT casing. Thus our aim is to design a closed CVT casing to increase the flowrate of air for cooling the belt as well as pulleys.

Key words: CVT; Thermal Analysis; StarCCM+; Al MMC; Fluoroinert

INTRODUCTION:

A Continuous variable transmission is an automatic transmission used to obtain infinite gear ratio within a definite range between driving and driven pulleys. It consists of two pulleys having fixed as well as movable sheaves and variable in their diameters and a belt wrapped around them. Fixed sheave of driver pulley is connected to the engine crankshaft, and the movable sheave of driven pulley is attached to the output drive.

The torque provided by the engine is taken by the driving pulley and it is transmitted to driven pulley by belt. Transmission allows the variation of torque between engine crank and road wheels by using different gear ratios. Automobile requires different torque at different driving conditions. Transmission is mainly classified as manual transmission and automatic transmission. Former consists of changing gears manually by using a clutch and gearshift lever. So the performance of transmission totally depends on skill of driver; whereas in automatic transmission, gear change is done by sensing speed of the vehicle all automatically. There is no need of disengaging clutch and the driver is free from gear changing efforts. It is a step less automatic transmission which offers infinite gear ratios. The gear ratio is changed by displacing movable sheaves of both the pulleys according to load required and speed transmitted, which changes the effective transmission ratio of both the pulleys. CVTs are used in various scooters, BAJA Vehicles, Lawnmowers, etc. During normal running conditions of the vehicle considering appreciable load, belt temperature may reach upto 150°C.At high loads, more power is required and subsequently more slippage occurs between belt and pulley due to frictional forces acting on them, thus generating heat at the contacts. At higher speed instances and clutch slippage situations, more heat is generated in CVT components and if it is operated for a long run, belt temperature may exceed 150°C. The Contact between V belt grooves and pulley sheaves is the main source of heat generation in CVT. Also, interference of foreign particles like dust or mud between CVT sheaves and belt reduces performance of CVT. This affects reduction in service life of pulley and belt due to the material degradation and deformation in the belt. Thermal Expansion of belt causes slip due to heating which results in the loss of transmission efficiency and less durability of the CVT parts. It may also cause hysteresis of the belt material in both longitudinal and transverse directions resulting in the cyclic deformation of the belt. This research aims at reducing the surface temperatures of pulley and belt so as to increase the life span of belt.

Heat generation and heat transfer are studied previously by various papers. First, components of CVT that may reach high temperatures are studied and efforts made to reduce heat transfer rate by extended surfaces methods. Also nature of temperature distribution is studied on heated disk. In order to increase belt life span, main objective is to increase heat transfer rate either through pulley to atmosphere and through belt to pulley. There are various methods by which this objective can be achieved with good outcomes. This project also deals with one of the methods among all to approach cooling of pulleys by forced convection.

LITERATURE SURVEY:

Increasing the lifespan of belt becomes our main concern in this project, thus we need to find many ways of belt cooling and other CVT components. To understand this, we first need to Analyze the temperature distribution of CVT pulleys and belt during normal running. Once the temperature distribution is understood, ways to cool down the CVT components can be found out.

Dhongde S. et al. [4] worked to identify the parameters which affect temperature change in CVT components such as Front Movable Drive (FMD), Clutch Pulley, Clutch outer and the belt. Experiments were performed on a 100cc Scooter engine by following customer driving pattern on chassis dynamometer. They fixed K-type Thermocouples on each of the component and tested the CVT for various trials with some modification in CVT housing and other parameters in each progressing trial. By this methodology, they were able to observe trend in temperature change of CVT components.

Johannes Wurm et al. [1] thought of modelling time efficient method to find temperature distribution of CVT pulleys. In their first paper, the objective was to develop a time efficient numerical model to compute temperature distribution of a fast rotating heated disk that is locally cooled by forced convection.

They focused on Enclosed CVT system for their work and performed Transient as well as Steady-state simulations for heated disk of Brake disk system to compute tangential homogeneous and radial symmetric surface temperature profile on it. They experimentally compared transient simulations by overset mesh method and steady state simulations using MRF approach and concluded the effect of both would be similar if steady state simulation is done by presuming constant speed of Driving and Driven pulleys as well as constant load case. By using simple Newton's law of cooling, they computed relation for surface heat transfer by-

$$q_{s} = \frac{\rho(y_c).C_p(y_c).u_\tau}{T^+\left(y^+(y^c)\right)}(T_s - T_c) \qquad \ldots [1]$$

Where, C_p is the fluid specific heat capacity, u_τ is velocity scale based on wall shear stress, T^+ is dimensionless Temperature, y^+ is dimensionless wall distance and y_c and T_c are normal distance and Temperature of near wall cell.

Any rotating disk can be compared or considered for the similar work with different application. They used Enclosed CVT with one decentral inlet and one tangential outlet channel for practical purpose and used commercial software package StarCCM+ for simulation purpose. They found MRF approach to be capable of computing significant flow structures. However, main disadvantage of MRF approach is that thermal stresses cannot be taken into account for a rotating disk. Thus the temperature distribution on the disk surface without developed temperature compensation is shown in Fig 1. Homogenization of surface temperature demands equalization of Boundary heat flux. Thus Heat flux generated on pulley surfaces is shown in Fig 2.

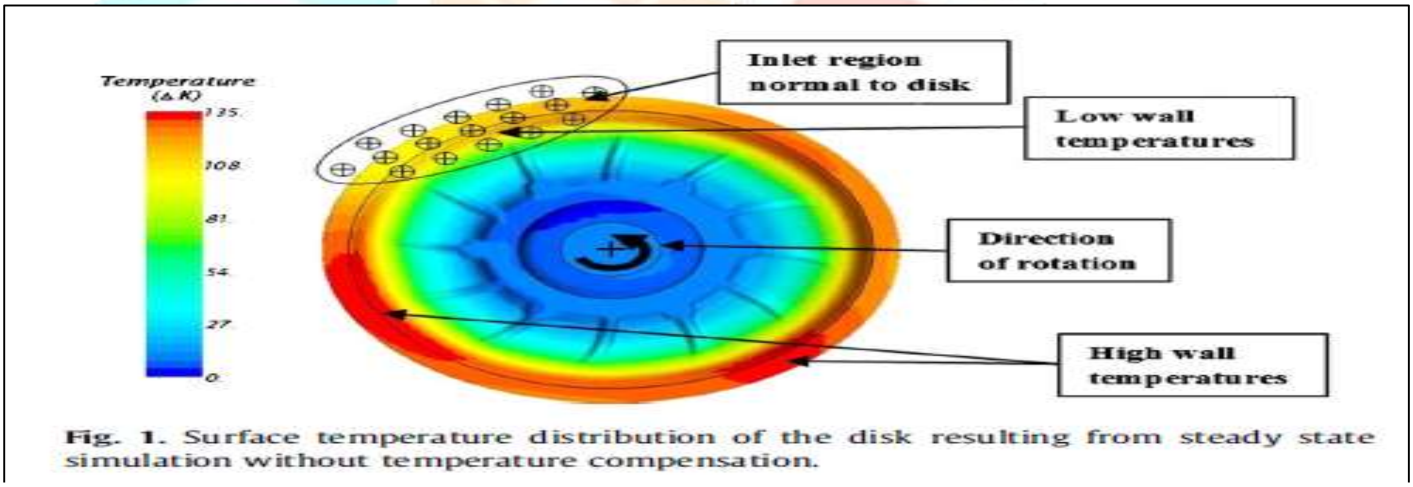

Fig 1: courtesy: novel cfd approach for the thermal analysis of continuously variable transmission(cvt), [1]

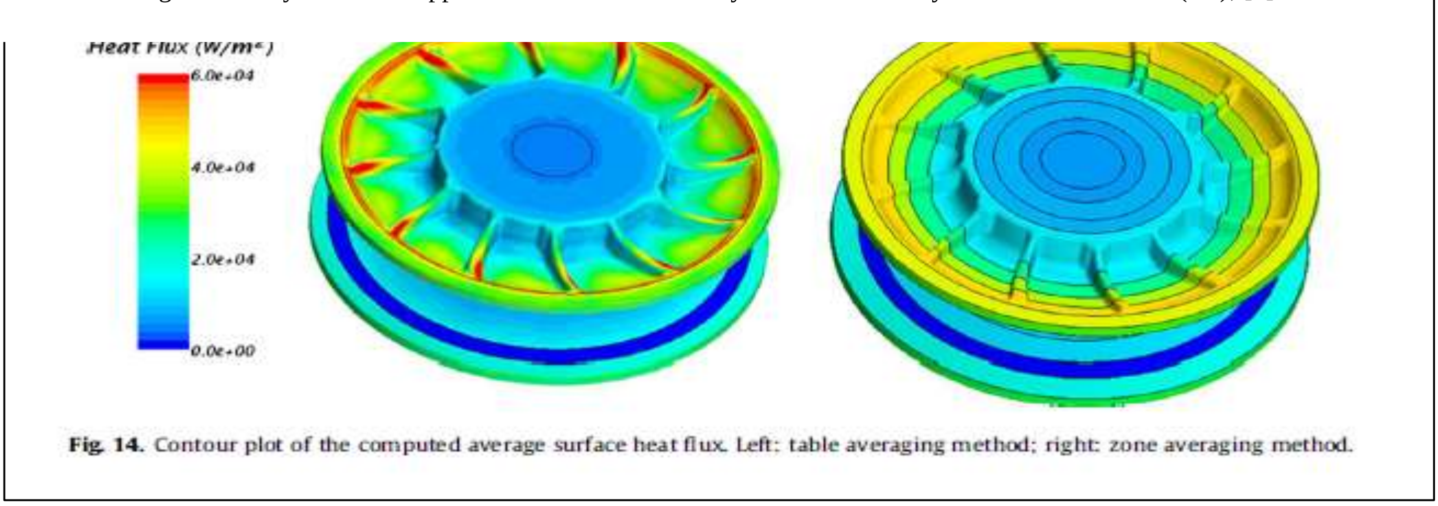

Fig 2: courtesy: novel cfd approach for the thermal analysis of continuously variable transmission (cvt) [1]

Then they themselves modified the design of casing to analyze impact on fuel economy and effect on efficiency. In that, basically two inlets and two outlets were provided to CVT casing. Pipes were mounted on inlet and outlet ports to calm down the airflow and minimize the measurement error. In this test rig, torque provided to driving pulley and torque taken by driven pulley are monitored. They also measured speeds of both the pulleys and found the power transmitted to driving pulley and power delivered to driven pulley. Hence difference in these powers, they equated to heat generated.

Fig. 1. CVT- Test Setup

Fig 3: courtesy: advanced heat transfer analysis of continuously variable transmission (cvt) [2]

They selected pulleys made of Aluminium Alloy having thermal conductivity of 130 W/m-K. Highest temperature on belt always occurs at contact surfaces of pulleys and belt and heat transfer to colder regions become more efficient. Temperatures were noted after five minutes of continuous running at 7500 rpm. Five temperature sensors were mounted on setup. Simultaneously Quasi-steady-state simulations were performed for same case and deviation in temperature result was found to be approximately 4 K.

Mayur Patil et al. [3] focused on modification in pulley design by using extended surface area method to increase the heat transfer rate from pulley surface to surrounding. They used AL MMC T5 which is having grade of A356 having 20% SiC reinforcement and thus, high thermal conductivity than that of steel of 97 W/m-K, low weight (2.75 g/cc), low wear, high strength (320 MPa) and low coefficient of thermal expansion (14e-6 /ºC). B&S Engine with 10Hp capacity is considered which is used in BAJA vehicle and fins are attached to Driving pulleys (secondary pulleys). For initial ambient temperature 22 ºC, belt temperature 150 ºC, Convection film coefficient between air and steel is 7.9 W/m^2-K and Convection film coefficient between aluminium and air is 147 W/m^2-K, They managed to reduce the temperature of driving and driven pulleys by 12.67ºC and 15.47ºC respectively by increasing the heat transfer area by 27.41% by applying fins.

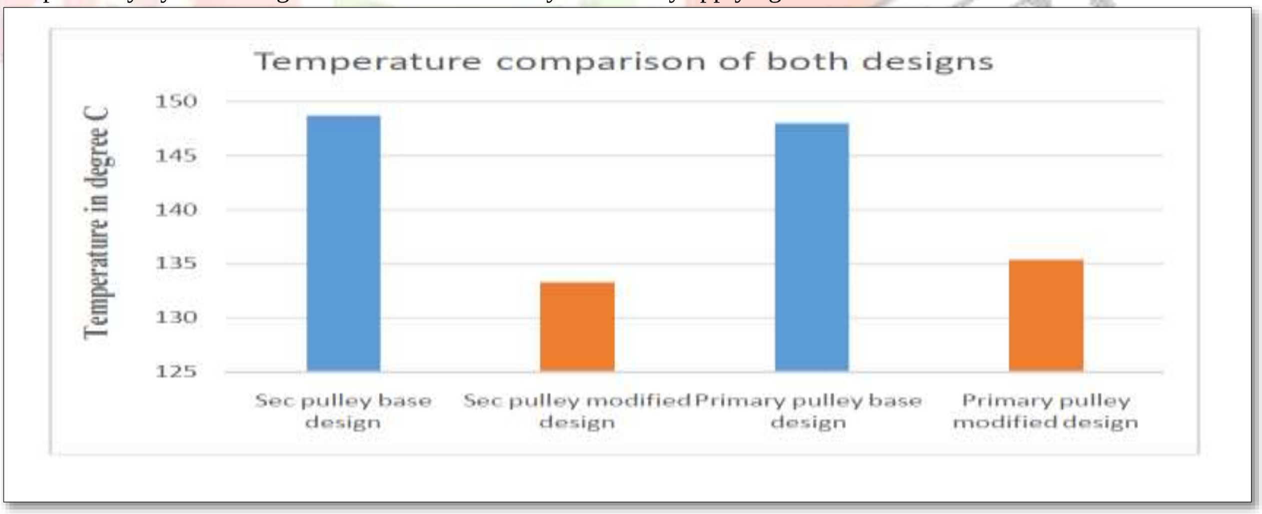

Fig 4: courtesy: a study of cooling of continuously variable transmission (cvt) [3]

Jorge C. Lallave et al. [5] analyzed heat transfer rate from a rotating heated disk on impinging a fluid jet. The objective of this study was to investigate how the heat transfer is affected by rotation of disk. The model covers the entire fluid region (impinging jet and flow spreading out over the rotating surface) and the solid disk as a conjugate problem. Calculations were done for a number of disk materials and working fluids such as water, ammonia, fluoroinert and lubricating oil for various flow and spinning rates. It was found that plate materials with higher thermal conductivity maintained a more uniform temperature distribution at the solid–fluid interface. A higher Reynolds number increased the local heat transfer coefficient reducing the wall to fluid temperature difference over the entire interface. The rotational rate also increased local heat transfer coefficient under most conditions. The simulation results compared reasonably well with previous experimental studies.

From the above literature review, it can be noticed that, to improve Belt life span, temperature of belt should be at or below 150 ºC. Heat transfer from pulley must be increased or the air flow from casing must be improved which will ultimately reduce the pulley temperature and thus the belt temperature. Johannes Wurm, et al. developed a time efficient method to compute the temperature distribution on CVT pulleys. This reduced the time consumption from 93 days to 17 hrs. Mayur Patil et al. reduced the temperature of Pulleys by using extended surface method.. So, to increase the heat flow from CVT components extended surface Area can be a better option. Jorge C. Lallave et al. studied the effect of rotation of disk on heat transfer by jet impingement through disk to fluid medium. So, to increase the net heat transfer rate through CVT pulleys, both Forced Convection as well as effectiveness of fins can be optimized.

METHODOLOGY:

Maintainig lifespan of CVT belt being our main objective, review is taken from various papers related to thermal analysis on CVTs and similar objects like rotating cylinder, etc. The major heat is generated due to frictional forces between pulleys and belt. Hence, to reduce heat generated, continuous cooling is to be provided to either of the pulleys.General methodology to provide cooling is to apply fins to pulley surfaces. This is the traditional method and trials are made to increase the effectiveness of fins so that overall fin efficiency will increase.

If surface area is kept as it is, another idea comes into practical application is convection heat transfer. This depends upon the fluid medium used. In CVT, fluid like water and oils cannot be used as they would act as lubrication there and lead to more power loss and also corrosion problems. Hence to provide cooling, air is the only option and it suggests forced convection over pulleys. Including additional air compressor system along with CVT will affect the mechanical efficieny of CVT; But if that loss is economical with respect to life span of CVT components, that can also be adopted as cooling option. As our CVT system is closed casing system, we look to modify casing design in order to increase degree of forced convection. In most of the rotating machines, lubrication is essential for smooth functioning and it is provided internally of each component. This idea also can be used for cooling purpose. Providing path from inside of shaft to CVT pulleys, any applicable fluid can be selected then for cooling purpose.

Among all methods, method in our scope is to modify casing design to increase overall forced convection rate. In this, driving pulley will be our main focus and concept of jet impingement can be used to provide forced air convection.

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