

Measurement of Oil Film Pressure on Running Continuously Variable Transmission Pulley - Part 2: Oil Film Thickness Calculation Based on EHL Theory

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ABSTRACT

In order to maintain the performance of push belt Continuously Variable Transmissions (CVT) over a long period of time, it is important to acquire a fundamental understanding of lubrication performance between a pulley and a metal V-belt. This work examined oil film thickness using the contact pressure on a sliding surface of pulley sheave during driving, which was obtained with a uniquely developed measurement technique. The contact between a belt element and a pulley sheave was treated as a group of small elliptical contact zones. The pressure-viscosity characteristics of lubricant were assigned to Reynolds equation with Roelands experimental formula. Also, in order to increase convergence of the calculation, a multigrid method was used. Calculation results indicate that the oil film thickness at a peak contact pressure measured was approximately 0.3-0.4 μm .

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INTRODUCTION

A severe lubrication condition of machine components causes oil film to become thin. In such a condition, subtle fluctuation occurred in oil film greatly affects part functionality and durability. It is therefore necessary to grasp these changes in detail. However, except for sliding / rolling condition in which an oil film is relatively thick, such as a piston ring surface [1] and a journal bearing surface [2], the oil film pressure and thickness in automotive parts have not been successfully measured. This is primarily due to the difficulty of technology that makes it possible to measure contact pressure or oil film thickness directly in harsh sliding / rolling condition such as elastohydrodynamic lubrication (EHL) and boundary lubrication.

The aim of this work is to acquire fundamental understandings of lubrication performance while machine parts perform in harsh sliding / rolling conditions. In order to achieve in-situ measurement, the authors developed a thin film pressure sensor with a robust protective layer, and that was formed on a CVT pulley sheave. Moreover, we developed a micro data logger system, which can directly be mounted on rotative machine components. Based on these methods, contact pressure on a CVT pulley sheave was measured.

This work examined oil film thickness distribution using the measured pressure. Numerical analyses based on EHL theory have been widely conducted to predict pressure and/or thickness distributions of fluid film formed on various sliding/rolling surfaces. This study introduces to EHL theory not only component shape and lubricant properties but also the pressure data acquired on a CVT pulley surface, attempting to obtain more accurate oil film thickness.

METHODS OF ANALYZING OIL FILM THICKNESS BASED ON ACTUAL MEASURED PRESSURE

Following sections describe how pressure data obtained on the pulley surface was applied to the calculation model.

Contact Pressure of Operating CVT Pulley / Belt

A thin film pressure sensor was formed on a CVT pulley surface using sputtering and plasma Chemical Vapor Deposition. Mounting the micro data logger system on the pulley, the contact pressure on the pulley from belt elements was measured while the CVT was operating. Details of the conditions for sensor formation and measurement are listed in the previous report [3]. Measurement results are shown in [Figure 1](#).

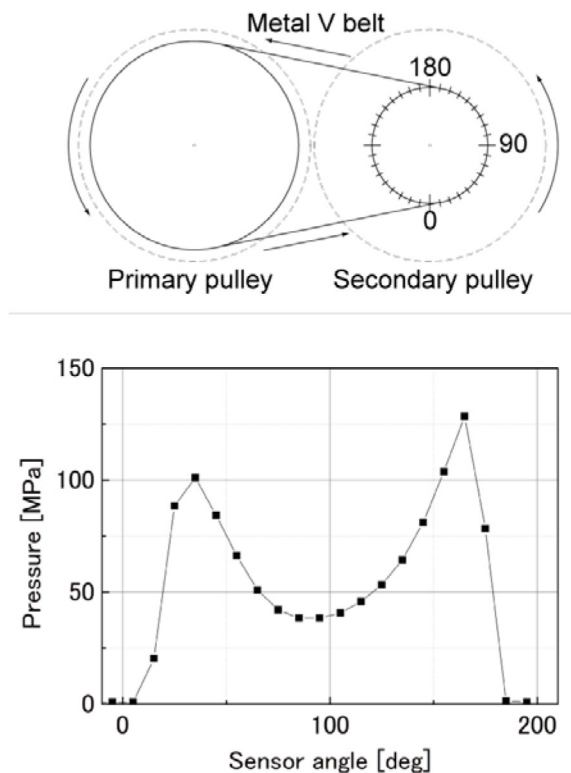


Figure 1. Contact pressures measured on an operating CVT pulley. The measurement was carried out on a secondary movable pulley sheave.

The pressure values show local maximum at near 30°, which is directly after the contact between a pulley and a push belt, and near 160°, which is directly prior to their separation. In the regions where the pressure rises steeply, lubrication state is harsher. Therefore oil film thickness calculation was conducted referring to the local maximum values.

Modeling of Belt Element / Pulley Contact

Calculations were carried out based on the following three settings.

Concave and convex are periodically fabricated on a belt element surface where a pulley sheave contacts. The analysis assumed that a group of convex shape formed elliptical contact zones on a pulley surface as shown in Figure 2.

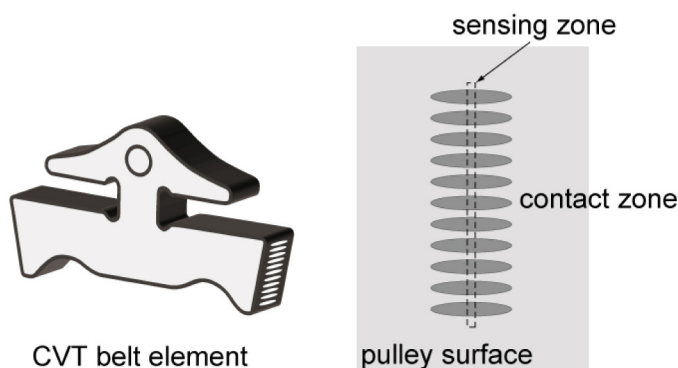


Figure 2. Contact zones between a pulley sheave and an element

In order to efficiently analyze oil film thickness near regions of high pressure where the film is believed to be the thinnest, operations below 1-3 are added to the measurement data in Figure 1 and motion is handled as the sliding / rolling contact motion shown in Figure 3.

1. Extraction up to the initial pressure peak
2. Extraction from the 2nd pressure peak until the pressure is 0
3. Assumption that pressure changes in 1 and 2 will occur continuously

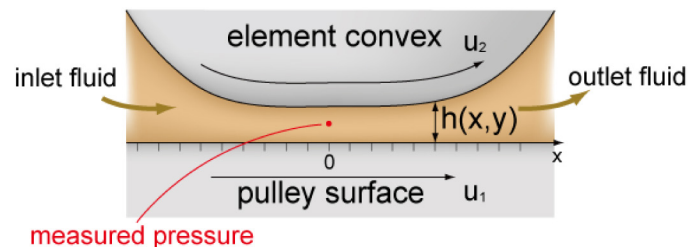


Figure 3. Rolling contact model

Each of the contact pressures in Figure 1 indicates mean values that the multiple convex shape on a belt element shown in Figure 2 contacted the sensor on a pulley sheave. The peak pressure on one convex should therefore be higher than the measured value. In order to consider this effect, the rule was added that the integral of the pressure distribution must be equal to the load obtained by multiplying the sensor area by the measured pressure.

Calculation Equations and Techniques

Governing Equation

Reynolds Equation

Reynolds equation was used to model the flow of lubricant oil as shown in formula (1). It ignores the inertial force of the fluid in Navier-Stokes formula and assumes a sufficiently narrow gap vis-a-vis analyzed surfaces [4].

$$\frac{\partial}{\partial x} \left(\frac{\rho h^3}{12\eta} \frac{\partial p}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\rho h^3}{12\eta} \frac{\partial p}{\partial y} \right) - \frac{\partial(u_m \rho h)}{\partial x} - \frac{\partial(\rho h)}{\partial t} = 0 \quad (1)$$

Here, p is the oil film pressure, h is the gap height of between two opposite surfaces-specifically, oil film thickness. u_m is the mean velocity of the moving surfaces. The movement direction is $+x$ and the y -direction is normal to that. Viscosity η and density ρ are functions of pressure respectively. Sufficient oil was assumed to exist on the inlet side of the contact zone.

Sometimes calculated pressure could be negative during a calculation process. This can be explained physically as the occurrence of cavitation produced by fluid pressure decline. At this time, however, the assumption was made that this negative pressure and treated it as zero. Even if a negative