Proceedings of WTC2005
World Tribology Congress III
September 12-16, 2005, Washington, D.C., USA

WTC2005-63532

THERMAL INFLUENCE ON TORQUE TRANSFER OF WET CLUTCHES IN LIMITED SLIP DIFFERENTIAL APPLICATIONS

Pär Marklund, Rikard Mäki, Roland Larsson, Erik Höglund
Luleå University of Technology
Div. of Machine Elements
S-971 87 Luleå, Sweden

Michael M. Khonsari, Joonyoung Jang
Dept. of Mechanical Engineering
Louisiana State University
Baton Rouge, LA 70803, USA

Bager Ganemi
Statoil Lubricants
Box 194, S-149 22 Nynäshamn, Sweden

Richard Olsson
Haldex Traction
Box 501, S-261 24 Landskrona, Sweden

ABSTRACT

Wet clutches operating under low velocity and high load are studied with the aim of obtaining reliable models for the torque transfer during boundary lubrication conditions.

INTRODUCTION

Disk-type wet clutches are exceedingly important for controlling torque transfer in modern drive trains for both two- and four-wheel drive passenger cars. Modern drive trains are generally equipped with on-board computers that make it possible to predict the vehicle dynamic in real time and enable quickly response to changes in the differential settings. Implementation of this system requires good theoretical or semi empirical models that are capable of accurately predicting torque transfer as a function of the actuator signal at any given operating condition.

The common simulation approach is to study an engagement from a high velocity to a state of lock-up. Typically the Reynolds equation is used to predict the torque and film thickness at the beginning of the engagement and then a measured friction characteristic is applied to the boundary friction at the later part of the engagement. In order to obtain good agreement with experimental data, it is necessary to include an appropriate thermal model to compensate the change of fluid viscosity during the engagement. The boundary friction, however, is generally not compensated for temperature [Berger, Jang].

Traditional engagement models are generally not suitable for application to limited slip differential (LSD) applications. An LSD-clutch is generally engaged from a rather low velocity, making the contribution of the full-film Reynolds equation less important. The common approach of using flow factors in the model can not be applied since the oil film thickness is so small that the flow factors are not valid [Patir & Cheng]. In addition, it is not always desired to reach a state of lock-up, but rather to allow a controlled limited slip, hence transferring only a certain given torque. Since this period of limited slip can be long, a significant amount of heat might be generated, making it important to use a temperature dependant model for the boundary, or asperity, friction.

The aim of this work is to develop a technique suitable for modeling thermal behavior and torque transfer for wet clutches in LSD-applications.

APPROACH AND NOMENCLATURE

The wet clutch model of Jang and Khonsari [Jang], with a somewhat modified boundary friction model, was applied to investigate an LSD clutch (velocity < 0.5m/s, pressure > 5MPa). It was found that the contribution from the Reynolds equation to the transmitted torque is negligibly small, since the system primarily operates in boundary lubrication regime. Thus, the Patir and Cheng flow factors are not applicable. For the working conditions in an LSD application, a boundary friction model only depending on velocity is not sufficient because friction is influenced by the heat generated.

Based on these findings a new approach was adopted. This model is valid at low velocities. For applications where the velocity can be expected to be in excess of somewhere around

1m/s, it should be combined with a model including hydrodynamic effects by using Reynolds equation where inertia forces on the fluid are taken into account.. The suggested model features a semi-empirical boundary friction model that calculates the friction as a function of sliding velocity, temperature, and applied pressure. This friction model is connected to a thermal model that predicts the temperature in an LSD clutch based on current operating conditions and the temperature history of the clutch.

Thermal Model

The thermal model considers heat dissipation in the fluid as well as heat transfer into the separator, friction material, and core disc. The calculation domain is one half of the thickness of the separator disc and friction disc, respectively. Since the simulated friction discs are considered to be located in a clutch consisting of several similar discs, the heat conduction over the edges in axial direction is neglected due to symmetry [Zagrodzki, Yang]. Temperature in the domain is solved with a finite difference method for a frictional heat source with friction coefficient calculated according to the boundary friction model. The cooling oil flow is approximated by a simple energy dissipation depending on clutch velocity and temperature.

Boundary Friction Model

The boundary friction is modeled as a function of load, velocity and temperature based on an extensive amount of experimental data. The data is analyzed according to the method described in an earlier publication [Mäki], generating friction-velocity profiles for different loads (10 – 25kN) and temperatures (-40 - +200ºC). Each profile is fitted by the following equation, where μ is friction and v is sliding velocity.

$$\mu = C_1 \tanh(C_2 \cdot v) + C_3 v^{0.1} + C_4$$

The fitting parameters are stored for different loads and temperatures are stored in a matrix, and the friction is calculated using a linear interpolation between the closest two values.

Solution Technique

Engagement force, sliding velocity, and initial temperature are assumed to be known parameters and are given as input to the model. These parameters can be easily measured on-board the vehicle. The clutch is represented by an axisymmetric grid.

The friction in each sliding grid point is given by the boundary friction model at each time step based on velocity, pressure, and temperature. The generated heat is calculated based on the friction and velocity and is used in the thermal model to predict the temperature in the next time step. Based on this temperature, a new friction value is calculated. Finally, the transmitted torque is calculated by integration of the friction force over the clutch area.

RESULTS

Results from the simulation and measured data are presented in Figure 1, based on a test cycle in which the rotational speed increases linearly with time for ten seconds. The new model is able to give good predictions of temperature and transmitted torque. This temperature and velocity-dependent friction coefficient in combination with the temperature model of the friction discs enables one to perform simulations of longer clutch engagements. This makes the model useful for simulating real working conditions of the clutch, when located in an LSD mounted in a vehicle drive train.

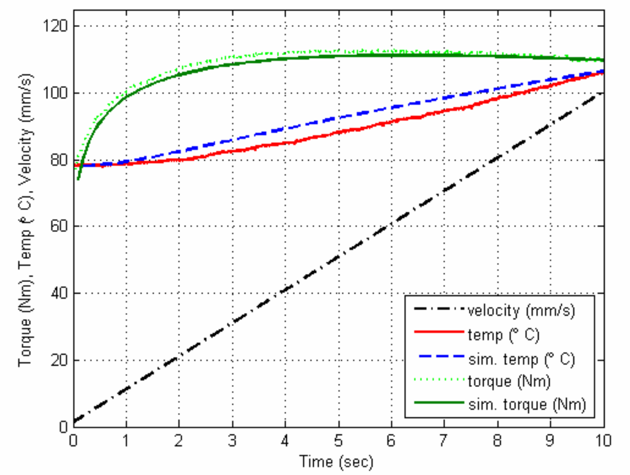

Figure 1: Comparison between measurements and simulation of test cycle.

CONCLUSIONS

Thermal effects have a significant influence on the torque transferred by the differential under limited slip conditions. It is possible to accurately determine the transferred torque knowing the current operating conditions and the thermal history of the clutch, given that the boundary friction model is taking clutch temperature into account.

ACKNOWLEDGMENTS

The authors would like to express gratitude to The Swedish Agency for Innovation Systems and The Swedish Foundation for Strategic Research through the HiMeC and Interface research programs for financial support.

REFERENCES

Berger, E. J. et al., 'Analytical and numerical modeling of engagement of rough, permeable, grooved wet clutches', Journal of Tribology, vol. 119, pp. 143-148, 1997.

Jang, J.Y. et al., 'Thermal characteristics of a wet clutch', Journal of Tribology, vol. 121, pp. 610-617, 1999.

Patir N. et al., 'Average Flow Model for Determining Effects of Three-Dimensional Roughness on Partial Hydrodynamic Lubrication', Journal of Lubrication Technology, vol. 100, pp. 12-17, 1978.

Zagrodzki, P, 'Numerical analysis of temperature fields and thermal stresses in the friction discs of a multidisc wet clutch', Wear, vol. 101, pp. 255-271, 1985.

Yang, Y, et al., 'Modeling of heat transfer and fluid hydrodynamics for a multidisc wet clutch', Proceedings of SAE international congress and exposition, Detroit, Michigan, 1995.

Mäki R., et al., 'Measurement and characterization of anti-shudder properties in wet clutch applications', SAE Technical Papers, Paper number: 2005-01-0878, 2005.

