APPARATUS FOR MEASUREMENT OF FRICTION SURFACE TEMPERATURE IN A WET CLUTCH

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SUMMARY
This paper describes the development of a test apparatus designed for surface temperature measurements of sintered friction clutch discs under a continuous slip condition. In the apparatus an infrared temperature monitoring system is used for temperature measurements. The applied force, transmitted torque and sliding velocity are monitored during operation. Both the normal force and the sliding velocity can be varied during operation to simulate working conditions commonly experienced by the clutch in the transmission system of an all-wheel drive vehicle. Initially, the new apparatus has been used to investigate the friction-velocity (μ-v) behaviour of the clutch under high clutch disc pressure conditions. The results obtained show that the increase in the surface temperature during a typical test has a substantial impact on the resulting μ-v curve. The main influence is observed at higher sliding velocities, where the slope of the μ-v curves increases substantially when the temperature change during the tests is accounted for.

Keywords: test apparatus, wet clutch, surface temperature, friction, automotive transmission.

1 INTRODUCTION
A new generation of all-wheel drive systems for automobiles has recently been developed by Haldex Traction Systems with the aim of meeting new demands on short system activation/deactivation time. The Haldex LSC AWD system features a limited slip wet clutch that consists of clutch plates covered with a sintered friction material.

Characteristic operating conditions for wet clutches in this type of application include low sliding velocities and high clutch disc pressure. Under these conditions it is common that stick-slip and shudder arise. This behaviour has been investigated by a number of authors, both experimentally [1, 2, 3, 4] and theoretically [5, 6, 7].

The general opinion on this matter states that in order to avoid vibrations the μ-v relationship should have a low static coefficient of friction (μs) and a dynamic coefficient of friction (μd) that increases as the sliding velocity increases.

A typical μ-v relationship from a friction test conducted by Haldex Traction Systems in a test apparatus with the commercial coupling is presented in Figure 1. It can be observed that the static friction is low indeed, but as the velocity increases beyond a certain point, the dynamic friction tends to decrease significantly. Although this behaviour implies that vibrations should be likely to occur, they seldom do.

One theory that may explain the change in friction is a change of temperature in the clutch during the test. Although no temperature rise can be detected in the oil sump during the test, it is reasonable to assume that the local temperature experienced by the oil film between the clutch plates is increased as torque is transmitted by the clutch.

In order to investigate these ideas a test apparatus for temperature measurements of the disc surface has been designed.

2 EXPERIMENTAL APPARATUS
The clutch pack in the commercial product has 14 active friction faces. In this application, however, it is sufficient to observe only one interface, and thereby reduce the required torque substantially. Therefore we use only one sintered friction disc against one steel plate, both submerged in the lubricant.

The commercially used friction disc consists of a steel core covered with a dispersion-sintered friction lining with a brass base. The inner diameter of the disc is 76 mm, and the outer diameter is 108 mm. The contact area is approximately 3,940 mm² when the area of the oil grooves has been accounted for.

The designed test apparatus is depicted in Figure 2. The apparatus is driven by a hydraulic motor (4). The motor can deliver 255 Nm between 5 and 940 rpm. The velocity is controlled by a flow limiting proportional hydraulic valve.

Figure 1: Typical μ-v relationship obtained from a test conducted with the actual coupling. At time t=17 seconds a velocity of 1 rpm is applied, and at t=27 the velocity is further increased to reach 100 rpm at t=40 seconds.
The motor drives the gearwheels (6) and (7) with a gear ratio of unity. The friction disc (8) is mounted on the second gearwheel. The gearwheel (7) is mounted on a hydraulic cylinder (5). The cylinder applies a normal force in the range 0-20 kN to the clutch.

The opposing steel lamella (12), with a laser cut inspection hole, is mounted on the non-rotating backing holder (11).

The force and torque applied to the backing holder are transmitted to the housing (2) and (3) by piezoelectric load cells. The force cell can measure loads up to 200 kN with an accuracy of ±1.25 %. The torque cell can measure torque up to 200 Nm with an accuracy of ±4.33 %. Both accuracy statements include the cross-talk sensitivity of the measuring cells.

The velocity is measured with a magnetic field sensor mounted against the teeth of the gearwheel (6).

The temperature of the clutch surface is measured with an infrared thermometer through a hole in the housing, backing holder and steel disc. The thermometer measures the temperature over a spot 4 mm in diameter, and the measured temperature will be a mean surface temperature over the area. Wavelengths detected by the thermometer are in the interval between 8-14 µm, allowing good sensitivity to be achieved in this application. The thermometer has a temperature range of –50 °C to 1000 °C, a response time of approximately 30 ms and an accuracy of ± 1.5 °C.

The temperature measurement method has been used previously in an apparatus by Holgerson [8]. Although this test rig was primarily designed for investigations of paper-based wet clutches used in automatic gearboxes, it is still possible to use the basic design ideas of that apparatus.

All the data has been collected in a PC with a 16-bit DAQ-board from National Instruments. The sampling rate used was 100 Hz. The PC controls both the normal force and the sliding velocity, and feedback control loops were implemented in the software to eliminate any steady-state errors.

3 EXPERIMENTS CONDUCTED

In this work two different experiments will be presented:

> In the first experiment both the velocity and the applied normal force were held constant, and the torque and temperature were monitored. From this experiment a friction-temperature (µ-T) relationship could be derived.

> In the second experiment the normal force was held constant while the velocity was increased linearly from 10 to 100 rpm, in order to obtain a µ-v relationship.

In all the tests the coupling was submerged in Statoil LSC transmission fluid that had been specially tailored for the application at hand [9].

The mineral oil based Statoil LSC transmission fluid has been additivated in order to achieve proper frictional characteristics and long-time durability of the fluid.

3.1 Constant velocity tests

In this experiment, the main task is to obtain a µ-T relationship that can be used later to compensate the µ-v curve for changes in the temperature of the friction face during the experiments.

In Figure 3 data from a test with a velocity of 100 rpm and a normal force of 10 kN is presented. The data is used from T = 40 °C and 60 seconds thereafter.
From a number of tests conducted according to this method it is also possible to observe the temperature rise as a function of the power transmitted by the clutch. This relationship, presented in Figure 5, agrees well with results from other authors [8] and suggests that the method used gives accurate temperature readings.

### 3.2 Linearly increased velocity tests

The main objective of this test is to simulate a test method that has been used for a number of years to evaluate the friction characteristics of the clutch system.

Figure 6 shows the torque and temperature measured during an increase in the sliding velocity from 10 to 100 rpm during 10 s. The load is 20 kN.

The \( \mu \)-v relationship that can be derived from the measurement data shows good agreement with data obtained from similar tests conducted on the Haldex LSC clutch in question [9].

In this test, however, we also know both the temperature of the friction surface and the \( \mu \)-T data obtained from the constant velocity tests. This knowledge may be used to compensate the \( \mu \)-v curve with respect to temperature.

In Figure 7 both the measured friction and the temperature-compensated friction are plotted together. The figure shows a substantial difference between the friction coefficients, especially at higher sliding velocities. Since the temperature-compensated \( \mu \)-v curve
does not present any negative slope, the friction-induced vibrations will be suppressed.

A number of tests have been conducted using this method to evaluate the repeatability of the test apparatus. Typically the magnitudes of the measured coefficients of friction vary by less than 5% between the different tests. The change in the temperature of the friction face during the increase of the sliding velocity varies by less than 3 °C. From this it can be concluded that the new apparatus can produce accurate results with only a small number of tests.

4 CONCLUSIONS

From this work it is concluded that the temperature in the clutch interface rises rapidly during operation. As expected the temperature rise depends on the power transmitted by the coupling.

This change of temperature is responsible for the decrease in friction at higher sliding velocities experienced in other test methods. This means that the coupling experiences a positive $\mu$-$\nu$ slope, and therefore does not tend to induce vibrations in the transmission system.

The friction measurements with this new apparatus show good agreement compared with results from other test equipment used for friction evaluation. The apparatus is also able to reproduce measurements with good accuracy.

Although the testing apparatus worked reasonably well, there are still some problems that will need to be addressed. In this application an electric motor would be preferred, instead of a hydraulic one. The pulsations from the different pistons in the hydraulic motor are quite large, especially at low sliding velocities. This problem will be solved by fitting the apparatus with an electric motor that does not induce this type of noise in the measurements.

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6 REFERENCES


