

Experimental Characterization of Drag Torque in Open Multi-Disks Wet Clutches

Shoaib Iqbal, Farid Al-Bender, Bert Pluymers, and Wim Desmet
Katholieke Universiteit Leuven

ABSTRACT

The objective of the present study is to experimentally characterize the drag torque in open multi-disks wet clutches. For this purpose, two groups of experiments are performed using an advanced SAE#2 test setup. The experiments are designed under real conditions of variable automatic transmission fluid (ATF) flow rate and higher clutch speed range as experienced by wet clutches in real operation. The first test group examines the influence of parameters such as ATF flow rate, ATF temperature, and disks size whereas, the second test group investigates the effect of disks rotational conditions on the drag torque. By analyzing, the obtained experimental results, the relationship between the amount by which the parameters are varied and the corresponding change in the drag torque are established. In addition, a general qualitative behavior of the drag torque as function of clutch speed is proposed and the associated physical phenomena are explained.

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INTRODUCTION

A wet clutch is a mechanical device which transmits power from the driver member to the driven member through frictional and viscous effects. Wet clutches play a significant role in on-road, off-road vehicles, and in industrial machinery equipped with automatic transmissions (AT's), limited slip differentials (LSD's), lock-up clutches (LC's) and wet brakes (WB's) [1]. During a wet clutch closing (*i.e.*, engagement) and opening (*i.e.*, disengagement) process frictional heat is generated which causes wear and deterioration of the disks. Therefore, the disks must be cooled in order to increase the service life of the clutch. For this purpose, the ATF is continuously supplied to the disks, irrespective of the state (closed or open) of the clutch. Inherently, this supply of the ATF also helps in maintaining the disks surfaces clean, and provide smoother performance. However, the use of ATF reduces the power transmission capacity of the wet clutches due to reduction in the coefficient of friction, as compared to dry clutches. Therefore, in order to reach the required power transmission capacity, the clutches are assembled with several pairs of friction disk (FD) and separator disk (SD). This arrangement of disks is termed as multi-disks wet clutch.

During the operation of an AT, some of the clutches are closed to transmit power while the remaining clutches are in open state. In addition both the sets of closed and open disks

are rotating surrounded by the ATF. Ideally, when the clutch is in open condition no torque should be transmitted. However, in reality, the relative motion between the FD's and SD's causes viscous shearing of the fluids film in the gap between the disks resulting in a drag torque on both the disks. Fluids collectively refer to the ATF and the mist (suspension of ATF in air). Depending upon the configuration of the clutches in an AT, the drag torque transmitted by the open clutches is considered as loss. This unwanted drag torque reduces efficiency and increases temperature of the transmission. The increased temperature in turn promotes the wear in the gears, bearings, and the aging of the ATF. Currently automotive designers are concerned about how to reduce the drag torque in open wet clutches because it is one of the potential areas where the improvement can be made to increase the efficiency, performance, and lifetime of systems incorporating wet clutches [2]. This requires a good understanding of the physical phenomenon and the drag torque characteristics of the open wet clutches.

The articles addressing the issue of drag torque through experimental observations are limited in open literature. Some of the old published reports in this regard are as follows. In 1971, Schade [3] carried out several experiments to understand the effect of disk grooved pattern on the behavior of drag torque. Subsequently, Lloyd [4] in 1974 investigated the influence of parameter like ATF flow rate,

ATF viscosity, gap height, friction material, speed, and groove geometrical properties on the drag torque. Later, Fish [5] in 1991 studied the influence of variables like friction disk geometry, surface finish, groove design, and separator disk flatness at various level of ATF flow rate, ATF temperature and gap height on the drag torque. Recently, in 2000, Oerleke [6] investigated the drag torque through experiments considering several parameters and proposed drag torque characteristic curve at increasing relative speeds. More recently, in 2003 Kitabayashi et al. [7] experimentally examined the affect of factors like the facing area, wave height, number of grooves, and flow rate on the drag torque.

From the above review of previous works, it is evident that the trends in drag torque behavior of wet clutches are already examined for several geometrical and flow parameters. However, during these experimental studies [3, 4, 5, 6, 7] a constant ATF flow rate is considered, whereas in reality the ATF flow rate increases with increasing clutch speed. In addition, in most of the studies a lower clutch speed range of 0-3000 rpm is considered. However in actual operations, the clutch maximum speed can go higher up to 4000-4500 rpm *e.g.*, when the clutch is associated with top gears. Furthermore, in most of the previous studies, the rotation of only one of the disks is considered while the other set of disks remains stationary. However, in certain circumstances both the sets of disks can rotate with different speeds and directions, simultaneously. Moreover, mostly a single pair of disks is considered instead of multi-disks configuration.

This study aims at experimentally investigating the influence of several parameters on the drag torque behavior of open wet clutches under real conditions. More precisely, the objective is to understand how the drag torque curve evolves with the variation in the ATF flow rate, ATF temperature, disks size, and disks rotational state. A profound understanding of the influence is essential to establish the relationship between variation in the parameters and the related change in the drag torque. The knowledge gained can be further employed to predict the drag torque in open wet clutches. In this way, some of the precious energy can be saved by improving the efficiency, performance and lifetime of the machines equipped with wet clutches.

The paper is organized as follows. Section 2 presents the advanced SAE#2 test setup utilized to perform the experiments in this study. The configuration and the working principle of the clutch package are also briefly discussed in this section. Section 3 describes the experimental procedures. The test specifications are also given in the second part of this section. The results obtained from the experiments are then presented and discussed in Section 4, where the results are analyzed and the relationships between the amount by which the parameters are varied and the respective change in the drag torque are established. Finally, a general qualitative relationship between the drag torque and clutch speed is described, and the appropriate conclusions are drawn from the study are listed in Section 5.

TEST SETUP DETAILS

This section begins with the description of the clutch package wherein its working principle is briefly explained. The mechanical and hydraulic parts of an advanced SAE#2 test setup used to perform experiments in this study are also illustrated in this section.

Clutch Package Configuration

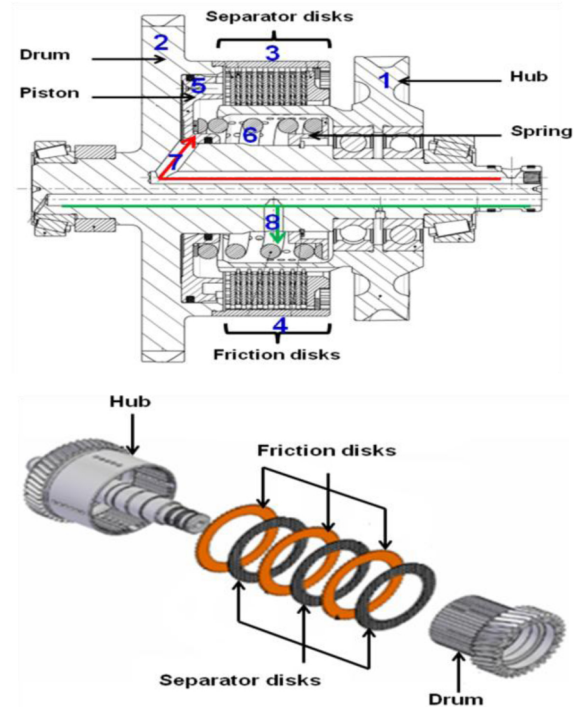


Figure 1. Schematic of the clutch package: cross-sectional view (top), exploded view (bottom)

Cross sectional and exploded view of the clutch package is shown in Fig. 1. It consists of a hub (1), a drum (2). SD's (3) are mounted to the drum by splines, and the FD's (4) are mounted to the hub by lugs. The SD's and the FD's core are typically made from plain carbon steel, where as the FD's are lined on both sides by paper, bronze or carbon fiber based materials. The engagement process begins when the clutch is actuated by supplying the ATF under pressure which produces the normal load acting on the piston (5) against the spring (6) for engaging the disks. The actuating ATF (flow direction shown by red line in the figure) flows through the internal hole (7) directed towards the piston. Once the clutch is fully locked or relative velocity between the driver and driven members is zero, the power is transmitted through shafts via the drum and the hub. As described previously, the ATF is also supplied continuously, irrespective of the state of the clutch (closed or open). The purpose of this continuous supply of ATF is to cool the disks, maintain the disks surfaces clean, and provide smoother performance and longer life time. The cooling ATF enters the clutch through the internal holes (8) in the shaft and then flows into the gap

between the disks (flow direction shown by green line in the figure). Afterwards it flows outward in the radial direction by pressure and centrifugal forces and then flows back into the reservoir through the holes in the drum. In the present study we are concerned with the flow of the cooling ATF, since we are dealing with the wet clutches in an open condition.

An Advanced SAE#2 Test Setup

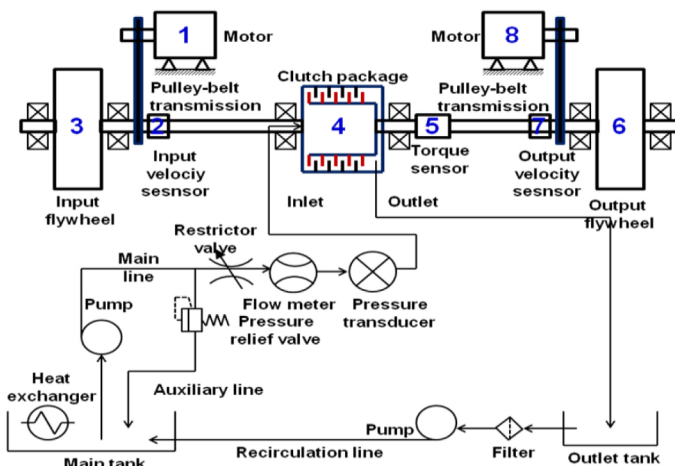


Figure 2. An advanced SAE#2 test setup: Actual photograph [Courtesy Dana SOHB] (top), schematic diagram along with hydraulic circuit (bottom)

The drag torque experiments are performed on an advanced SAE # 2 test setup designed and built by our industrial partner, Dana Spicer Off Highway, Belgium as shown in Fig.2. The SAE#2 test setup is called *advanced* in the sense that both set of SD's and FD's can rotate independently. In case of the previous version of the SAE#2 test setup [5], only one set of disks were able to rotate while the other set were held stationary. Therefore, the previous version of the SAE#2 test setup cannot be utilized to perform the drag torque tests considering different rotational state of the disks, i.e., different rotational speeds as well as directions of rotation of SD's and FD's. The test setup basically consists of three main systems namely driveline, control, and measurement system. The driveline consists of nine components: Input and output 30 kW AC motor for

independently driving the input and the output members through pulley-timing belt transmission (1 & 8), input and output speed sensors, based on hall effect encoder comprises sensing gear having 51 teeth (2 & 7), input flywheel (drum-side containing SD's) (3), output flywheel (hub-side containing FD's) (6), multi-disk clutch (4), torque sensor (5) based on optical-electronic light method which senses the twisting of the torsion shaft. It comprises of two slotted disks placed in between two flexible flanges. One flange is connected to the output of the clutch package, while the other flange is connected to the output shaft. Since, the clutch is in open condition, the development of the drag torque at the output of clutch package results in a relative motion between the two slotted disks. Light is passed through these two slotted disks and the transmission ratio of the light changes proportionally to the drag torque as the slotted disks rotate relative to each other.

The hydraulic circuit of the test setup is discussed as follows. A heat exchanger installed in the main tank allows the tests to be performed at the elevated ATF temperature as experienced in real operation. Thermocouples measure the ATF temperatures at the inlet and outlet of the clutch near the housing. Centrifugal pump feeds the ATF from the main tank at a flow rate (set as per test condition) to the main line. The flow pressure rises due to pumping action. A pressure relief valve installed in the main line helps in maintaining the flow pressure to required level. The excess ATF is diverted to the main tank through an auxiliary line. The flow rate circulated to the clutch package is further adjusted by the restrictor valve according to the signal obtained from the flow meter. A pressure transducer (based on deformation of a membrane) records the flow pressure near to the housing. The outlet flow from the clutch is temporarily stored in the outlet tank which is pumped to the main tank after filtration for recirculation. An integrated control system is used for controlling the ATF flow rate, flow temperature, as well as the desired rotational speed of the disks.

EXPERIMENTAL PROCEDURES AND TEST SPECIFICATIONS

The first part of this section deals with the procedures carried out to perform the experiments in this study. The drag torque tests are conducted according to the specifications described in the second half of the section. There are two consecutive tests to be carried out that are discussed in the subsequent paragraph. A new clutch undergoes a run-in test for 200 cycles, before the drag torque tests are carried out. This is done in order to achieve the stabilized friction characteristics of the clutch. In the present paper, the clockwise and counter-clockwise rotations of the disks are considered as positive and negative, respectively. The test results are mostly presented as function of clutch speed. However, for better comparison, in some cases, the test results are presented as function of clutch absolute speed. In the present paper, the clutch speed is defined as the

magnitude of difference between the rotational speed of FD's and SD's considering the rotational direction, whereas the clutch absolute speed is referred to as the magnitude of speed of rotation of either FD's or SD's without considering the rotational direction, *i.e.*, the absolute value.

Run-In Test Procedure

The run-in test procedure is in principle same as that of engagement cycle test procedure [8], but the starting relative velocity (energy level) for the run-in test is kept lower than that of the engagement test. This is done to avoid any thermal failure of the clutch due to the development of excessive braking energy during engagement. Figure 3 (top) illustrates a typical run-in test cycle performed using an advanced SAE#2 test set-up. The entire process of run-in test cycle can be divided into four phases as follows.

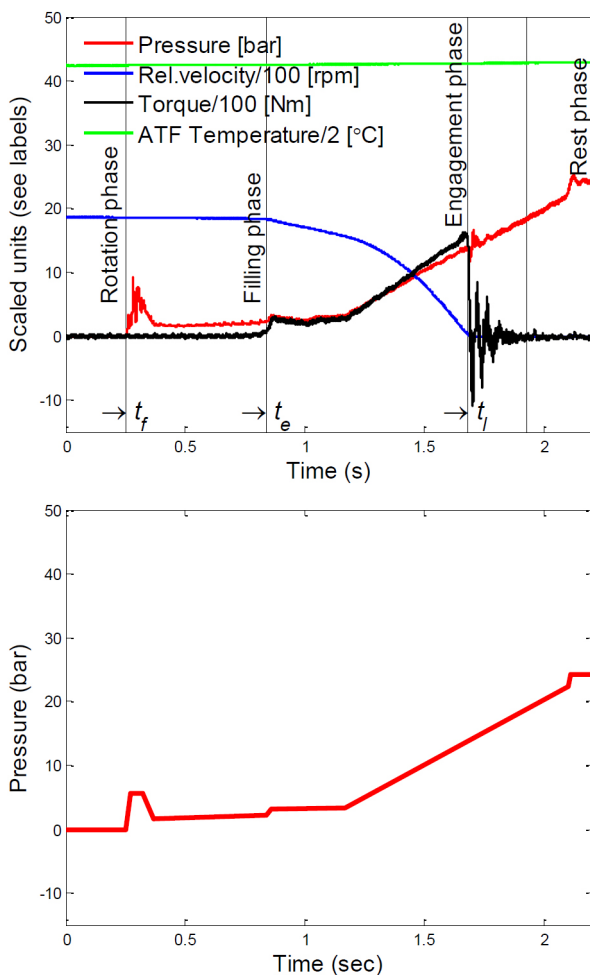


Figure 3. A typical run-in test cycle (top), A representative of the applied pressure profile (bottom)

During the first phase called the *rotation phase*, both input (drum-side) and output (hub-side) flywheels are rotated independently by two electrical AC motors at the same initial velocity, but in opposite directions. Simultaneously, the cooling ATF is circulated at a design flow rate under ambient

pressure. The initial velocity and the flow rate are estimated according to the size of the disks under investigation. In the present study, it is determined to be 1800 rpm and 40 Lmin⁻¹. Once the required velocity is stabilized, the motors are switched off. In this phase no contact between the disks occurs, only the system achieves some driving energy. The clutch is still in open condition. The relative motion between the disks in presence of ATF results in the drag torque. In second phase, the actuating ATF is introduced into the clutch chamber. This phase is called the *filling phase*, which starts at time instant t_f and ends at time instant t_e *i.e.* when the clutch chamber is full of ATF and the piston is just about to move. The third phase is called the *engagement phase*, which starts at time instant t_e . In this phase the pressure of the actuating ATF is increased gradually (See, Fig. 3 (bottom)) which activates the clutch piston. The piston pushes the disks towards each other against the returning spring and a contact is established between the disks. As a result the asperity contact torque starts to build-up and simultaneously the drag torque reduces. During the engagement phase, the velocity of the flywheels reduces and the kinetic energy of the flywheels is absorbed by the clutch, which is dissipated as heat. Consequently, the temperature of the ATF increases. When the relative velocity of the flywheels are about to reach zero level, the asperity contact torque reaches to the peak value. Finally, when the relative velocity reaches zero at the time instant t_l , the clutch is fully locked up (*i.e.*, closed). At this instant, the asperity contact torque reduces to zero except for some residual torque after the applied pressure reaches to its maximum controlled value. The last phase is called the *rest phase* which starts from the end of the engagement phase and continues till the applied actuation pressure is released for the next run-in test cycle. The clutch remains in the closed condition during this phase. After this, the pressure is released and the clutch is left as it is for few seconds, for cooling before the next cycle begins.

Drag Torque Test Procedure

The drag torque test is performed with a run-in disk as follows. The FD's are mounted to the hub by lugs, whereas, the SD's are mounted to the drum by splines with a desired gap height set by the end stopper. The disks are enclosed in a metallic chamber. The inertias of the flywheels are set to 0.5018 kgm². This inertia provides an energy level of a typical light throttle engagement for a shifting clutch. As the drag torque tests are performed in an open condition; therefore the supply of actuating ATF to the clutch is shut off. After adjusting the required flow conditions (cooling ATF flow rate and temperature), the disks are set to rotate to the required speed and direction. Once, the desired rotational state is achieved, the disks are rotated for 5 s in order to stabilize the drag torque before the actual measurement is initiated. After stabilization time period is over, the data is recorded for every 5 s and the average values are estimated. The repeatability of the experiment is tested for three runs.