

New Development of a Gas Cavitation Model for Evaluation of Drag Torque Characteristics in Disengaged Wet Clutches

Shahjada A. Pahlovy, Syeda F. Mahmud, Masamitsu Kubota, Makoto Ogawa, and Norio Takakura
Dynax Corporation

ABSTRACT

A significant reduction of CO₂ emission can be achieved by improving the efficiency of transmission of cars. A reduction of drag torque or spin loss of disengaged clutches can improve the efficiency of transmissions. Generally, the drag torque is measured by conducting drag test which needs making samples, manpower, power and wastage of raw materials. In this paper, an analytical model is proposed to predict the drag torque of a disengaged wet clutch at different rotation speeds, clearances, disk sizes and oil temperatures without making any samples and conducting any drag tests. Various assumptions are made from the results of visualization investigations. Visualization results show that the volume of oil existed in between the clutch disk and clutch plate decreases with increasing speed due to centrifugal force. It is also noticed that several visible air bubbles are formed in the oil film at lower speeds and the size of the bubbles increase with increasing speeds. We consider that the gas cavitation has a significant role in air bubble formation. The model is validated with test results and it shows that they are almost coincident with each other.

CITATION: Pahlovy, S., Mahmud, S., Kubota, M., Ogawa, M. et al., "New Development of a Gas Cavitation Model for Evaluation of Drag Torque Characteristics in Disengaged Wet Clutches," *SAE Int. J. Engines* 9(3):2016, doi:10.4271/2016-01-1137.

INTRODUCTION

At present lowering CO₂ emission of car is one of the world's most important issues in automotive industry. This can be achieved by reducing the friction and other losses of energy in cars. Some estimates show that only 18-25% of the total energy is used to drive a car down the road and the remaining 75-85% energy gets lost [1]. Among the energy loss, about 5-6% energy is lost due to drive train and transmission inefficiency. Therefore reducing energy loss of vehicle is an urgent issue.

A lot of researches have been done for reduction of fuel consumption by reducing the friction loss of Engine or weight of cars. But, very few researches have been done on improvement of fuel efficiency by reduction of drive train loss. The goal of this research is to develop an analytical model to calculate the drag torque in a disengaged wet clutch. The proposed research can make a significant contribution in improvement of fuel efficiency of cars from the source of transmission wet clutch.

Fig. 1 shows a cut sectional model of a transmission which consists of several clutch packs. A clutch pack is made with several clutch disks and clutch plates. A clutch plate is just like a steel plate but the facing of the clutch disk is made with paper materials and the core plate is made with iron materials. During the operation of a transmission, some of the clutches are engaged for power, while the rest of clutches remain disengaged. Due to the engagement and disengagement process, a frictional heat is generated which leads to some damage to clutch. Therefore, it is necessary to cool down the

disks to increase the service life of clutch. An automatic transmission fluid (ATF) is delivered in between the friction disk and separator plate to cool them. Since the friction plates and separator plates are always in relative motion to each other, a shear force is generated on the fluid in the gap between the disks. This shear force generates a drag torque which is considered as a loss which reduces the efficiency of power transmission and increases the fuel consumption of a car.

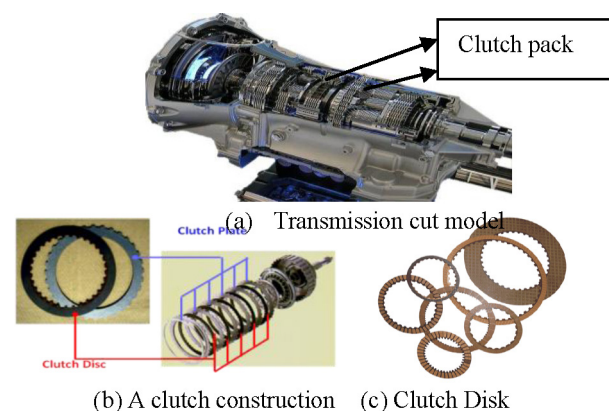


Figure 1. Schematic images of transmission & Clutch

One of the potential key techniques is: reduction of spin loss or drag torque of clutch during the operation of a transmission. This drag torque is developed due to presence of automatic transmission fluid (ATF) in between clutch disks and clutch plates. Even though the unwanted drag torque is developed, the presence of ATF is necessary

to reduce the viscous heat of clutch/transmission. Therefore, techniques of drag reduction are very important and challenging issue for manufacturers of transmission to improve fuel efficiency of car.

According to the literature review and previous several test results at Dynax, the major factors that reduce the drag torque of an open wet clutch are: (a) Introducing grooves on facing of clutch disk (b) Changing the properties of ATF (Automotive transmission fluid), and Oil flow rate and, (c) increasing the amount of gap between clutch disk and clutch plate. Introducing a groove pattern on facing of clutch disk gives a significant reduction of drag torque. The optimum reduction depends on the shape and dimension of grooving which is decided by trial and error method. A trial and error method is time consuming, expensive and required wastage of material. Moreover, it is not a green environment friendly. In this paper, an analytical model is proposed to predict the drag torque of a disengaged wet clutch at different rotation speeds, clearances, disk sizes and oil temperatures without making any samples and conducting any drag tests.

Several models have been developed to calculate the drag torque in disengaged wet clutches by several researchers in the past few decades. In 1984, Hashimoto et al. [2] presented the governing equations for the flow in a thrust bearing subject to centrifugal force. These equations describe the flow between two adjacent flat rotating plates facing each other at an angle. However, this model is not suitable for wet clutch. To overcome the issue, Kitabayashi et al. [3] presented a theoretical model based on laminar flow in the gap between clutch disk and clutch plate. But the limitation of his model is, it cannot capture the multiphase drag torque characteristics behavior. To overcome the limitation, Kato et al. [4] proposed a model to capture multiphase characteristics. However, one of the important factors, surface tension coefficient was not considered in his model. Moreover, in his model he considered the oil film starts breaking from inner circumference which is a little different from real time visualization investigation. Later, Yuan et al. [5] introduced an additional term into Kato's pressure distribution equation to take ATF surface tension effect into account considering its relative importance over other forces in the low speed region. In both Kato's and Yuan's models, the major equations were derived considering turbulent flow, though their experimental data reflects that the flow would be laminar since the critical Reynold's number is far below 1400.

Recently, in 2013, Iqbal et al. [7] presented a DT model accounting the effect of cavitation in laminar flow. In his model it was experimentally proved the vapor cavitation was occurred. In our previous study [6], we proposed a drag torque model for wet disengaged clutches based on aeration phenomenon (air enters to the oil film). However, in our recent visualization study with high speed camera, we noticed bubbles are formed without aeration process. Therefore, we consider the bubbles are formed due to pressure dropped/cavitation. We measured the pressure with a real time visualization tester and it shows that the pressure decreases with increasing speeds and at a certain point it goes down below the ambient pressure and forms bubbles. We define this phenomenon as gas cavitation. Based on the gas cavitation phenomenon, we proposed our model which is validated with test results and it shows that they are almost coincident with each other.

MODEL DEVELOPMENT

A basic image of a typical clutch is shown in Fig. 2. As shown in the fig, the distance between clutch disk and clutch plate is h , inner radius of facing of clutch disk r_{in} and outer radius of facing of clutch disk is r_{out} . The ATF enters into the gap from inner circumference, experiences a viscous shear force due to relative motion of clutch disk and clutch plate and then leaves the gap through outer circumference due to centrifugal force. The viscous shear force and surface tension force of ATF work against the radial flow. The ATF film is full and continuous at lower speeds but gets ruptured with bubbles formation due to gas cavitation at higher speeds. We consider two points before using the term gas cavitation: (i) presence of dissolve gas 8-12% in fluid, (ii) pressure drops below the ambient pressure.

It is well known that liquids (under normal operating conditions) cannot sustain pressures below its saturation or vapor pressure (P_{sat}) since then the fluid vaporizes. On the other hand for pressures below ambient (~ 1 bar [14.7 psia]), the dissolved gases in a lubricant (air for example) are released. Streamers of flow coexist with vapor or gas generating the cavitation region. Most mineral oils contain between 8 and 12 % in volume of dissolved air (Pinkus, 1990). We have contacted with ATF manufacturer who confirmed us the presence of dissolve gas in the ATF (5-10%). Next, we investigated the pressure characteristics at different speeds to see whether pressure drops below the ambient pressure.

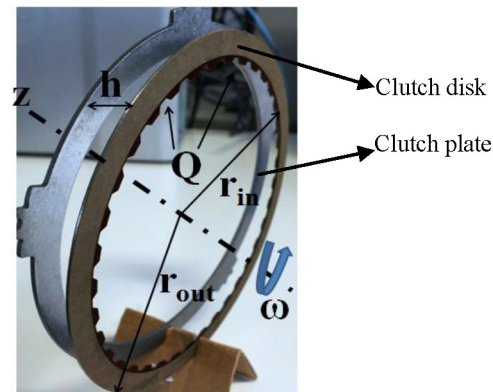


Figure 2. Basic image of a transmission clutch disk and clutch plate

We measured the pressure at near the inner and outer circumference by a high accuracy semiconductor type pressure sensor. Fig. 3 shows the sensor mounting procedure to test stand. The results are shown in fig. 4 where, it shows that the ΔP decreases with increasing speeds and at a certain speeds it becomes negative. Since the pressure is very small and there are a lot of factors that influence the pressure measurement result, therefore we considered the tendency of curve not amplitude of pressure. From the obtained characteristics, we can conclude that there is a possibility, ATF pressure on facing of disk goes down below the atmospheric pressure which increases the possibility of occurrence of gas cavitation.

We have extended our investigation to understand the fluid behavior after cavitation is occurred. The tests were done by a visualization tester with no groove sample. To capture the fluid behavior we used high speed camera. Since the high speed camera can take only black and white image, therefore to get a clear image, we painted sample in