Dynamic Torque Modeling of a Wet Lamella Clutch Pack

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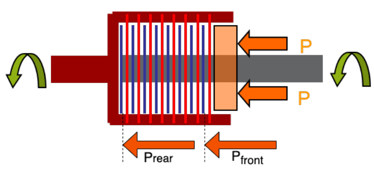
Wet lamella clutches are used in the automotive industry to enable all-wheel drive by transmitting torque from an incoming- to an outgoing shaft through a series of lamella - steel-disc friction surfaces (called a lamella pack), lubricated by a viscous oil. Based on temperature- and wheel-speed measurements, a mathematical model of the clutch can be used to calculate the appropriate actuation of applied pressure to match a desired torque output. However, in some "extreme" driving scenarios, dynamic torque responses are common. This thesis therefore evaluates the physical properties of a wet lamella clutch to better understand the reasons behind the dynamic torque outputs.

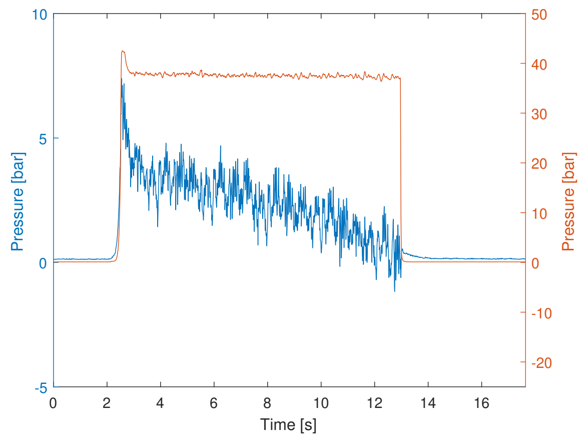
By analyzing previously collected data from tests in rigs and cars, two hypotheses are formed. Hypothesis 1 suggests that there are frictional forces in the splines between the lamellas and lamella drum leading to a variation of normal force over the lamella pack. Hypothesis 2 suggests that the properties of the oil film in the friction interface changes at relative rotational speeds close to zero in the clutch which leads to a significant increase in friction.

To evaluate the hypotheses, rig tests are performed where dynamic torque responses are provoked by initiating a relative rotational speed in the clutch and applying pressure in 5 different sequences. Some tests are also performed where relative speeds instead are initiated after a pressure has been applied. A novel measurement technique is introduced comprising of four thin force-measuring sensors (FlexiForce) being placed at the front and rear lamellas in the pack respectively in an attempt to measure any variations of force (proportional to pressure) over the package.



$$P_{diff} = P_{front} - P_{rear}.$$

However, since the sensors were shown to have taken damage during the tests, no absolute measurements of force could be made, but by processing the measurements using mathematical estimations, relative comparisons can be made. By doing this, a difference in pressure between the front and rear lamella can be seen which varies over time depending on applied pressure sequence, see Figure below. This kind of behavior is expected according to Hypothesis 1. Similarly, some indications toward hypothesis 2 could also be seen, although not as convincingly.



P_{diff} (blue) during a step pressure input (orange).

To account for the spline friction forces according to Hypothesis 1, two similar mathematical models assuming each lamella to be affected by a spring force, a damping force and a spline friction force acting on its body are presented. Both versions assume the frictional forces to be a function of the transferred torque; the first using an optimized filter, and the second using a manually fitted viscous friction function based on the axial speed in the spline interface.

Both versions of the model are evaluated by being compared to a reference model which assumes no time-dynamic behavior by measuring the root mean squared error of the torque accuracies. Overall both versions were shown to increase the torque accuracy on tested data; especially at low speeds. It is proposed that this is due to more dynamics being introduced at higher speeds. The proposed models are not believed to account for all clutch dynamics. Although the models showed some improvements compared to the reference model, it is not concluded that they are an improvement in general.

Johan Appelros & Jacob Wallersköld, Dynamic Torque Modeling of a Wet Lamella Clutch Pack, Lund University, Industrial Electrical Engineering and Automation, TEIE-5455 (2021).

Keywords: wet lamella clutch, friction modeling, torque modeling, torque accuracy, force measurements, system identification, grey-box modeling.