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A novel monitoring method of wet friction clutches based on the post-lockup torsional vibration signal

Agusmian Partogi Ompusunggu [a,b,*], Jean-Michel Papy [a], Steve Vandenplas [a], Paul Sas [b], Hendrik Van Brussel [b]

[a] Flanders' Mechatronics Technology Centre (FMTC), Celestijnenlaan 300D, 3001 Heverlee, Belgium
[b] Katholieke Universiteit Leuven, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300B, 3001 Heverlee, Belgium

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ABSTRACT

Wet friction clutches play a critical role in vehicles equipped with automatic transmissions, power shift transmissions and limited slip differentials. An unexpected failure occurring in these components can therefore lead to an unexpected total breakdown of the vehicle. This undesirable situation can put human safety at risk, possibly cause long-term vehicle down times, and result in high maintenance costs. In order to minimize the negative impacts caused by the unexpected breakdown, an optimal maintenance scheme driven by accurate condition monitoring and prognostics therefore needs to be developed and implemented for wet friction clutches. In this paper, the development of a condition monitoring system that can serve as a basis for health prognostics of wet friction clutches with a focus in heavy duty vehicle applications is presented. The developed method is based on monitoring the dominant modal parameters extracted from the torsional vibration response occurring in the post-lockup phase, *i.e.* just after the clutch is fully engaged. These modal parameters, namely the damped torsional natural frequency f_d and the decay factor σ, are computed based on the pre-filtered Hankel Total Least Squares (HTLS) method which has an excellent performance in estimating the parameters of transient signals with a relatively short duration. In order to experimentally validate the proposed monitoring method, accelerated life tests were carried out on five different paper-based wet friction clutches using a fully instrumented SAE#2 test setup. The dominant modal parameters extracted from the post-lockup *velocity signals* are then plotted in function of the service life (duty cycle) of the tested clutches. All the plots exhibit distinct trends that can be associated with the progression of the clutch degradation. Therefore, the proposed quantities can be seen as relevant features that may enable us to monitor and assess the condition of wet friction clutches. Since velocity sensor(s) is typically available in a transmission, the proposed monitoring method allows for the practical implementation.

1. Introduction

1.1. General aspect

Wet friction clutches are mechanical components enabling the power transmission from an input to an output shaft, based on the friction occurring in lubricated contacting surfaces. The clutch is lubricated by an automatic transmission

* Corresponding author at: Flanders' Mechatronics Technology Centre (FMTC), Celestijnenlaan 300D, 3001 Heverlee, Belgium. Tel.: +32 16 32 80 42.
E-mail address: agusmian.ompusunggu@gmail.com (A.P. Ompusunggu).

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fluid (ATF) having a function as a cooling lubricant cleaning the contacting surfaces and giving smoother performance and longer life. However, the presence of the ATF in the clutch reduces the coefficient of friction (COF). In applications where high power is necessary, the clutch is therefore designed with multiple friction and separator discs. This configuration is known as a multi-disc wet friction clutch as can be seen in Fig. 1, in which the friction discs are mounted to the hub by splines, and the separator discs are mounted to the drum by lugs. In addition, the input shaft is commonly connected to the drum-side, while the output shaft is connected to the hub-side. The friction disc is made of a steel-core-disc with friction material bonded on both sides and the separator disc is made of plain steel.

An electro-mechanical-hydraulic actuator is commonly used to engage or disengage wet friction clutches. This actuator consists of some main components, such as a piston, a returning spring which is always under compression and a hydraulic group consisting of a control valve, an oil pump, *etc.* As can be seen in Fig. 1, the piston and the returning spring are assembled in the interior of a wet friction clutch. To engage the clutch, pressurized ATF that is controlled by the valve is applied through the actuation line in order to generate a force acting on the piston. When the applied pressure exceeds a certain value to overcome the resisting force arising from both spring force and friction force occurring between the piston and the interior part of the drum, the piston starts moving and eventually pushes both friction and separator discs toward each other. To disengage the clutch, the pressurized ATF is released such that the returning spring is allowed to push the piston back to its rest position.

In general, the duty cycle of wet friction clutches can be classified into four consecutive phases: (1) *fully disengaged*, (2) *filling*, (3) *engagement* and (4) *fully engaged* phase. The illustration of a complete duty cycle is depicted in Fig. 2. In the fully disengaged phase ($t < t_f$), the returning spring holds the piston at its rest (re-tracked) position so that there is no direct contact between the friction and separator discs. This condition allows the friction and separator discs to rotate independently. In this initial phase, the relative rotational velocity, from now on called the sliding velocity, between the input and the output shaft is at high value. Afterwards, the actuator is activated at a given initial sliding velocity n_{rel}, pushing the piston to move as quick as possible before making contact with the neighbor disc. The latter phase is called the filling phase which occurs between time instant t_f and t_e. In the engagement phase ($t_e < t < t_s$), the clutch is actuated by gradually increasing the ATF pressure such that gentle contacts between the friction and separator discs can be established. As a result, the transmitted friction torque increases gradually with the increasing ATF pressure. Because of the increasing friction torque, the sliding velocity gradually decreases until it reaches zero value. As sliding (rubbing) in the engagement phase constitutes an irreversible process, some portion of the transmitted energy is converted into heat which

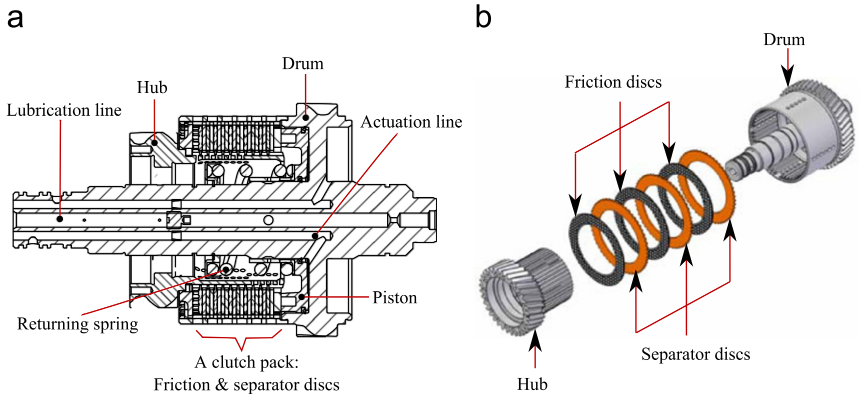

Fig. 1. The configuration of a multi-disc wet friction clutch, (a) cross-sectional and (b) exploded view.

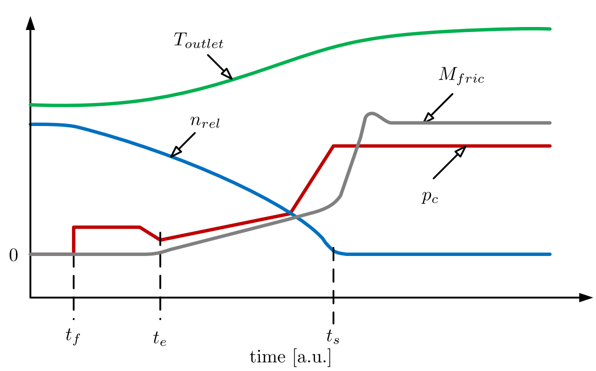

Fig. 2. A graphical illustration of a complete duty cycle of a wet friction clutch. Note that a.u. is the abbreviation of arbitrary unit.