Tribologic Analysis, Wear Evolution and Torque Trend Estimation of an LSD Clutch Pack

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ABSTRACT

The wear phenomenon in friction clutches involves a variation in the contact pairs characteristics, defining a decay of transmissible torque properties. For multidisk clutch packs installed in electro-actuated differentials, the friction torque evolution allows to define how wear decay can influence the dynamic of the vehicle where the differential is installed in. A tribological analysis of a molybdenum-coated clutch pack was made under typical working conditions in terms of temperature, normal load and sliding speed. Friction coefficient and wear rate trends were outlined to define material characteristics through block-on-ring tests. Metallurgic studies on the specimens used in tribologic tests validated the base material used in the samples. Results from experimental analyses were used as input for a numerical study regarding wear and pressure evolutions during clutch engagement. The application of Reye’s theory and Archard’s law on a FE model of the clutch led to the definition of an algorithm to estimate the friction torque generated by the clutch system and the its lifetime.

KEYWORDS
Archard, Clutch, FEM, Friction, LSD, Molybdenum, Reye, Torque, Wear

INTRODUCTION

The dynamics of clutch pack installed inside electro-actuated differentials are highly influenced by the disks engagement behavior and their material properties. Torque transmission in differential clutch pack is guarantee by friction surfaces; lots of applications in motorsport field use commercial treated disks, typically treated with molybdenum-based coating or other treatments, with the aim to control as well is possible the vehicle dynamics. To keep a high performance level of the differential during its lifetime it is important to know how each component works, especially the internal clutch.

Tribologic studies on clutch apparatus were made in last years by Lingsten et al. (Lingsten, et al., 2012) developing an apparatus for continuous wear measurement with the aim to obtain more information about clutch characteristics. Another example of tribologic study has been made by Marklund et al. (Marklund & Larsson, 2008), where wet clutch characteristics have been described to obtain a friction coefficient trend in relation with the temperature and with the implementation of

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oil characteristics. The influence of surface topography on the friction characteristics of a sintered-treated clutch pack has been outlined by Nyman et al. (Nyman, Maki, Olsson et al., 2006). A large number of studies were carried out with the aim to evaluate the progressive wear trend in some contact, as it is possible to see in (Thompson & Thompson, 2006). In this work, Thompson et al. calculated wear strain in order to modify the elastic strain in an element using the Archard equation. Another Archard application could be found in Garleanu et al. work (Garleanu, Popovici, Garleanu et al., 2008); the Archard’s law was used to define wearing phenomenon in a FE domain, obtaining a medium level of prediction of wear. Andersson et al. (Andersson, Almqvist, & Larsson, 2011) and Liu et al. (Liu, Jang, & Barber, 2014) studied the application of Archard equation to define a modified pressure distribution. In Liu’s work the method was applied only on linear systems where full contact is maintained at all times, while in Andersson’s study the application of Archard’s wear equation outlined some important factors as roughness, temperature and lubricant additive-surface interaction. Kim et al. (Kim, et al., 2005) studied the implementation of wear trend analysis in oscillatory contacts. Adhesive wear was studied by (Waghmare, 2016) using an accurate FE model of asperity contact. An important study on the correlation among experimental campaigns and finite element analysis could be found in (Podra & Andersson, 1999), where wear trend was defined using a pin-on-disk apparatus and implemented in a FE domain. A detailed study on the tribological and mechanical characteristics of a brake disc using a FE approach was performed by (Belhocine, 2015) and later by (Ali Belhocine, 2016). On the friction characteristics definition, an important study was made by (Asif, Chandra, & Misra, 2013), evaluating the characteristics of brake pads material with the aim to provide improved manufacturing process. An optimization in the design of contact pairs production using a Taguchi approach was developed by (Zaharudin, Talib, Berhan, Budin, & Azriurah, 2012). Taguchi method was also followed by (Rajesh, 2013) in order to define a statistical model and analysis of SiC reinforced aluminum MMCs. The same approach was used by (Prasanta Sahoo, 2014) and (Priya Shekar Gajjal, 2015) with the aim to define optimized tribological relationship in different contact pairs.

Other important studies on clutch pack tribologic characteristics definition were made, as outlined in (Gao & Barber, 2002) where the engagement of wet clutches were simulated using the most influencing parameters as roughness, fluid viscosity, friction characteristics and groove area ratio of the friction surfaces. An interesting comparison between experimental and numerical analyses was described in (Berger, Sadeghi, & Krousgrill, 1997) where a test rig was designed to quantify the torque transmission characteristics of wet clutches. The friction-velocity relationship of wet clutches was examined in (Mäki, Nyman, Olsson, & Ganemi, 2005) outlining how different parameters influence anti-shudder properties. Mäki (2005) carried out a large study on the characterization of wet clutches for automotive differential application, showing the influence of several operating parameters on the frictional behavior of the clutch. The entire design of a test bench to define frictional characteristics of transmission fluids was described in (Mäki, Wet Clutch Tribology - Friction Characteristics in All-Wheel Drive Differentials, 2003), outlining the high influence of temperature in transmission fluid properties. The lifetime of clutch pack was evaluated by (Ost, De Baets, & Degrieck, 2001) using SAE#II and a pin-on disk test rigs; the friction coefficient and wear rate trends were defined according to materials properties and operating conditions. In (Ingram, Spikes, Noles et al., 2010) the contact units formed between a paper based friction material and a glass counterface have been investigated under different pressures and during rubbing in order to evaluate the conditions present in a wet clutch contact.

In this paper it is highlighted a study on the contact behavior between treated and untreated disks of a differential clutch aimed to obtain a better knowledge of the relationship between the material properties and the performance of the clutch system during its lifetime. An experimental analysis was
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