How friction modifier influences the dynamic friction behavior in wet-running clutch systems and its potential for extended use in hybrid drive trains.

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1. Introduction

The modern clutch system with its good controllability offers a multitude of possibilities for extending the basic function of the clutch with additional functions such as dynamic control and vibration reduction. Especially in view of the change in mobility and energy resource consumption, a function extension to a demand-oriented vibration reduction can provide the possibility to reduce the dimensions of conventional vibration reduction systems and thus save installation space and mass, especially in hybridized powertrains. The potential for this function extension is presented e. g. [1, 2] and could be proven in previous investigations as shown e. g. in [3]. In [3] it is shown that the tribological system has a significant influence on the vibration reduction effect. A specific design of the tribological system can favor other vibration-reducing effects besides damping. How the tribological system has to be designed for this intended usage and which properties influence the behavior is not sufficiently known and is being researched at IPEK.

In this publication the friction coefficient curve is adjusted by means of a specific change in the tribological system and the extent to which this adjustment affects the dynamic friction coefficient behavior is investigated.

2. Validation Approach

2.1 Validation Environment and Research Method

The investigations are conducted under use of a high dynamic test bench at IPEK. The validation environment enables the investigation of wet-running multi plate packages during controlled micro slip operation. It is developed in such a way that precise statements on the dynamic friction behavior as well as the vibration reduction effect can be made. According to the IPEK X-in-the-Loop approach [4], both input-side and output-side drive train dynamic interactions are considered. Detailed information about the validation environment is shown in Figure 1 and can be found more detailed in [5, 6].

The tests are performed in a dynamic slip operation. Therefore, a differential speed between input and output of the clutch is set. The base speed of the prime mover is superimposed with a sinusoidal excitation. The measurements are then evaluated in the stabilized dynamic continuous slip mode.

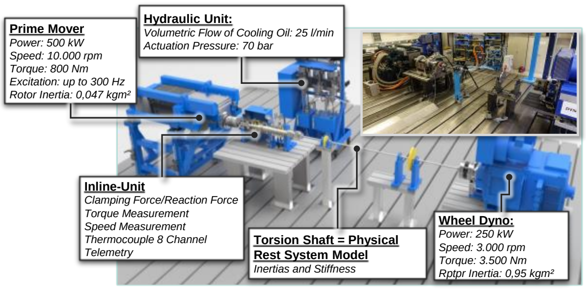

Figure 1: Powertrain-in-the-Loop test bench with Inline-module for the investigation of wet-running multi plate packages including consideration of dynamic drive train interactions, based on [5]

2.2 Objective of Research

Four different tribological systems are used as the object of research. Each tribological system is composed of a multi plate package consisting of two friction plates and three steel plates, as well as a lubricant used as cooling oil. The tribosystems differ in their oil variants. TS 1 uses a common ATF. In TS 2 to TS 4, the additives in the oil are specifically changed by adjusting the friction modifier. The differences between the variants regarding the characteristics of stationary friction behavior are listed in Table 1.

Table 1: Tribological system variants: variations of oil

	Oil Design (stationary fricition behavior)
TS A	Conventional ATF
TS B	High friction coefficient (µ) at low and high differential speed
TS C	Low µ at low, high µ at high diff. speed
TS D	Low µ at low and high diff. speed

2.3 Dynamic Friction Behavior

The dynamic friction behavior is evaluated with characteristic values presented in [7]. In addition to the values absolute friction coefficient and friction coefficient gradient, which are also common in characterization of quasi-stationary friction behavior, the parameter ‘Hysteresenausdehnung' d_{max} is considered for a first description on the form of the friction hysteresis. Figure 2 shows the characteristic values based on an exemplary dynamic friction coefficient curve.

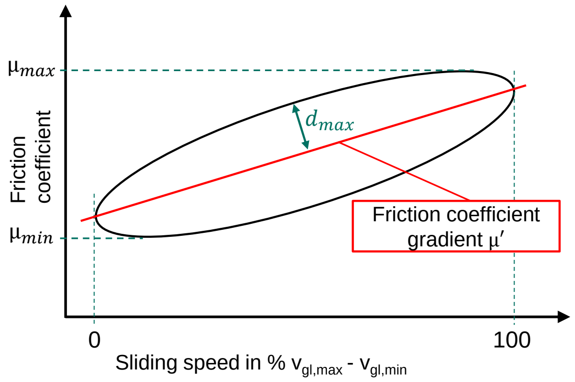

Figure 2: Dynamic friction behavior values 'Reibungszahl' (friction coefficient) μ_{min}, μ_{max} 'Hysteresenausdehnung' (hysteresis expansion) d_{max} and 'Reibungszahlgradient' μ' (friction coefficient gradient) [7]

3. Results: Dynamic Friction Behavior

The differences in the dynamic friction coefficient behavior between the tribological systems are presented here using a reference test with fixed parameters for surface pressure, differential speed, drive speed, cooling oil flow as well as defined sinusoidal excitation. Each test is performed a total of three times for each tribological system. The evaluated characteristic values of the tribosystems are compared in the following boxplots. Results of further tests, e. g. at higher excitation amplitudes, are presented in the full publication.

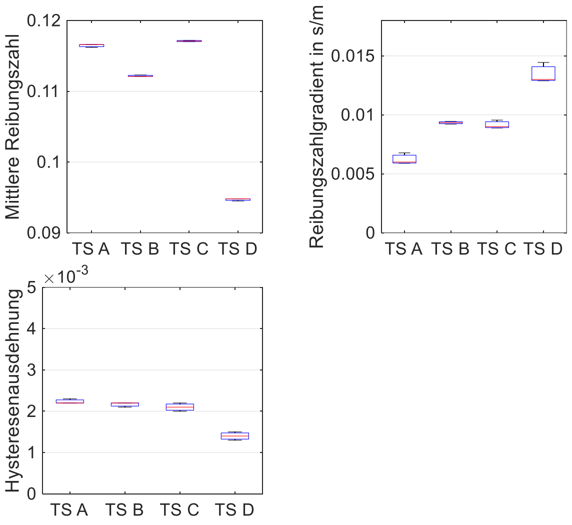

Figure 3: Dynamic friction behavior, characteristic values in reference test (each three runs) of the tribological systems TS A-TS D

It can be observed that all tribosystems show differences in dynamic friction behavior. TS C shows a similar mean friction coefficient and a similar hysteresis shape as the reference system TS A, but a larger gradient. TS B shows a similar gradient to TS C, but has a reduced friction coefficient compared to TS A. TS D, on the other hand, shows the significantly lowest friction coefficient and the highest gradient of all systems. In addition, the hysteresis expansion is reduced compared to TS A - TS C. The adjustment made regarding the friction modifier (FM) also affects the dynamic friction coefficient behavior and the shape of the hysteresis. It can be seen that the adjustments of the FM in the range of the stationary friction behavior, however, lead to different characteristics in the dynamic friction behavior. Here, the adjustment of the FM to low friction values also reduces the hysteresis expansion at the same time, but increases the gradient in the investigated range (TS D).
In general, it can be concluded that an adjustment of the FM towards an increased positive gradient over a larger range of the differential speed does not necessarily also lead to an increase of the gradient in the dynamic slip operation (see TS B and TS C). This may result from the fact that, depending on the excitation amplitude, the dynamic friction coefficient curve only changes over a small range of differential speeds. Thus, the sliding speed changes at high frequency, but also only in a small range, which ensures that the change in the FM seems to has only a limited effect here.

4. Conclusion and Outlook

The investigations show that the modifications made by adapting friction modifiers do have an effect on the dynamic friction coefficient behavior during dynamic continuous slip operation. A modified friction coefficient curve adjustment was thus made possible. In future investigations, the vibration reduction effect in the wet-running clutch system will be investigated with the various friction coefficient curves of the tribological system variants. Correlation analysis is to be used to investigate the extent to which characteristics of the dynamic friction coefficient behavior affect vibration-reducing mechanisms in the friction contact.

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