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Third body layer—experimental results and a model describing its influence on the traction coefficient

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ABSTRACT

When adding substances to the wheel–rail contact, they mix with wear particles and form a Third Body Layer (3BL). This layer influences the initial gradient of the traction characteristic.

During twin-disc tests presented in this paper, a granular layer consisting of iron and iron oxides with a thickness of up to 50 μm was found. In addition, a creepforce model is presented that uses non-linear properties of the 3BL to describe its influence on the traction characteristic. The results of the model were compared to the results of the experiment. A qualitative and quantitative agreement was achieved. This will improve, e.g., the quality of vehicle dynamics simulations, optimizations of control devices for traction and braking, and predictions of wear and damage on wheel and rail.

1. Introduction

The traction characteristic of the wheel–rail contact is of high importance for the vehicle–track interaction. Thus, accurate models are essential for, e.g., reliable investigations of vehicle dynamics, optimization of traction and braking control devices, or predictions of wear and damage on wheel and rail. Therefore, a lot of research has been done on this topic. Empirical models exist but the necessary parameters need to be fitted for every set of boundary conditions. The advantage of a physical model is that it can cope with different boundary conditions and it leads to a better understanding of the underlying processes taking place in the contact. The most widely used physical model is Kalker's Exact Theory for rolling contact [1]. There, it is assumed that the wheel and the rail adhere to each other if the local ratio between the tangential and normal stresses is less than the globally assumed coefficient of friction μ. If the ratio exceeds μ, the wheel and the rail will slide relative to each other. Using these assumptions, the resulting traction characteristic shows two distinct domains: in the micro-creep domain, adhesion and sliding occur at the same time leading to a steep gradient depending on the contact geometry, the load, and the wheel and rail material. In the macro-creep domain, the traction coefficient equals μ which is assumed to be constant.

Several effects have been observed in measurements that cannot be explained by Kalker's Exact Theory which assumes a constant μ: different initial gradients have been measured in the micro-creep domain, although the contact geometry and the normal load were not changed [2]. In the macro-creep domain, negative gradients, a second traction maximum, and the dependency of the traction maximum on the velocity and normal load have been observed [3–6].

A model published by Tomberger et al. is able to reproduce these macro-creep related effects by using physical sub-models for describing local tribological effects [7]. In contrast to Kalker, a local μ is calculated that depends on the local temperature in the contact due to frictional forces and on the metallic contact area due to surface roughness. It also takes into account interfacial fluids. However, this model is not able to explain the different initial gradients in the micro-creep domain mentioned above.

This change has been observed when additional substances are present in the contact [6]. They form a so-called Third Body Layer (3BL). This layer has been categorized into two types: the natural 3BL is caused by the presence of dirt, water, snow, leaves, dust, or others. These contaminants occur naturally and can hardly be influenced. The second one is the artificial 3BL, which is created when substances are artificially added to the contact, e.g. greases, friction modifiers, or sand. In the last decade, a lot of papers have been published that focused on these layers [8–12].

However, recent research regarding friction modifiers suggest that the effects caused by an artificial or natural 3BL can only be explained by the presence of a third kind of layer in the contact and their

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interaction [13]. This third kind of layer, the basic 3BL, is the most basic kind of layer that can be found and consists of particles stemming from wheel and rail only, i.e. iron and iron oxides.

There have been investigations regarding the properties of this basic 3BL in the past, but the conclusions differed. While some predicted it to be 1–3 μm thick and attributed it to wear reducing properties [14,15], others described a 20 μm thick layer that causes the coefficient of friction to increase when its thickness increases [16].

This paper focuses on the properties of this basic 3BL and its influence on the traction characteristic. Therefore, experiments were performed on a twin-disc machine under laboratory conditions. This ensures that there are no natural or artificial contaminations in the contact. After the tests, the used discs were optically investigated. The wear debris was collected and analysed by X-ray powder diffraction (XRD) analysis. There, a coherent beam of monochromatic X-rays interacts with a powder and produces spectra. These spectra are then used to identify the materials present in the powder. Additionally, a creepforce model was developed. This model is able to predict the influence of a 3BL on the traction characteristic.

2. Experiment

The basic 3BL was created by performing twin-disc experiments, which were executed under laboratory conditions. This ensured that only a basic 3BL developed in the contact. Additionally, all necessary parameters could be adjusted independently. Fig. 1 shows the schematics of the test machine. The development and operation of the machine was described previously in detail [17,18]. The experiments consisted of measuring the traction coefficient in dependence of the maximum normal stress p_0, velocity v, and the longitudinal creepage c_x. The tests were performed until the traction coefficient reached a stable value which supposedly indicates a steady state.

Two kind of discs with a diameter of 47 mm and a width of 10 mm were used in the experiments. The rail discs were made of R260 rail material; the wheel discs were made of ER8 wheel material. All discs were polished and cleaned in an ultrasonic acetone bath before the tests. The mode of operation was that the rail discs were set to a certain velocity while the wheel discs were faster according to the creepage. During the tests, room temperature, which was in between 20 °C and 24 °C, and humidity of air, which was in between 34% and 48%, were measured. Also, the bulk temperature was measured, as it was not possible to measure the contact temperature.

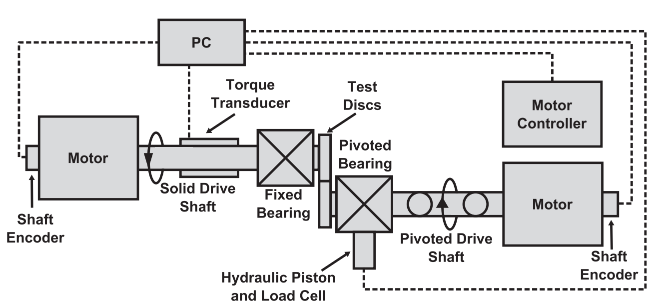

Fig. 1. Schematic diagram of the twin-disc test rig used.

After the tests, the discs were embedded in a resin. Then, they were sectioned and the marked area in Fig. 2 was investigated with an optical microscope. The results of these investigations were compared to a baseline: an unused pair of discs.

During the measurements, a box was placed around the discs to enclose both in order to collect the wear debris which was later investigated via XRD analysis. The wear debris must consist of the same substances as the basic 3BL, although the percentage of their occurrence might vary. Nevertheless, it gives insight into the composition of the layer.

2.1. Experimental results

Fig. 3 shows the traction characteristic for different normal loads and different velocities. The measured bulk temperatures were increasing with creepage and velocity, but all were below 100 °C for the measurements presented. Increasing the normal load leads to a lower level of traction. The same is true for the velocity where a higher velocity leads also to a decrease. This is all in accordance with the results of the model developed by Tomberger et al. [7].

The optical investigations of the surfaces of the discs show that the basic 3BL is different on the wheel and on the rail disc. The surface on the rail disc shows a flake like structure with cracks. Some particles can be seen in the cracks. Cracks can also be found on the wheel disc. In addition, all wheel discs showed the formation of a layer consisting of compacted particles. For low creepages, this layer only covers parts of the surface while for creepages higher than 1% the whole surface is

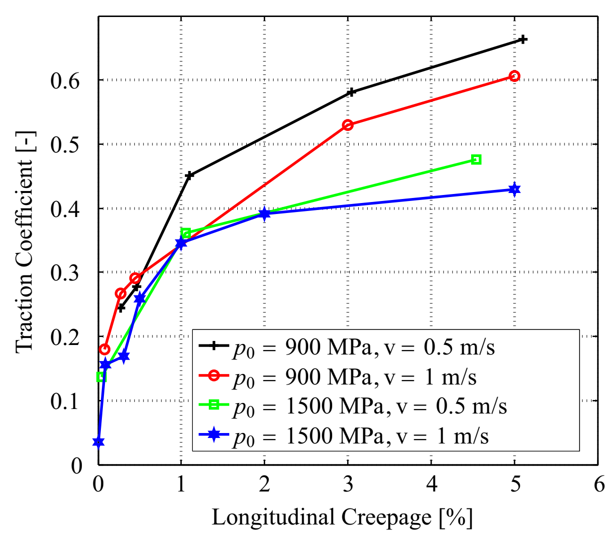

Fig. 3. Results of the traction characteristic for two different maximum normal stresses p_0 and two velocities v. The velocity of the rail-disc was set to v while the wheel–disc was faster according to the creepage.

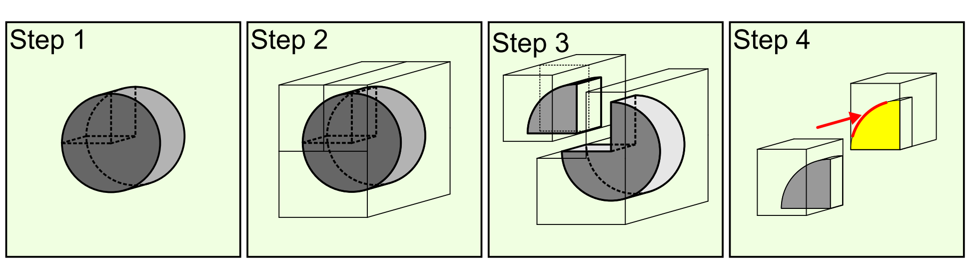

Fig. 2. Preparation of the discs for optical investigations. First, the discs were embedded in a resin, then, they were sectioned. The arrow indicates the observed area.