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Conceptualization of Test Configuration for Tribological Characterization of the Rail-wheel Contact

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Abstract: *Rail-wheel contacts are of great importance for tribologist due to the challenges faced from the view point of maintenance and repairs. Three major challenges are found in the wheel/rail contact are adhesion, rolling contact fatigue (RCF) and adhesion. As wear causes material removal, RCF can lead to surface defects/fracture and adhesion has an influence on the energy consumption. These three tribo-characteristics have an economic, environmental and safety impact on the train transportation. Experimental simulation of rail-wheel contact largely depend on the particular tribo-characteristics which is to be investigated. The present paper discusses the number of available test rigs and their advantages and disadvantages which may aid an easy selection of test configuration for tribo-characterisation. It is also understood from literature that a modular approach complying the different test configuration in a single set-up is an absolute must considering the test duration, cost and representativeness of real application. Hence a novel setup with a modular layout, combining the twin-disc, plane-on-cylinder and twin-disc with interfacial plane configuration is conceptualized.*

Keywords: *Rolling Contact Fatigue (RCF); Adhesion; Wear; Wheel/rail contact; Novel test setup*

1 INTRODUCTION

Rail transportation is one of the most cost effective methods for moving passengers or freight due to its low energy consumption. The wheel/rail contact with low rolling resistance aids to low energy loss. Thus making the train transportation a freightage mode with lowest environmental impact. Since the early beginning of rail transportation continuous, improvements have been made which are all oriented toward the same targets: increased durability, reduction of maintenance costs and increased safety [1]. The problems encountered in rail transportation cover the entire domain of tribology and can be divided into problems associated with rolling contact fatigue (RCF), adhesion and wear.

A first problem found in the wheel/rail contact is RCF. It origins from repeated wheel contacts applying normal stresses and tangential traction. These two stresses combined are typically above the yield strength of the material [2], which gives rise to crack initiation and propagation. Both surface and subsurface initiated cracks can be found, depending on the amount of adhesion in the wheel/rail contact [3]. With increasing adhesion the point of highest stresses shifts towards the surface, giving more chance of a surface defect. Secondly the wheel/rail adhesion is critical in the train transportation in terms of energy consumption and control. In railway terms, adhesion is defined as the rolling friction between wheel and rail. When accelerating under low adhesion values, the wheels will start to spin and resulting in negligible movement of the carriage. During braking the wheels will start to slide over the rail. In both cases wheel and rail wear strongly increases. The adhesion in dry clean wheel/rail contacts is typically sufficient for the adhesion requirements of rolling [4]. Many factors have an influence on adhesion in wheel/rail contact such as the running speed, slip ratio, wheel and rail materials etc. Also the environmental factors such as temperature and humidity have a non-negligible influence [5]. Moreover, wheel/rail contact takes place in an open system which means contaminants such as water, grease, leaves etc. cannot be avoided. In presence of contaminants there is an reduction in adhesion when compared with clean dry conditions [4].

Finally the wear of wheel and the rail in the train transportation is important considering the maintenance. In rail-wheel system three major wear mechanisms can be foreseen, namely abrasive, corrosive and adhesive wear [6]. For abrasive wear both two and three body abrasion are encountered. Presence of sand simulates the three body abrasion, which may increase adhesion however this has the disadvantage of increasing the abrasive wear. In regards to the abrasion and corrosion, the progression of damage depends upon on environmental factors such as relative humidity environmental contaminants (leaves) etc [4].

It is evident that there are several variables are to be considered for tribo-characterisation of rail-wheel contact. In order to idealize the tribo-system these three different challenges are investigated using different test configuration. However, in real application all the three occurs simultaneously. This can be however taken care by a modular set-up which can accommodate different configuration. In this review the authors attempts to study the advantages and disadvantages of the different test configurations used for characterizing adhesion, RFC and wear. Thereby a new test setup concept for tribo-characterisation of rail-wheel contact is established.

2 EXPERIMENTAL SIMULATION OF WHEEL RAIL CONTACT

Experimental simulating of rail-wheel contact with respect to adhesion, RCF and wear is a challenging task. This is due to the multiple factors (material, operational and environmental) which is related to the tribo-characteristics. as many factor have its influence and the same must be taken into account. Performing field measurements is one of the best way to simulate rail-wheel contact to represent real contact condition. However, the field tests are time consuming and expensive.

Experimental simulation of rail-wheel contact in a small scale laboratory setup is far from real application (except for the type of contact). However it may offer the advantage of short test duration from the accelerated testing. Additionally the specimens size and energy input are at a smaller scale for laboratory testing. Figure 1 shows a schematic illustration of different tribosystems. The test configurations are related to the corresponding tribological characteristics (RCF, adhesion, wear) which is to be investigated.

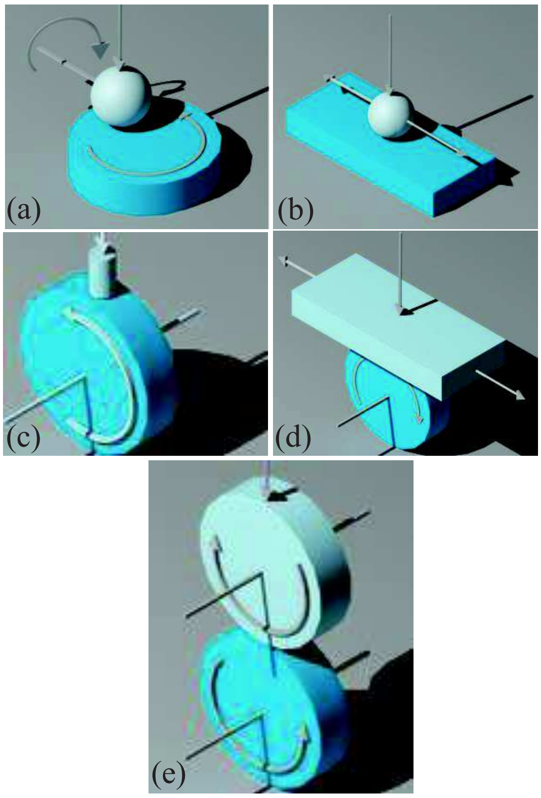


Fig 1 *Different tribosystems to simulate wheel/rail contact: rotary ball-on-plate (a), linear ball-on-plate (b), pin-on-disc (c), plane-on-cylinder (d) and twin-disc (e) [8]*

In the rail-wheel system three types of contact conditions can be expected which are pure rolling, partial sliding and pure sliding. A summary of different setups which can be used to simulate rail-wheel contact is given in Table 1. It is evident from the literature that there are several setups with characteristic features representing different. contact kinematics, load and speeds. Amongst all five most commonly available test configurations are chosen for discussion. From the limitation of the test configuration as presented in the Table 1, it is clear that the ball on plate, plane on cylinder, pin on disc and pin on plate are rather unrealistic in representing the real contact condition. It is evident that twin-disc and plane on cylinder stands common in terms of contact kinematics for pure rolling to pure sliding condition. Though plane on cylinder is the close representative of rail-wheel contact the limitation in the sliding speed does not fully comply with real application. Hence the twin-disc setup is often used to simulate rail-wheel contact [9-12].

Table 1*. Overview of test set-up for experimentally simulating rail-wheel contact*

Test configure-tion	Advantages	Disadvantages
Rolling/sliding		
Twin-disc	-Symmetric contact -Slip ratio can be controlled within narrow tolerances	Misalignment
Ball-on-plate	Small setup	-Slip cannot be controlled -Spinning of the ball during testing -Asymmetric contact
Plane-on-cylinder	-Realistic contact conditions -Slip ratio can be controlled within narrow tolerances	Limitation in speed
Rolling		
Twin-disc	Similar to Rolling/sliding	Misalignment
Plane-on-cylinder	Similar to Rolling/sliding	Limitation in speed
Sliding		
Pin-on-disc	Small setup	Asymmetric contact
Pin-on-plate	Small setup	Asymmetric contact
Plane-on-cylinder	Similar to Rolling/sliding	-
Twin-disc	Similar to Rolling/Sliding	Misalignment

2.1 Setups used for adhesion, RFC and wear

In most cases adhesion between wheel and rail is investigated using a twin-disc setup [9-11]. The setup is know for its high rotational speeds varying dimensions of discs, controllable slip between both discs (between 0 to 100 %) and different boundary conditions can be imposed easily. This makes it possible to simulate in realistic laboratory conditions for the wheel/rail contact.

Considering the investigations on adhesion the ball-on-plate and pin-on-disc setup were also used [12]. These setups have the advantage of having rather small dimensions compared to the twin-disc setup, which makes it more easy to build such a configuration and control the imposed boundary conditions. However, the disadvantage is that the contact is only pure sliding in the case of the pin-on-disc and moreover, the spin of the ball cannot be controlled in case of ball-on-plate setup. Hence these configurations are less suited to simulate a rolling/sliding contact of rail-wheel tribo-system. Though twin-discs are frequently used for adhesion characteristics they are also often used to study RCF. D.I. Fletcher et al. [2] and M.Takikawa et al. [13] have used the twin-disc setup to characterize the RCF behavior of wheel and rail material in dry conditions. Frequently the pitting behaviour are studied using the twin-disc setup. Unlike the ball on plate or pin on disc, the twin-disc is capable of simulating a range of contact condition from pure rolling to pure sliding.

Beside twin-disc, the full scale setups mainly considers plane-on-cylinder configuration due to the close representation of rail-wheel contact. Donald T. Eadie et al. [14] have used a full scale plane-on-cylinder setup to simulate RCF. The plane-on-cylinder configuration has however the disadvantage that the linear speed is limited due to inertia forces, which makes that the wheel/rail contact can only be simulated up to a limited speed. Specific tests focusing on wear are mainly performed on a pin-on-disc setup. J.Sundh et al. [15] and Y. Lyu et al. [16] have used the pin-on-disc tribometer to simulate wear in wheel/rail contact. The pin-on-disc tribometer is only capable of simulating full sliding conditions, which do not correspond to the actual wheel/rail contact that involves both rolling and sliding. Full sliding conditions are however beneficial to accelerate the wear and to characterize the wear behavior of the materials.

Wear, RCF and adhesion are in general simulated using different tribometers. Combining all of these aspects in one single setup will require modular approach. Based on our review it is evident that twin-disc configuration would be used to simulate adhesion because of its continuous movement. The plane-on-cylinder configuration to simulate RCF because of its realistic contact conditions and the pin-on-disc setup to simulate wear because of its full sliding conditions giving a fast characterization of wear. It should however be mentioned that the plane-on-cylinder configuration operating at 100% slip can also be used to simulate wear instead of the pin-on-disc setup. A novel modular concept may have a combination of twin-disc and a plane-on-cylinder configuration in one single tribometer, which makes it possible to experimentally simulate adhesion, RCF and wear.

3. DESIGN OF A NOVEL TEST SET-UP FOR EXPERIMENTAL SIMULATION OF ADHESION, RCF AND WEAR

The proposed concept foresee a modular design for engaging tribo-characterization activities for adhesion, RCF and wear. This means that switching from one configuration to another only requires minimum number of parts to be changed and most parts are to be interchangeable. In general there can be three different operating modes distinguished: the twin-disc, plane-on-cylinder and twin-disc with interfacial plane configuration. Table 2 gives an overview of these different configurations. The proposed three modes can be achieved using a twin disc configuration driven by independent servo motor to control the slip characteristics. A fixed lower disc and a sliding upper disc in the same linear guide (see Figure 2) will enable us to maintain the collinearity between the axis centre of the discs. This will enable us to imply the normal force to the floating disc where continuous contact will be ensured by the floating disc. Besides, the floating disc allows to introduce intermediate plane for the plane on cylinder configuration which is to be driven by a lead-screw.

From Table 2 it can be noticed that a horizontal layout can be prioritized for the plane-on-cylinder and twin-disc with interfacial plane configuration. The horizontal layout was chosen for its versatility in the test configuration. In the vertical layout the two contacts points formed between the two discs and the intermediate plane would be identical. Hence the focus of study may not reach beyond the influence of contact pressure and creepage. In the horizontal layout the wear particles formed tend to stay in the contact for the upper disc, where as in the lower disc the debris may get removed due to gravity. This difference in contact conditions will possibly have its influence on the test results and thereby the influence of contaminants can be well studied from an individual test which is ideal for filtering the uncertainties.

A major advantage of the proposed concept to the existing setups is that the position of the upper wheel and rail can be adjusted with respect to the lower wheel (which is fixed) such that the actual contact conditions can be controlled and are independent of manufacturing and mounting tolerances. Beside the experimental simulation of rail-wheel contact other applications such as cold rolling process, gear contact, cam wear testing and also testing of roller bearings can be foreseen in the proposed test configuration. A systematic approach can be followed in realising the concept by separating the modules for driving, loading, measuring and controlling the different configuration. A solid model of the test configuration is presented in Figure 2.

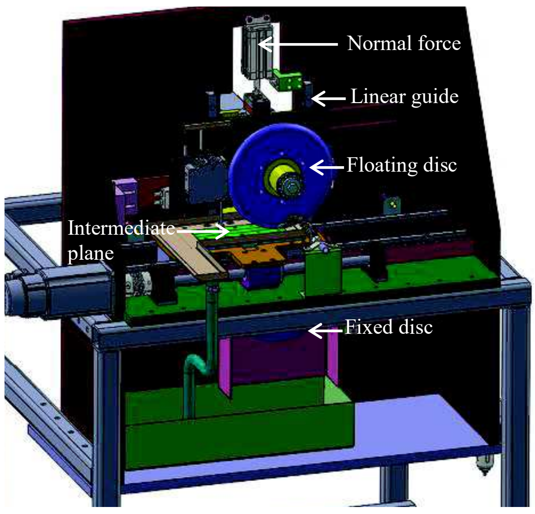
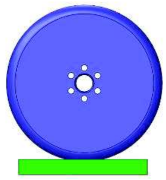
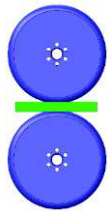


Fig 2 *3D model of the modular test rig concept*

Table 2. *Schematic of the different test mode in the proposed test-rig*

Configuration	Twin-disc	Plane-on-cylinder	Twin-disc with interfacial plane configuration
Schematic	= 		
Measurements	Tangential traction for adhesion and displacement measurement for wear characterisation		
Advantages	-Discs driven independently -High accuracy of slip	-High accuracy of slip -Small dimensions -Position disc/rail adjustable	-High accuracy of slip -Small dimensions -Position discs/rail adjustable
Applications	-Wheel/rail contact -Gears -Bearings -Cold rolling process	-Wheel/rail contact -Cold rolling process	-Wheel/rail contact -Cold rolling process

4 CONCLUSION

Tribological characterisation of the rail wheel contact for adhesion, RCF and wear are briefly reviewed in this paper. It is evident from the review that laboratory scale testing is often used for tribological characterisation of rail-wheel contact. The three tribo characteristics are investigated using different test configuration for the purpose of maintaining the idealized test condition. Amongs the different test configuration the twin-disc has the possibility to investigate all three tribo-characteristics. The other configuration such as ball on plane and pin on disc fail to achieve the contact kinematics and hece the same may not be considered to investigate tribo characteristics of rail-wheel contacts. Based on the abouve review a modular concept was proposed where three modes of testing can be used to coves the tribo characteristics such as adhesion, RFC and wear. In the proposed concept thr three modes namely twin-disc, cylinder on plane and a twin-disc with interfacial plane can be accomodated.

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