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A scaled roller-rig for investigation on adhesion recovery

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Abstract

Contaminants lying on the track (water, oil, leaves, etc.) can reduce the wheel-rail adhesion level to extremely low values, with serious drawbacks, namely reduction of traction\braking performances, high creep values and severe wear of wheel profiles. However, in degraded adhesion conditions, the work of the friction forces removes the contaminant from the wheels (wheel adhesion recovery) and from the rails (rail adhesion recovery), thus partially restoring dry adhesion levels on the wheelsets. The term adhesion recovery can be used to refer to the effects of both phenomena, since they are not easy to distinguish in normal train operations. A deep knowledge of adhesion recovery in full slip conditions would be fundamental to improve contact models as well as WSP and antiskid algorithms. The investigation of the wheel adhesion recovery phenomenon was performed by many researchers with full-scale roller-rigs. The typical configuration of roller-rigs is not suitable for rail adhesion recovery studies, which require a configuration with many wheelsets running over the same surface. Therefore, the authors developed a new 1:5 scaled multi-axle roller-rig with four wheelsets running over the same pair of rollers, thus representing the four wheelsets of a two-bogie vehicle running on the track. A braking system allows to control independently the braking torque on each wheelset, while the rollers are motorized by a 6 poles brushless motor controlled in servo mode. This configuration allows to reproduce different creep levels to study the whole adhesion characteristic. The paper describes the mechanical design of the bench with great attention to the control logic and the acquisition of data measured by several sensors. The new roller-rig configuration allows to perform three kinds of experimental tests, namely simple adhesion curve tests, wheel adhesion recovery tests and rail adhesion recovery tests. Then, attention is given to presentation of the experimental results obtained in the three types of tests. Simple adhesion curves are presented for both speed and torque control modes, showing a good repeatability and a trend just as witnessed in the literature. Wheel adhesion recovery tests in wet conditions showed an adhesion recovery in the backwards (i.e., decreasing creep) cycle, but this phenomenon proved to be significantly affected by the roller speed. Finally, data from railway adhesion recovery tests demonstrated that the cleaning effect is mostly performed by the leading wheelset, so that the rear ones have a higher adhesion level.

Keywords: roller-rig, adhesion recovery, braking operations, wheel-rail contact.

1 Introduction

Contaminants lying on the track (water, oil, leaves, etc.) can reduce the wheel-rail adhesion level to extremely low values, with serious drawbacks, namely reduction of traction\braking performances, high creep values and wear of wheel profiles [1-4].

To overcome low adhesion issues, sand [5-7] is spread on the rails to restore dry adhesion conditions, friction modifiers [8, 9] are used to maintain the adhesion coefficient at an optimum value (0.35), while modern WSP (wheel-slide protection) and antiskid systems [10-14] adjust the tractive and braking effort respectively, to maximize performances while avoiding severe wear of the wheel profiles. However, when a wheelset reaches high creep values in degraded conditions, the dissipated energy at the wheel-rail contact can partially destroy the contaminant layer, thus cleaning the rail and ensuring a higher friction coefficient on the following wheelsets (rail adhesion recovery, RAR). Concomitantly, the work of the friction forces removes part of the contaminant sticking to the leading wheels, thus restoring a higher adhesion coefficient on the wheelsets of the front vehicles (wheel adhesion recovery, WAR). The term “adhesion recovery” can be used to refer to the effects of both phenomena, since they are not easy to distinguish in normal train operations. A deep knowledge of adhesion recovery would be fundamental to improve contact models [15-18] as well as WSP and antiskid algorithms [19].

Laboratory investigation of these phenomena requires the simulation of the vehicle dynamics, so roller-rigs [20-22] represent the typical solution for this purpose. WAR was observed by Zhang et al. [23] and deeply studied by Voltr and Lata [24] using full-scale roller-rigs. Investigation of RAR is more difficult to perform since the condition of following wheelsets running on the same contaminated track section must be simulated. The authors of the present paper tried to replicate this condition on a 1:5 scaled roller-rig, equipped with a roller contamination system and a wheel cleaning device, but some inefficiencies in the cleaning operation caused a difficult interpretation of the experimental results [25]. Therefore, an innovative 1:5 scaled roller-rig, following Jaschinski’s similitude model [26], was designed, consisting of four wheelsets running over the same roller pair [27-31].

First, the paper briefly describes the mechanical design of the bench and then attention is drawn to the tests performed on the rig. Finally, the main results obtained from experimental tests of WAR and RAR are shown.

2 Methods

The test bench, shown in Figure 1, comprises the following main modules: a frame, two rollers, four wheelsets, eight spring suspension systems and a pneumatic braking system. The two rollers, with the external surface machined to the 1:5 scaled UIC60 rail profile and a diameter of 368 mm, are connected using a rigid joint and powered by one 6 pole brushless motor. The external surface of the wheelset, with a diameter of 194 mm, reproduces the S1002 wheel profile. At the ends of each wheelset are two axle-boxes, jointed to the main frame using a spring suspension system. Two brake disc-brake caliper pairs are mounted on each wheelset and the braking system allows an independent regulation of the braking pressure on each wheelset, to impose the creepage between each wheelset and the rollers. Four encoders are used to measure the angular speed of the wheelsets, while four electropneumatic regulators allow to independently regulate the braking effort on each wheelset. The normal load on each axle-box can be independently adjusted and measured with 8 button-load cells while the braking force of each pad is measured by 8 S-beam load cells installed on reaction rods. An industrial PC acquires the signals and manages the bench by means of a LabVIEW VI.

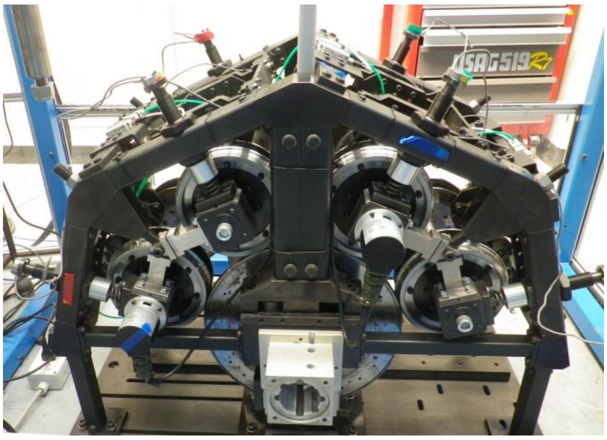

Figure 1: Front view of the test bench.

Three kinds of tests can be performed with the roller-rig. Simple adhesion curves can be obtained on each wheelset, by increasing the air pressure until full sliding conditions and then quickly venting the calipers. WAR curves can be obtained by setting a pressure increasing ramp on a wheelset and then reducing pressure with the same gradient after full sliding is detected. These two tests can be performed in both dry and contaminated conditions, however in WAR test there is no layer to remove in dry conditions. Finally, RAR tests can be performed by braking all four wheelsets together with a constant pressure which guarantees good adhesion at the wheel-roller interface, and then contaminating the roller surface. Figure 2 shows the trend of the pressure signal in all the experimental tests. In all tests, the roller speed feedback is transmitted from the motor drive to the industrial PC via the TCP\IP Modbus protocol. The brushless motor can be controlled both in speed and torque by setting the drive to servo mode.

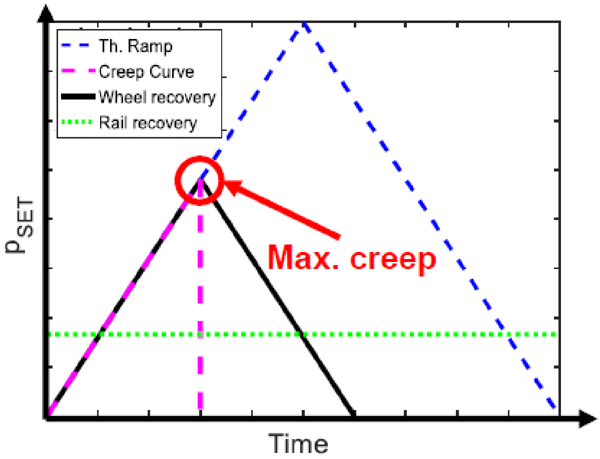

Figure 2: Pressure signal in the experimental tests.

3 Results

The first set of experimental tests was carried out to obtain adhesion curves for the two motor control modes. Figure 3 presents the results for wheelset 4 with the rollers rotating at 200 rpm in dry conditions. The two curves show good repeatability and little influence of the control mode on the experimental results. Each curve features both an increasing and a decreasing trend, related to partial and full slip conditions respectively.

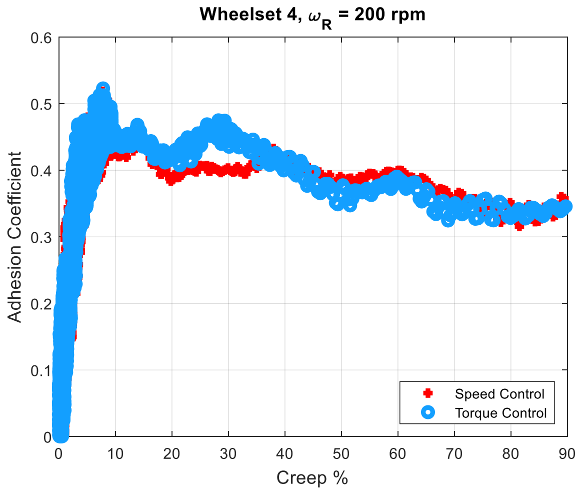

Figure 3: Adhesion curves for wheelset 4 (speed and torque control).

After assessing the capability of the roller-rig of producing good adhesion curves, WAR tests were performed on wheelset 3 controlling the motor in torque with the roller speed set to 100 and 300 rpm, see Figure 4. The adhesion is lower with respect to Figure 3, as the roller surface was contaminated continuously during the test. The adhesion recovery is noticeable for both speeds, but the shape of the hysteresis loop is strongly related to the roller speed. In fact, at 300 rpm, an evident adhesion recovery occurs in the forward (i.e., increasing creep) curve at a creep value of about 45%. Moreover, the hysteresis loop is slenderer in the test performed at 100 rpm. These differences arise since at fixed creep, the sliding speed increases if the roller speed increases. Furthermore, the temperature at the wheel-roller interface can be affected by the roller speed.

Figure 4: Wheel adhesion recovery tests on wheelset 3.

Finally, a RAR test was performed, setting a braking pressure equal to 1.5 bar on all four wheelsets and contaminating 3 times the wheel-roller interface by injecting water on the roller surfaces. Figure 5 shows the creep values on all wheelsets, numbered in ascending order starting from the first one facing the contaminant, during the first contamination. The first wheelset reaches the highest creep values, while the last one has a very little variation of creepage during the test, since the cleaning action is performed by the leading wheelsets. The creepage on wheelset 3 is higher with respect to wheelset 2, and this is not in line with the expectations, however this behaviour could be related to differences in the adhesion level and in the normal load on the four wheelsets.

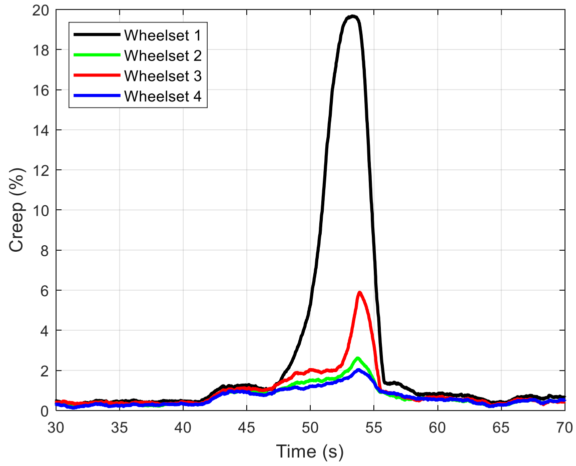

Figure 5: Rail adhesion recovery test.

4 Conclusions and Contributions

The experimental activity described in the paper is intended to investigate adhesion at high creep values, when full sliding occurs at the wheel-rail interface. In degraded adhesion conditions, the work of the friction forces due to sliding removes the contaminant from the wheels and from the rail, thus restoring partial dry adhesion levels on the rear wheelsets. Although some laboratory studies of WAR are witnessed in the literature, little experimental data is available concerning RAR, since the investigation requires to simulate more wheelsets running on the same surface. Therefore, an innovative 1:5 scaled multi-axle roller-rig was designed by the authors, which is described in its mechanical architecture in the first part of the paper, together with the transducers used to measure the quantity of interest and the control logic to carry out the experimental tests. Different creep values can be imposed by setting the motor to a constant speed and decelerating the wheelsets with a pneumatic braking system, which includes two brake discs and two calipers on each wheelset. Both speed and torque control mode can be performed with the motor drive.

The new roller-rig configuration allows to carry out three different kinds of experimental tests, namely simple adhesion curve tests, WAR tests and RAR tests. The experimental results are shown in the second part of the paper. First, simple adhesion curves are presented for both speed and torque control modes, showing a good repeatability and a trend just as witnessed in the literature. WAR tests in wet conditions were carried out and the adhesion curves showed an adhesion recovery in the backwards (i.e., decreasing creep) cycle, but the shape of the hysteresis loop proved to be significantly affected by the roller speed. Finally, data from RAR tests demonstrated that the cleaning effect is mostly performed by the front wheelset, so that the rear ones have a reduced adhesion loss. However, some deviations from expectations were registered during this test, but they can be related to variations in adhesion conditions and normal load of the wheelsets.

The experimental activity showed that the new bench configuration allows to carry out both WAR and RAR investigations. Scheduled tests will investigate the dependency of adhesion on normal load, roller speed and nature of the contaminant. A future upgrade of the activity could be the installation of PWM valves to test new WSP algorithms.

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