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Experiments on Polygonization of Railway Wheels Based on a Small-Scale Test Rig

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Abstract

A small-scale test rig to perform experiments on the formation mechanisms of polygonization of railway wheels is built at the Institute for Rail Vehicles and Transport Systems. The functionality is based on imposing a sinusoidal yawing motion on a wheel while it is rolling on a drive disc that represents the rail. The wheel speed and the yaw frequency can be set independently. It is expected to create polygonal wear if a certain ratio of rolling and yaw frequency is set. The first experimental results are presented in this paper. It is shown that the test rig works and that a polygonal pattern is clearly visible on the specimen wheels within 10 minutes of the experiment. The yaw frequency was set in test series such that a third and a fifth polygonization order are expected, respectively. The orders aimed for are not achieved in any of the experiments performed. Instead, the observed orders lie between 9 and 11 instead of 5 and 13 instead of 3. The selected yaw frequency affects how dominant the measured polygon patterns are. The appearance of the wheel treads indicates that the wheels have been plastically deformed and that the usual wear mechanisms present in the wheel-rail interface are insufficiently achieved. The observations of the test series cannot be explained so far, which shows the need for further research in this field. Therefore, the findings on the wear that occurred to the wheels within the experiments are to be used to further develop the test rig and to select reasonable parameter variations for further tests.

Keywords: Railway Wheel, Test Rig, Wheel Wear, Polygonization, Roller Rig

1 Introduction

Polygonization of railway wheels is a wear phenomenon in which waves develop along the circumference of the wheel [1]. An example of a polygonized wheel is depicted in Figure 1. Such a wear behavior of railway wheels is undesired because it induces periodic vibrations, which in turn increase stresses on track and bogies and reduce the ride comfort [2]. In addition, polygonization increases the maintenance effort as the wheels have to be re-profiled more frequently. Re-profiling is the only way to prevent the vibrations if the root cause of polygonization of railway vehicles suffering from this wear behavior is not known.

Typically, the wear pattern is evaluated concerning the so-called polygonal order. The order represents the ratio of the wheel circumference and the wavelength of the wear pattern [1]. In the case of the example wheel shown in Figure 1, the 8th order dominates, even if other orders are present as can be seen by the irregularity created by the superposition of other waves.

The formation mechanism of polygonized wheels is not yet understood. Material inhomogeneity, initial out-of-roundness, and structural vibrations of the vehicle and track are considered as possible root causes of polygonization. Experimental research of the polygonization process is difficult because wear occurs on a large time scale. Therefore, field studies are limited to measuring structural vibrations and linking them to the polygonization orders observed as done in [3]. To address this issue, a small-scale test rig being capable to create polygonal wear patterns to wheels is built at the Institute for Rail Vehicles and Transport Systems. In the long term, the test rig shall be employed to investigate the formation mechanism of polygonization in detail.

The purpose of the present work is to check if the designed test rig works as expected. In particular, it is to be examined whether polygonization can be generated at all and, if so, whether this occurs in a sufficiently short experiment duration. In addition, it is to be observed whether theoretically expected polygon orders can be generated by imposing a wheel motion during rolling. Finally, the findings of this first experiment series performed with the new test rig are to be used to derive improvements for the further development of the test bench.

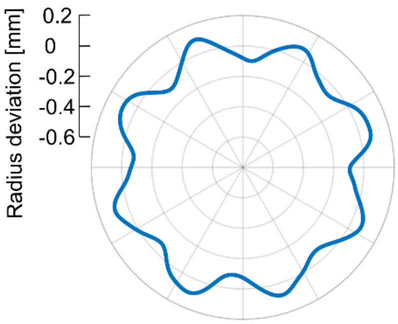

Figure 1: Polygonized wheel with dominant 8th order.

2 Methods

The main concept of the test rig is to apply a yaw motion to a small-scale wheel when it is rolling so that repetitive changes in the wheel-rail contact patch are induced. For that, a single wheel rolling test bench was equipped with the extension shown in Figure 2. It is a device that guides a specimen wheel made of free-cutting steel with D = 50 mm in diameter representing a vehicle wheel on a large drive disc. The drive disc represents the rail. A sinusoidal yaw motion of ± 5 degrees is imposed while the specimen rolls on the drive disc. For this purpose, the support arm holding the specimen is mounted such that it can rotate about its longitudinal axis (x-axis). The yawing is achieved by a connecting rod that engages eccentrically with the support arm and is mounted on an eccentric shaft of a flywheel. A preloaded spring applies the static wheel load and ensures contact between the wheel and the drive disc when the wheel diameter decreases due to wear. The static force is approximately 130 N based on the stiffness and pre-compression.

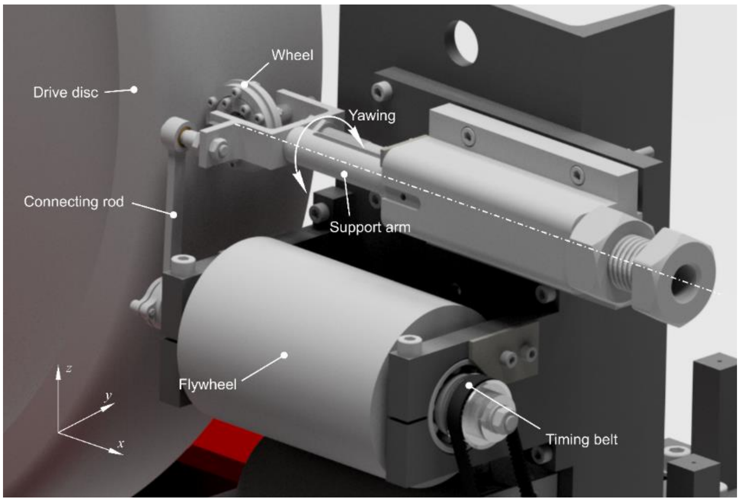

Figure 2: Small-scale polygonization test rig.

For the test, the drive disc is accelerated to a speed of 8 km/h. The wheel's rotational speed and the frequency of yawing are constantly measured. A closed-loop controller ensures that the ratio of rolling and yaw frequency remains constant.

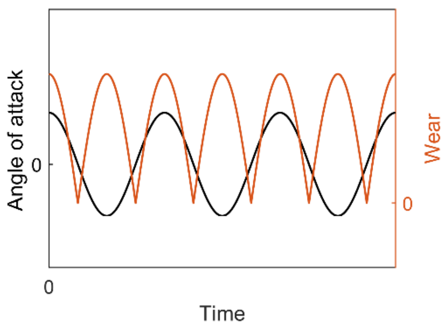

Figure 3: Expected wear due to a sinusoidally varying angle of attack.

The sinusoidally varying angle of attack resulting from the applied yawing leads to lateral creepage, which in turn increases the wheel wear. Since the sign of the angle of attack does not influence the wear, the expected wear function has twice the frequency of the yaw frequency as depicted in Figure 3. Hence, the expected polygonal order due to an applied yaw motion yields:

$$\Theta = \frac{\pi D}{v} \cdot 2 \cdot f_{\mathrm{yaw}} \tag{1}$$

Replacing the wheel velocity by

$$v = \omega r = \pi D f_{\mathrm{roll}} \tag{2}$$

leads to the polygonal order:

$$\Theta = 2 \frac{f_{\mathrm{yaw}}}{f_{\mathrm{roll}}} \tag{3}$$

For the test procedure, the specimen is mounted to the test rig and the static wheel load is applied. Then, the drive disc and the flywheel are accelerated to their desired speeds, which are afterward kept constant for the test duration. Several tests with three different parameter settings are conducted as stated in Table 1. After each test, the specimen is clamped in an indexing head so that the out-of-roundness can be manually measured with a dial gauge and a step size of 6 degrees.

Experiment No.	Ratio f_{yaw}/f_{roll}	Duration	Expected Polygonal Order Θ
1, 2, 3	2.5	25 min	5
4, 5	2.5	10 min	5
6, 7, 8	1.5	10 min	3

Table 1: Parameters of the test series.

3 Results

During the tests, a significant polygonization is achieved for all specimens, which is visible to the naked eye. The radius reduction of the wheel is about 1 mm for all tests. The specimen of test #7 is exemplarily depicted in Figure 4. However, all wheels exhibit a burr at the edges of the tread, which results from plastic deformation as can be seen in Figure 4b. Therefore, it can be concluded that the polygonal out-of-roundness results from exceeding the yield strength of the specimen material rather than adhesive and abrasive wear that is normally dominating the wear in railway wheels.

Figure 5 shows the measurement results of the first five tests. The radius deviation from the mean radius of the test wheels is depicted in subfigure 5a. All of the wheels show waves along the circumference but a common dominating order cannot be identified, as the wear patterns differ from each other. The figure indicates that specimens #1, #2 and #3 exhibit large eccentricity. However, it cannot be assessed whether the eccentricity actually is present on the specimen wheels or whether an eccentric clamping in the indexing head for the measurement causes it. The order plot in Figure 5b clearly shows that the expected 5th order of polygonization is not dominant for any of the tests. The dominant orders observed are in the range of 9 to 11. Tests #5 and #6, in which the test duration is reduced compared to #1 to #3, exhibit the highest amplitudes, which is also expressed by the fact that the wear pattern is well defined in the polar plot.

Figure 4: Specimen of test #7 after the experiment, (a) polygonal shape, (b) burr at tread edge.

Figure 6 shows the same analysis for the test series in which a third order is expected due to the adjusted yaw frequency. The variance of the results is less than for experiments #1 to #5 and the 13th order is heavily dominant in all tests. The polar plot confirms the observation as the tread is superimposed by a wave with a wavelength of 1/13 of the circumference. The wear pattern obtained again does not correspond to the expected wear pattern.

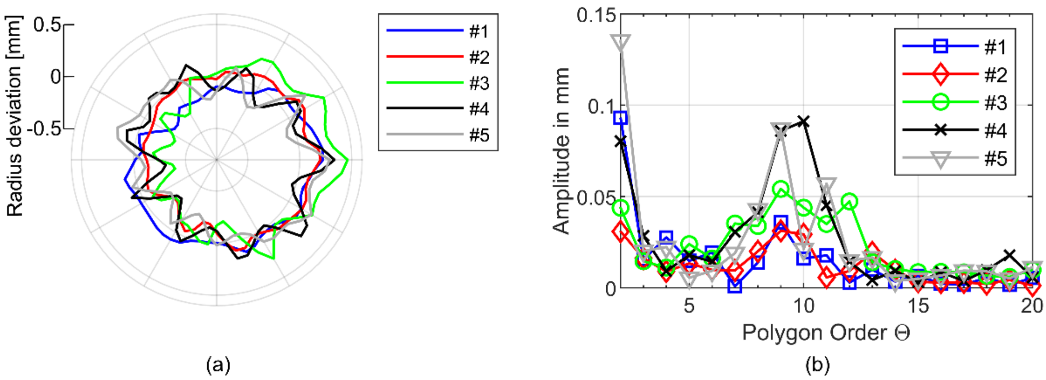

Figure 5: Measurement of specimen #1 to #5, (a) radius deviation from mean radius, (b) order amplitudes.

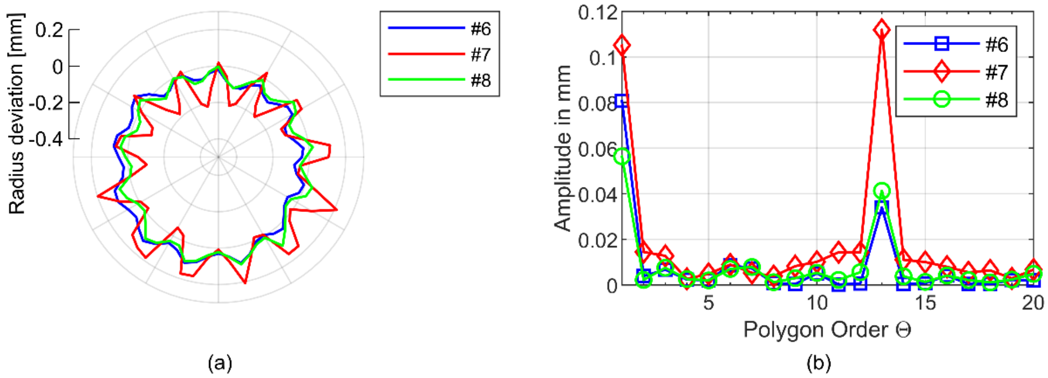

Figure 6: Measurement of specimen #6 to #8, (a) radius deviation from mean radius, (b) order amplitudes.

4 Conclusions and Contributions

The Institute for Rail Vehicles and Transport Systems developed an extension for the existing single-wheel test rig to perform investigations on the formation of polygonal wear patterns on small-scale wheels. For this purpose, the test bench applies a sinusoidal yaw motion to a rolling wheel, which leads to fluctuating lateral creepage and, consequently, fluctuating wheel wear. The first experiments presented in this paper confirm that the functionality of the test is capable of inducing polygonal wear patterns to the small-scale wheels.

The first experiments with the new test rig show that the expected wear patterns could not be achieved. In the case of expected dominating 5th order, the wheels exhibit dominating orders in the range of 9 to 11. In another setup, the 13th order is observed instead of the expected 3rd order. It raises the question to what extent the widely used assumption of a fixed ratio between structural vibration frequency and polygonization order may be applied. In the tests carried out, the extent to which the wear pattern is dominated by one order depends on the yaw frequency and the experiment duration. The shorter the duration, the more predominant one order is. The findings described, especially the creation of certain polygon orders, cannot be explained so far.

The interpretation of the test results is limited since the test wheels are plastically deformed on the running surface by the experimental setup. Therefore, it can be assumed that the wear pattern is not created due to adhesive and abrasive wear as is the case in railway wheels. A reason for this may lie in the high yaw amplitude of 5 degrees, which was applied to create sufficient wear within a reasonable test duration. Furthermore, the specimen wheels are made of free-cutting steel instead of common wheel steel like E7 and E8.

The aforementioned issues shall be addressed in future investigations. The specimens are to be made of common wheel steel and the applied yaw amplitude is to be reduced. Future studies will include parameter variations regarding the maximum angle of attack and the static wheel load. Additionally, the test rig is to be equipped with accelerometers and high-speed cameras so that the formation process of polygonal wear patterns can be studied in detail.

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