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Substantiation of the Parameters of the Bench for Testing of Railway Wheels for Contact and Fatigue Strength

S. Raksha[1], P. Anofriev[2], O. Kuropiatnyk[3], K. Glavatskij[4], V. Bohomaz[5], O. Posmitiukha[6], S. Volkova[7]

[1]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: raksha@ukr.net*
[2]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: anofrievp@ukr.net*
[3]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: kuropyatnick@gmail.com*
[4]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: kazimir.glavatskij@gmail.com*
[5]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: wbogomaz@i.ua*
[6]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: 2aleksandraa@gmail.com*
[7]*Ukrainian State University of Science and Technologies, Lazaryana St. 2, 49010, Dnipro, Ukraine, E-mail: svolkovav2017@gmail.com*

Abstract

Strength indicators are important parameters of the railway wheels, as they determine the allowable service life of both the wheel itself and the wheelset as a whole. Therefore, the development of bench equipment that allows in the laboratory to reproduce or simulate the real conditions of the wheel load in order to conduct strength tests, is an urgent scientific and practical task. The purpose of this work is to substantiate the parameters of the bench for testing railway wheels for fatigue and contact strength. As the bench has to test railway wheels for fatigue and contact strength at the same time, the requirements of various normative and methodological documents, which determine the procedure for conducting such tests on separate benches, were combined when determining the parameters of the bench. We determined that the working force of the bench should vary from 10% to 100% of the wheel endurance limit, the duration of the tests should correspond to five million load cycles with a frequency of 5 to 10 Hz. To reduce the duration of the tests, pushing on the wheel was carried out by several rollers, which were evenly distributed around the wheel. For the proposed bench, we obtained the dependence that connects the parameters of the test wheel, the parameters of the bench, the wheel pair axle load and the wheel material endurance limit. The results of this study can be used as a basis for the development of new schemes of benches for railway wheels tests.
KEY WORDS: *railway; test bench; contact strength; fatigue strength; parameter*

1. Introduction

One of the main parameters of the railway wheel is its resource, which determines the allowable service life of both the wheel and the wheel set as a whole. Therefore, the development of bench equipment that allows in laboratory conditions to reproduce or simulate real conditions of wheel pair loading for the purpose of carrying out resource tests, is an urgent scientific and practical task.

Among the types of bench tests, which are regulated before the current regulatory documents [2-5], resource tests include tests for fatigue strength of railway wheels and wheelsets axles. Such tests involve the study of the wheelset parts operation under cyclic loading conditions under the modes defined by current standards and methods. There are many developments on tests for fatigue strength of axles [13, 16, 17]. A number of publications have been devoted to the issue of strength and interaction of wheel-rail [6, 11, 12, 14]. Additional factors that determine the railway wheels life are contact strength and wear of individual surfaces of the wheel (rolling surface, flange). The current normative documents do not provide for bench tests taking into account the influence of these factors. However, there are studies [1] that indicate the advisability of such tests.

To reduce the duration of the general procedure for determining the wheels service life, it is efficient to combine different types of tests with their simultaneous performance using one test sample (railway wheel).

The main purpose of this work is to determine and analyze the technical parameters of the bench for complex tests of railway wheels, which provides a combination of tests for fatigue and contact strength, their simultaneous performance on one bench.

2. Research Methodology

The authors of this work have some experience in the development of benches for testing railway wheels for fatigue strength [7]. Similar developments were conducted by other employees of the Ukrainian State University of Science and Technologies, as well as members of the international scientific community [8, 9]. The application of cyclic loading to different surfaces of the railway wheel (rolling surface, flange) is realized in these benches.

Tests for contact strength involve the creation in the contact zone of a force equivalent to the contact force that occurs in real operating conditions of the wheels. Work in this direction proposes to replace one of the parts of the wheel-rail contact pair (rail [15]) or both parts [1] on rollers and set the load conditions close to real.

2.1. Analysis of Requirements for Tests and Bench Equipment

Interstate standard [2] establishes requirements and characteristics for testing wheels used in wheel pairs of freight and passenger cars of locomotive traction, passenger, freight and shunting locomotives, motor and non-motor wheel pairs of electric and diesel trains, special railway rolling stock:

- endurance limit (F_r) – the maximum force in the contact zone that can be perceived by the wheel for a specified period depends on the wheelset axle load (for example, for wheelsets with axle load up to 230.5 kN endurance limit F_r = 400 kN);
- test duration corresponds to 5 million load cycles;
- load is asymmetric with an asymmetry factor of 0.1;
- load is applied to the wheel rim.

The test method [10] duplicates the standard [2] in terms of endurance, test duration and nature of the load, but indicates the need to apply it to the wheel flange. In addition, the value of the cyclic loading frequency is set – 300…600 cycles per minute (5...10 Hz). Since the interstate standard has a higher regulatory force than the methodology, we believe that the load should be applied to the wheel rim; it also corresponds to the wheelset real operating conditions.

The interstate standard [5] applies to mainline railway cars. It establishes the need to test the wheels for fatigue strength by implementing alternating bending under the action of circular bending moment during 20 million cycles. For wheels of locomotive wheelsets and railcars, the interstate standard [4] defines fatigue strength tests in the form of circular bending under asymmetric loading (its alternation and asymmetry coefficient are not normalized), and the endurance limit is specified at 125 MPa (depends on the wheels design).

Summarizing these requirements, we come conclusions:

- bench for complex tests of railway wheels must provide a load on the wheel, which varies in the range from $0.1F_{max}$ to F_{max}, where $F_{max} = F_r$ is the wheel endurance limit according to [2], which depends on the wheel pair axle load;
- test duration corresponds to 5 million load cycles;
- cyclic loading frequency is 300…600 cycles per minute;
- cyclic load is applied to the wheel rim.

As a basis for the development of a bench for complex tests of railway wheels, we take the bench for resource tests of railway wheel pairs [15], the scheme of which is shown in Fig. 1.

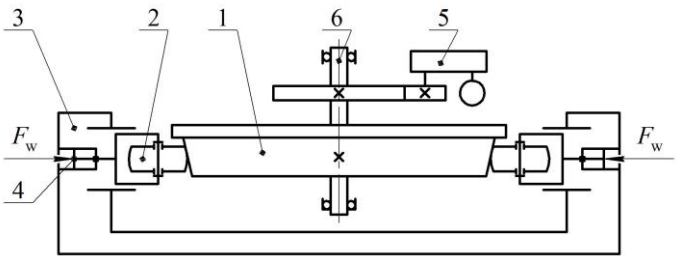

Fig. 1 Test bench scheme: 1 – test wheel; 2 – roller; 3 – frame; 4 – loading device; 5 – bench drive; 6 – axle (F_w – working force of the bench)

In this bench, the roller 2 simulates the rail, and the loading device 4 with the working force F_w creates a force in the contact zone of the wheel-roller pair, equivalent to the force in the contact zone of the wheel-rail pair in wheelset real operating conditions. In this case, the wheel 1 is in contact with several rollers at the same time (at least three rollers); this makes it possible to conduct accelerated tests. To ensure compliance of the conditions of bench tests with the wheelset real operation conditions, the test bench parameters was determined so that the maximum contact pressure in the wheel-roller pair is equal to the maximum contact pressure in the wheel-rail pair.

2.2. Establishing the Possibility of Conducting Comprehensive Tests

Since the bench for complex tests of railway wheels must be tested simultaneously for fatigue and contact strength, we form requirements for the value of the bench working force (F_w):

– force F_w must be pulsating and provide a change in load on the wheel in the range from $0.1F_{max}$ to F_{max} (fatigue strength test);

– cyclic loading frequency is 300…600 cycles per minute (fatigue strength test);

– F_{max} value must correspond to the axle load of the wheelset whose wheel is being tested (fatigue strength test);

– force F_w should ensure the adequacy of the bench tests conditions (compliance with the actual load conditions).

The last requirement for the bench working force value can be met in the case of equality:

$$F_w = 0.5F\left(1+\frac{D_w}{d_r}\right), \tag{1}$$

where F – wheelset axle load; D_w – diameter of the wheel on the rolling surface; d_r – roller diameter.

The dependence of the F_{max} value on the axle load F is specified in the standard [2] (Table 1).

Given that the force F_{max} acts along the common normal to the contact surfaces of the wheel-roller pair (Fig. 2), we take:

$$F_w = \frac{F_{max}}{\cos\beta}, \tag{2}$$

where β – slope of the rolling surface (β = 2.86° corresponds to a taper of 1:10 specified in the standard [2]).

Table 1
Dependence of the wheel endurance limit on the wheelset axle load

F, kN	F_{max}, kN
230.5	400
245.3	450
264.9	510
294.3	600

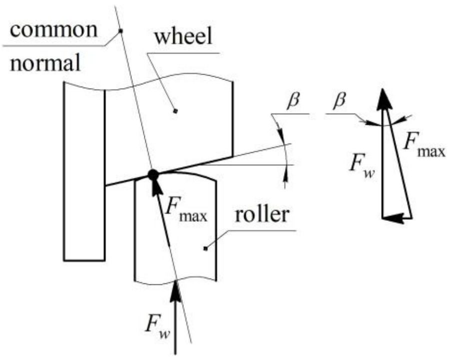

Fig. 2 Scheme of force action in the wheel-roller pair

Combining conditions (1) and (2), we have:

$$0.5F\left(1+\frac{D_w}{d_r}\right) = \frac{F_{max}}{\cos\beta}. \tag{3}$$

Thus, we obtained the dependence, which connects the test wheel parameters (D_w, β), the bench parameter (d_r), the wheelset axle load (F) and the wheel endurance limit (F_{max}).

From Eq. (3) it follows that the roller diameter can be determined by the formula:

$$d_r = D_w\left(\frac{0.5F\cos\beta}{F_{max}}-1\right)^{-1}. \tag{4}$$

3. Research Results

Preliminary analysis of dependence (4) indicates that the function $d_r(F_{max})$ has a second-class discontinuity. Let determine whether it falls on the area of change of the argument from $0.1F_{max}$ to F_{max}.

Analysis of the data given in the standard [2] showed that the wheel diameter (D_w) does not depend on the wheelset axle load (F). To perform calculations, we take the following values of the wheel parameters [2]: D_w = 957 mm; β = 2.86°. The combination of wheelset axle load (F) and endurance limit (F_{max}) is taken from Table 1.

The $d_r(F_{max})$ dependence for each of the combinations of calculated data is shown in Fig. 3 as a set of curves. The graph shows that the second-class discontinuity of the function $d_r(F_{max})$ falls on the interval of change of force in the contact zone of the wheel-rail pair from $0.1F_{max}$ to F_{max} (on the abscissa axis shows the interval 40… 400 kN for the first combination of forces in Table 1).

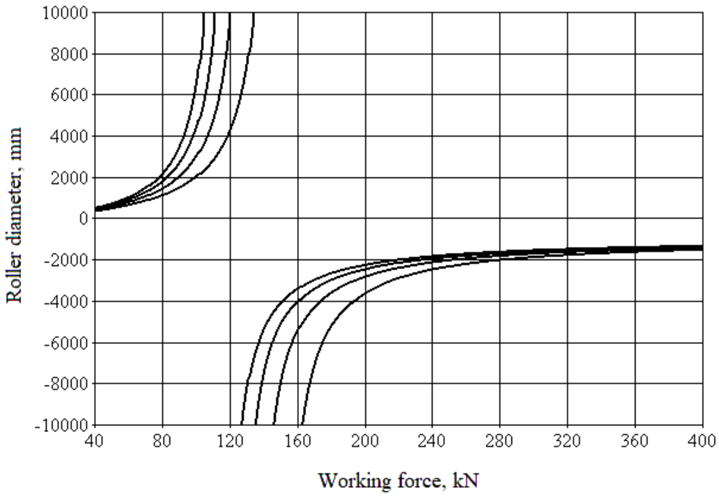

Fig. 3. Graph of $d_r(F_{max})$ dependence

4. Conclusions

During the research, we determined the test bench parameters (roller diameter and working force) and the dependence, which connects the test wheel parameters, bench parameters, wheelset axle load and wheel endurance limit. Based on the results obtained, we conclude that conducting comprehensive tests of railway wheels, which involve combining fatigue strength tests with contact strength tests, and the simultaneous conduct of them on one test bench is impossible.

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