High Frequency Vibrations Arising in System Wheel-Rail. Part II. The Influence of High Frequency Vibrations on the Structure of Rail Steel M76

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Abstract. In this paper, the influence of high-frequency vibrations in the wheel-rail system is studied, the main causes of their occurrence are described, the study of the structure of M76 rail steel at operating stress levels of 700 MPa and more is given. Investigated the microstructures of samples cut from the actual rails, following the action of high-frequency loading by means of optical microscopy and micro hardness testers.

1. Introduction
Currently, the development of modern rail transport systems have a several directions such as: increasing speeds, increasing the load transmitted to the axis of the wheel pair, the length and weight of trains and in general, more intensive use of railway infrastructure. All this can significantly influence on increase in the range of vibrations in the wheel-rail system, therefore, that makes scientists and engineers to refine the results of research in this area [1, 2, 3]. The main source of high-frequency vibrations is the impact of wheels on the joints, on welding joints, on zone of local defects on the rolling surface of rail and wheel. Their frequency spectrum depends on the condition of the rail track, including roughness, wave wear and other irregularities on the surfaces of rolling, appearing, as from wear of rail, and after grinding and milling of the rail head with specialized rolling stock.

In wheel-rail system when the train is moving arise impact loaded that are largely dependent on speed, on quantity and type of cargo transported by the train. The magnitude of impact forces for most modern trains varies from 200 kN to 900 kN [5]. On the North American railways when the train was moving was recorded a impact load exceeding 400 kN and on the Canadian National Railway (CN) about 885 kN [6]. Was found [7, 8] that when there are defects on the rolling surface wheel in the form of sliders and navars with sizes exceeding standard and uneven rolled metall arising pulsed impact forces of 350 ... 640 kN. If the track structure has a satisfactory technical condition in accordance with the norms and standards, then in most sections of the track the value of the dynamic forces of interaction between the wheel and the rail does not exceed 200 kN.

The second part of the research presents a mathematical modeling of wheel–rail contact. During bench tests (Fig. 1) simulating the behavior of the wheel – rail system [12–14], was obtain contact areas in the range of 204 - 263 mm².
Therefore, taking into account the high-frequency vibrations arising during rolling stock movement, the real acting impact loads and the calculated areas of wheel and rail interaction, it is relevant to study the influence of high-frequency vibrations in the wheel-rail system [11, 15, 16] on the structure of rail steel M76 with amplitudes stresses from 700 MPa and more.

2. Test Method
To the study influence of high-frequency vibrations in the wheel-rail system was develop the author's technique, which includes operations such as fatigue testing, structural analysis (optical metallography) and microhardness measurement.

Fatigue tests was carry out on USF-2000 ultrasonic machine (Shimadzu, Japan) with a frequency 20,000 Hz on series samples with amplitudes of 710 MPa and more. Samples had shape of a rotating body with cylindrical ends Fig. 2a)

Analysis the structure of study samples (Fig. 2b) was carry out in longitudinal axial section on inverted microscope Eclipse MA200 (Nikon, Japan) at magnifications of 100–500. During etching was use a 2% salicylic acid solution in ethyl alcohol, revealing the structure of perlite more accurately than standard etching agents based on nitric acid. Microhardness tests were carried out on an automatic microhardness testing HMV-G-FA-D (Shimadzu, Japan).

3. Result and Discussion
The study of influence of high-frequency vibrations on the structure of rail steel M76 was carried out on a series samples with stress amplitudes of more than 700 MPa (Fig. 3). Table 1 shown results in order of decreasing stress amplitudes.
Table 1. Experimental data.

| №  | Amplitude $\sigma_a$, MPa | Number of cycles $N$ | Cause of destruction | Microhardness HV |
|----|---------------------------|----------------------|----------------------|------------------|
| 1  | 800                       | $<10^4$              | crack                | WL 738…1188      |
| 2  | 790                       | $1,1942-10^4$        | crack                | WL 997…1313      |
| 3  | 770                       | $4,0601-10^4$        | crack                | 247…343          |
| 4  | 755                       | $1,0076-10^5$        | crack                | 295…362          |
| 5  | 750                       | $8,9894-10^4$        | crack                | 267…330          |
| 6  | 745                       | $8,2897-10^4$        | crack                | 276…324          |
| 7  | 740                       | $7,2232-10^4$        | crack                | 285…349          |
| 8  | 740                       | $2,8477-10^5$        | crack                | 281…343          |
| 9  | 740                       | $9,6302-10^4$        | crack                | 290…350          |
| 10 | 730                       | $1,4701-10^5$        | without changes      | 264…332          |
| 11 | 710                       | $2,4275-10^8$        | without changes      | 283…339          |

Note: WL - "white layer"

For steel M76 characteristic pearlite structure. With high-frequency loading and amplitudes of about 800 MPa, obvious changes occur in the structure - in the most stressed zone (near the crack) a structure is formed which is called the “white layer”. This structure occurs on the working surface of the rails. It is considered that the "white layer" arises from pearlite as a result of severe plastic deformation due to the distribution of carbon in the grain boundary phase [4, 9]. According to other data [12], the “white layer” is an austenitic-martensitic structure. Near the crack, the microhardness exceeds 1000 HV (which corresponds to 66 HRC). High hardness indicates a high density of defects in the “white layer”.

Sample 1, magnification 100’

Sample 1, magnification 500’
Increasing microhardness has a very clear localization: when removed from the “white layer” by 100 μm, the microhardness decreases by a factor of 3–4, and the pearlite structure remains in its original state. Microhardness at distances from a crack of 200 μm and more is ~ 250 ... 350 HV, which is typical for the structure of rail steel.

**Figure 3.** Microstructure of samples with «white layer».

**Figure 4.** Microstructure of cracked samples.
At amplitudes of 770–730 MPa, in samples under high frequency loading cracks form, but the “white layer” does not appear (Fig. 4). The changes in microstructure of these samples and microhardness over the longitudinal section is not detect. Thus, a sharp local increase in microhardness indicates the beginning of the process destruction [17, 18], but low values microhardness are not a sign the absence destruction place in it.

![Figure 5. Graph of microhardness measurement along the crack length.](image)

Measurements of microhardness (Fig. 5) in the area of tip crack show an increase in it, but this increase is small — the average microhardness is 50HV higher than at exit to the surface [15, 19-21]. This suggests that the accumulation of defects under the action of high-frequency vibrations in the body of grain occurs, but destruction is very fast. Since there is a fatigue crack in the sample, but optical metallography does not show structural changes (the increase microhardness of grains is also insignificant), it can be assumed that defects accumulate at the grain boundaries (or, perhaps, blocks) and these accumulations of defects turn into microcracks, one or several of which may become main crack.

4. Conclusion
1. With the combined effect of high-frequency vibrations and real amplitudes (800 MPa) operating in a wheel-rail system, destructions occur in rail steel with appearance of “white layer,” the microhardness which exceeds 1000 HV.
2. In the amplitude range of 770–730 MPa, cracks are formed in most cases, but the “white layer” does not appear. Purposeful measurement of microhardness in the zone of cracks shows only insignificant changes, which indicates the rapidity of process destruction.
3. When effect to high-frequency vibrations in the M76 rail steel, damage accumulates, leading to destruction, but at this stage of study, it was not possible to fix these damages before cracking. Thus, this question requires more detailed study.
4. At amplitudes of 710 MPa and below and the number of cycles $N \approx 2 \cdot 10^8$, no structural changes were identified, which determines it as the optimal amplitude.

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