The definition of longitudinal forces in the rail by changing its eigen frequency

S V Chunin, V I Shabunevich and M G Akashev
Joint-Stock Company “Scientific-Research and Design-Technology Institute of Rolling stock” (JSC “VNIKTI”), 410, Oktyabrskoy Revolutsii st., Kolomna, 140402, Russian Federation

vnikti@ptl-kolomna.ru

Abstract. The article discusses methods to evaluate the longitudinal stress level in the rail formed as a result of the thermal expansion of the continuous welded rail track. The comparative analysis of results of bench and field tests, as well as the verification of the mathematical model of the track section, have been performed.

1. Introduction
The continuous welded rail track having a number of advantages over the jointed track has been widely applied in railways. However, it also has its disadvantages. One of the problems of operating the continuous welded rail track is the control of the longitudinal stress in the rail occurring because of its seasonal thermal expansion. The operation of such a track with an erroneously or insufficiently accurately obtained value of the longitudinal stress can lead to the railway track buckling, accidents and the interruption of the transportation process.

2. Problem description
Currently, the continuous welded rail track laying, packing-up, maintenance and repair are determined by the instruction of OJSC “RZD” No. 2788r as of December 29, 2012. However, the method of monitoring the rail stress state during its operation is not specified in it. An accidental change in the stress state of the continuous welded rail may occur as a result of the rail creeping, maintenance, changes of the track geometry, etc. For example, 22 cases of rolling stock derailment due to track buckling were recorded from 2010 to 2016.

3. Problem solution
The most effective method seems to be the approach to define longitudinal stress in the rail by changing its eigen frequency. Compared to current methods (for example, welding-on or putting sensitive strain gauges in a rail), this approach has a number of advantages which allow, in case of using distributed optical systems, to monitor longitudinal stresses along the entire length of the rail, and, in case of using noncontact sensors, to perform monitoring with the help of portable systems.

In July 2017 tests were performed on the continuous welded rail track section of Ozerskaya branch of Moscow Railway in order to identify the dependence of the rail eigen frequency values on changes of the longitudinal stress in the rail. The change of the longitudinal stress in the rail is caused by the change of the rail temperature depending on the season. The rail oscillations were measured using
magnetic rectifiers mounted on the rail head in the transverse direction to the track axis. To define the mode of the rail head oscillations in the transverse direction, nine sensors were installed along the rail at a pitch of 500 mm.

As a result of tests on the continuous welded rail track section of Ozerskaya branch, the dependence of the change of the rail head eigen frequency in the transverse direction at various rail temperatures was obtained. The graph of the change of the first mode of rail eigen frequency selected as the easiest one in the identification, is shown in figure 1.

![Graph](image)

**Figure 1.** The graph of the change of the first mode of rail eigen frequency at different temperatures.

Tests were also performed to compare the eigen frequency readings using a noise meter and a magnetic rectifier.

The possibility of registering the rail eigen frequency using a noise meter has been confirmed, which approves the opportunity of using optical distributed (fiber-optic) systems to define them. Figure 2 shows the rail eigen frequency spectra in the transverse direction, measured using a piezo magnetic rectifier and a noise meter.

![Spectra](image)

**Figure 2.** The rail eigen frequency spectra in the transverse direction, measured using: a) a piezo magnetic rectifier; b) a noise meter.

The rail eigen frequency was measured on different sections of the test site. As a result, it is found that the first mode of the rail eigen frequency at the same temperature does not change depending on the measurement place along the rail. The first mode of the rail eigen frequency, measured on different
sections of Ozerskaya branch (jointed track, curve, etc.) at the same temperature, ranged from 100 to 350 Hz.

In May 2018 bench tests were performed to identify the dependence of the change in the rail eigen frequency on the longitudinal stress in it. The test bench is a part of the track panel and allows to create tensile and compressive forces in rails up to 25 tf, as well as to measure:

- the stress distribution along rails;
- rail oscillations;
- the rail deflection (the rail web deformation).

The comparative analysis of the test results obtained on the continuous welded rail section of Ozerskaya branch was performed under test-bench conditions and using the modal analysis of the track section finite element model. Figures 3–5 show the first two modes of the rail head eigen frequency in the transverse direction for relative test objects. Their frequency values are provided in table 1.

![Figure 3](image1.png)

**Figure 3.** Modes of the rail head eigen frequency in the transverse direction, obtained using measurements on the test section of the railway track: a) the first mode, b) the second mode.

![Figure 4](image2.png)

**Figure 4.** Modes of the rail head eigen frequency in the transverse direction, obtained during bench tests: a) the first mode, b) the second mode.

![Figure 5](image3.png)

**Figure 5.** Modes of the rail head eigen frequency in the transverse direction, obtained using the computer-based finite-element simulation of the track section: a) the first mode, b) the second mode.
Table 1. The rail head eigen frequency in the transverse direction obtained by different methods

| Test method          | Eigen frequency, Hz |
|----------------------|---------------------|
|                      | 1-st mode           | 2-nd mode         |
| On railway track     | 144                 | 270               |
| Bench tests          | 145                 | 180               |
| Numerical experiment | 152                 | 248               |

The dependence of the change of the first mode of the rail eigen frequency in the transverse direction on the longitudinal tensile force of the rail on the bench was also obtained (figure 6).

Figure 6. The dependence of the change of the first mode of the rail eigen frequency in the transverse direction on the longitudinal tensile force.

4. Conclusion
Comparing the results obtained using experimental and computational methods, we can draw the following conclusions:

1. The selected modes of the rail model oscillations are similar to modes of the real rail.
2. The difference in the values of the eigen frequency of the corresponding modes for the model and the real rail during the tests is:
   - 5 and 27 % on the test bench;
   - 5 and 12 % on the railway track.
3. Applying the dependence of the eigen frequency obtained for the rail model to the selected modes of the real rail oscillations and the rail temperature, we can define the actual rail fastening temperature. This, in turn, can contribute to improving traffic safety due to the timely detection of exceeding the permissible temperature of rail fastening.
4. The results of the work confirm the possibility and efficiency of the method to define the longitudinal stress in the rail by changing its eigen frequency.

References
[1] Vinogorov N P and Savin A V 2001 The determination of the stress state of lengths Put i putevoye khozyaystvo 4 pp 16–20
[2] Kish A and Samavedam G 1989 The measurement of longitudinal forces in rail bars Rail International 5 pp 58–62
[3] Lengstrum L V 1989 Finite Element Stability Analysis Rail International 6 pp 64–65
[4] Morozov S I 1986 About the diagnostics of the stability of the continuous welded rail track Vestnik VNIIZhT 6 pp 51–54