Railway Track Stress-Strain State Control – the Missing Link in the Railroad Traffic Safety

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Abstract. In recent years, due to appearance of long continuous welded rails and trains speed increase, railways faced the problem of trains derailment due to loss of their stability due to the lack of thermal expansions self-compensation. This problem, besides the use of conventional flaw detection, requires organization of non-destructive testing of the track's actual stress-strain state. In Russia and other countries the metal magnetic memory (MMM) method developed by Energodiagnostika Co. Ltd (Moscow) is more and more commonly used in practice for addressing the problem of local stress concentration zones (SCZ) determination in both new and used products. Russian and international standards on the MMM method are available. The fundamental difference of the MMM method compared to all the known magnetic NDT methods is that its application does not require artificial magnetization of the product, and it uses the natural magnetization and aftereffect, which manifests itself in the form of magnetic memory of metal to actual strains and structural changes. The paper presents experience of the use of the instrument-computer complex and specialized sensors for stress-strain state control of long railway track sections. The complex is installed at flaw detector car and is used self-magnetization of the rails. The inspection results shows possibility of the complex and the metal magnetic memory method to identify the sections with stress concentration zones that are most susceptible to damages development, and to prevent accidents associated with rails stability loss due to the lack of thermal expansions self-compensation.

Railways are complex engineering facilities with increased responsibility for transportation safety. The main object of control are the rails, which are inspected for the presence of internal defects (cracks, laminations, heads damages, etc.), as well as external properties of rails in the form of the rail track geometry change, local defects of the rolling surface, chips, etc.

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Currently ultrasonic, magnetic, optical, mechanical methods of nondestructive testing (NDT) and video monitoring with appropriate devices mounted on mobile vehicles (automotoris and flaw detector cars) are used for rails inspection.
Each of the listed above measuring devices and NDT methods are generally used independently of each other and have their own advantages and drawbacks. However, none of these NDT methods allows to assess the actual stress-strain state (SSS) of the rails.

It is known that the main sources of rails damages are stress concentration zones (SCZs), in which corrosion-fatigue damages develop most intensively.

Metallurgical and process rails manufacturing defects create high level of residual stresses in local zones and, combined with stresses from workloads, cause accelerated development of damages.

Thus, the lack of rails SSS control for determination of local SCZs is the missing link in ensuring rails reliability and railroad traffic safety. Exactly the local SCZs, occurring in individual rail sections, cause the loss of their stability and create a problem of trains derailment.

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In accordance with GOST R ISO 24497-1-2009 “Non-destructive testing. Metal magnetic memory method. Terms and definitions”, the MMM method is a non-destructive testing method based on the detection and analysis of the distribution of self-magnetic leakage fields (SMLF) occurring in stress concentration zones and structural inhomogeneity of products. These SMLF display irreversible variation of magnetization in the direction of maximum stress from workloads, as well as structural and process history of products and welded joints after their fabrication and cooling in the magnetic field of the earth.

The fundamental difference of the MMM method compared to all the known magnetic NDT methods is that its application does not require artificial magnetization of the product, and it uses the natural magnetization and aftereffect, which manifests itself in the form of magnetic memory of metal to actual strains and structural changes.

The MMM method does not require any preparatory work during the inspection and differs from other NDT methods by the fact that it indicates the level of stress concentration, i.e. it indicates the degree of detected defects hazard.

To perform the rails inspection using the metal magnetic memory method, Energodiagnostika Co. Ltd. (Moscow) experts developed and manufactured the instrument-computer complex, which was installed in a flaw detector car of Polish Railways Diagnostic Center.

Figure 1 shows the block diagram of the instrument-computer complex.

![Block diagram of the instrument-computer complex for rails inspection from the flaw detector car.](image)
In August 2013 Energodiagnostika Co. Ltd. (Moscow) experts in collaboration with PKP PLK Diagnostic Center experts performed inspection by the MMM method of railway tracks on the ~52 km long section from the city of Gora-Kalwaria to the city general Tarczyn using the above said instrument-computer complex. In order to determine the results repeatability, this section was inspected twice.

Figure 2 shows the scheme and inspection direction of railway tracks No.1 and No.2 between the Gora-Kalwaria and Tarczyn railway stations. The arrows show the direction of the flaw detector car travel.

Inspection was performed from the flaw detector car at a travel speed of 50 km/h. Travel path counting was carried out from the "encoder" connected to the instrument complex measuring unit. The mode of information reading by the MMM method was conditioned by the ultrasonic testing mode, at which the sensor mounting unit above the rails rose at railroad switches, and the values of the rails’ self-magnetic field in this mode decreased sharply.

**Fig. 3.** Results of the track No.1 right-hand rail inspection on the 58.263-58.270 km section: 

- $H_p$ – rail self-magnetic field value; 
- $dH/dx$ – field gradient; 
- $S$ – track width; 
- $l_{c-t}$ – distance between cross-ties; 
- $h$ – rail height.
Figure 3 presents the fragment of the results of the railway track inspection using the MMM method and specialized instrument-computer complex sensors mounted above the rails head at a distance of 6 to 7 mm from the surface. The upper part of the magnetogram presented in figure 3 displays the distribution of the self-magnetic field of the rail $H_p$ (A/m), and the bottom part – the field gradient $dH/dx$ ((A/m)/mm).

It can be seen in figure 3 that the distances between the anomalies of the magnetic field and its gradient were almost equal to the railway track geometric parameters: track width $S=1.435$ m, distance between the cross-ties fastening $l_{cr.-t}=400$ to $410$ mm, rail height $h=150$ mm. Similar patterns of the magnetic field and its gradient distribution were found in other stress concentration zones.

Figure 4 shows schematically the scheme of individual magnetic anomalies formation in SCZs due to bending and shear rails deformations under the action of car wheels bending effects on the rails (Figure 4, a) and of transverse force $P$ on the rails (Figure 4, b). Papers [1, 2] consider the formation mechanism of the magnetization vector and, accordingly, of the products' self-magnetic field on slide pads, occurring under the effect of workloads. Typically, the sliding pads slope angle is $45^\circ$ relative to the direction of the external load $P$.

![Fig. 4. Scheme of individual magnetic anomalies formation along slide pads under the effect of bending (a) and transverse (b) forces $P$: $h$ – rail height; $l_{cr.-t}$ – distance between cross-ties.](image)

The performed inspection by the MMM method of railway tracks at the Polish Railways test site (Gora Kalwaria-Tarczyn) showed the possibility in principle to apply the MMM method for quick rails inspection from the flaw detector car. Analysis of results of the railway track inspection carried out by the MMM method, compared to other inspection data submitted by the Diagnostic Center, showed that the reason for rail damages development is the combination of metallurgical and process manufacture defects with workloads caused by the railway track design features (track width, distance between the cross-ties fastening, rail height, etc.).

For example, as a result of inspection it was found that factory heat-treated rails have the significantly higher stress concentration and, accordingly, susceptibility to damaging.

A similar instrument complex installed in a flaw detector car was tested in 2000-2001 and put into trial operation in the Moscow metro.

The instrument-computer complex with program control, developed by Energodiagnostika Co. Ltd. displayed good performance in conditions of quick rail inspection from the flaw detector car. Experimental inspection also showed the
fundamental ability of the MMM method and the instrument complex to detect and classify defects, including detection of defects in welds produced by fusion thermite welding. However, development of such a defects classification by magnetic signals requires a set of statistics combined with the results of inspection by other NDT methods.

The most efficient use of the MMM method is assumed in combination with ultrasonic testing and visual examination. The MMM method allows to control the stress-strain state, to identify the most stressed track sections susceptible to damaging, and to assess the degree of defects hazard. At the same time ultrasonic method provides the opportunity, first of all, to carry out defects monitoring in the most stressed areas of the railway track.

Application of the MMM method also provides an opportunity of early detection of various types of failures in the railway track state: loosening of rails fastening on cross-ties; identification of stability loss sites due to the lack of temperature compensation; change of rails condition after passing of bulky cargo carrying trains, etc., and thus to monitor the railway track state variation.

More widespread practical implementation of the railway track stress-strain state control using the MMM method and related instrument complexes for the railway transport is mainly constrained due to various types of bureaucratic obstacles and low interest of responsible officials in implementation of the new technology.

For example, in order to prevent accidents with rail cars derailment due to rails stability loss, the Russian railways track maintenance service applies the industry guidelines on performance of periodic control of the railway track actual stress-strain state using very sophisticated techniques and tools. Implementation of the said instruction recommendations is a labor-intensive process, is carried out in a limited scope on small railway track sections by reference points and its efficiency is low. The presented experience of the use of the instrument-computer complex and specialized sensors using self-magnetization of the rails allow to carry out SSS control of long railway track sections, to identify the sections with SCZs that are most susceptible to damages development, and to prevent accidents associated with rails stability loss due to the lack of thermal expansions self-compensation.

References