Comparative analysis of structural state of welded joints rails using method of Barkhausen effect and ultrasound

To cite this article: A E Balanovsky et al 2018 J. Phys.: Conf. Ser. 1118 012006

You may also like

- Correlation between the piezo-Barkhausen effect and the fatigue limit of steel
  T Erber, S A Guralnick, C U Segre et al.

- Barkhausen noise in metallic glasses with strong local anisotropy: model and theory
  H George E Hentschel, Valery Illyin, Itamar Procaccia et al.

- Demonstrating the Barkhausen effect with high signal-to-noise ratio
  Jan-Peter Meyn
Comparative analysis of structural state of welded joints rails using method of Barkhausen effect and ultrasound

A E Balanovsky¹, M G Shtayger², V V Kondrat’ev¹, A I Karlina¹ and A S Govorkov¹

¹ Irkutsk National Research Technical University, 83, Lermontov Street, 664074, Irkutsk, Russia
E-mail: kvv@istu.edu

Abstract. To identify the imperfection of technological processes during smelting of rail steel and the subsequent production of rails in modern conditions, traditional methods of research are not enough. Implementation of Barkhausen effect amplitude measurement, residual stresses for defect detection, material structure analysis with the purpose of improving production technology is proposed. Thus, combination of traditional metallographic, mechanical and new research methods that complement and ascertain the requirements of GOST R 51685-2013 can allow conducting fast and accurate analyzes of the conformity of rail steels to GOSTs, and will also determine the causes of rail failure, inconsistencies in technological processes.

1. Introduction
The main requirements for the structure of rails are its homogeneity and uniformity in the depth of the head [1-2]. It should represent a thin-plate perlite with a minimum interplanar distance (sorbitol of quenching). It is necessary to strive for the complete elimination of needle-like structures of the upper bainite type in the structure of thermally strengthened rails. Investigation of the microstructure of rails allows one to reveal various deviations in the technology of their manufacture, determine the causes and nature of various external and internal defects of metal. Metallographic studies of the microstructure of damaged rails are often the main way to detect the causes of their destruction. The usual microstructure of non-thermally strengthened rails represents a finely lamellar and sorbitic perlite. It consists of very small plates of ferrite that alter with cementite plates, which can be detected only by means of an electron microscope. An average interplanar distance in the structure of non-thermally strengthened rails that largely determines the mechanical and operational properties of rail steel is in the range from 1 to 1.5 μm. The microstructure of thermally strengthened rails is a fine-dispersed thin-plate perlite (sorbitol of quenching), i.e. mixture of plates of ferrite and cementite much more dispersed than perlite. An average interplanar distance in the structure of thermally strengthened rails is approximately 0.1 μm.

It should be noted that the existing methods of monitoring the structural state, including mechanical characteristics, are labour intensive and require large material costs. In addition, tests are conducted selectively, and the obtained data do not provide information about the state of each unit of production. Increase in the single breakdown of the rails during operation, as well as a reduction of the volume of cargo transportation, indicates a deterioration in the quality of the rails in production. That’s why, it is necessary to develop new methods for monitoring the rails during the production and optimization of the production process. The most promising ones for final and operational control of rails with an
assessment of their technical condition and operational reliability are precision methods, based on
determining the velocity of ultrasonic waves in the material.

The aim of the work is to analyze and evaluate the possibilities of controlling the structural parameter
of the material - grain size in the welded joints of rails using the ultrasonic method and the Barkhausen
effect.

Materials and methods of research. To carry out manual ultrasound monitoring of the rail, a contact
piezoelectric transducer PET 111-5-K6 was used; ultrasonic flaw detector USD-50. Heat affected zone
of the butt welded joint should be cleaned of dust, dirt, scale, frozen metal spray, nicks and other
irregularities on both sides of the seam and along its entire length. The cleanliness of the surface
treatment of the heat affected zone of the rail should be no worse than Rz 40, waviness should not exceed
0.015. The marking of the controlled joint in the heat-affected zone is carried out over a distance of 40
mm on both sides of the weld. The marking should include a breakdown into sections, that correspond
to the scan step, that corresponds to 5 mm. To conduct studies using Barkhausen effect, measurements
were carried out using the Barkhausen digital noise analyzer Rollscan 300 from Stresstech Oy (Finland),
completed with special ViewScan software [3,4]. This device provides measurement signals digitally
with the help of a signal processing processor Figure 1. ViewScan control program formats the signal
according to the parameters determined in the measurement window or template. The system alerts the
operator about a positive or negative decision in accordance with the specified measurement limits.
Barkhausen effect signals are stored in the software. Upon completion of the work, the program
generates a report.

![Figure 1. Measurement of Barkhausen effect: a – Rollscan 300 analyzer; b – position of the sensor
during measurement.](image)

2. Results of experiments and discussion
The zone of thermal influence during butt-welding by burning-off of rails is located on both sides of the
welded seam. The distance between the zones near the joint of the rail welded by the continuous burning-
off method is 80 mm (40 mm on each side of the seam), in case of pulsating burning-off - (40-50) mm.
The width of the zone of thermal influence increases as the duration and intensity of heating increase
during the welding process. Defects of joints obtained by electrocontact welding are associated with
local heating up to the melting of one section of the rail, temperature on both sides of which reduces
quite intensively. Defects are also due to the large plastic deformation to which the heated metal is
subjected, that leads to the removal of liquid metal and the bending of the fibers of the base metal with
a change in their direction relative to the axis of the rail from longitudinal to transverse. There are defects
of the welded seam itself, appearing during the welding process, defects of the base metal that are
revealed during the welding of rails and side defects, formed during welding, as well as in the process
of mechanical and thermal processing of welded seams [2]. Due to the occurrence in the heating process,
the following basic defects are distinguished: oxidation (scaling); decarburization; overheating; overburn. Overheat of the metal is characterized by a strong growth of grains, significant scaling and decarburization, and can also be accompanied by the formation of loose scale on the surface of the workpiece. The main advantage of structural ultrasound analysis is the determination of the grain size of a metal with a sufficient degree of accuracy without making a thin section. This method is based on the fact that the attenuation of ultrasonic waves at certain frequencies depends essentially on the grain size of the metal. Prerequisite for the possibility of ultrasonic structural analysis of metals were theoretical and experimental studies of ultrasonic absorption and scattering processes in polycrystalline materials, carried out by domestic and foreign scientists. Determined regularities of the effect of structure and chemical composition on the damping of ultrasonic vibrations in metals and alloys have made it possible to develop methods for production control and to create special equipment. Experience shows that for the study of the features of the structure of the metal by attenuation of ultrasonic waves it is not always necessary to determine the attenuation coefficient by a known technique. Measurement of the absolute value of the attenuation coefficient is rather labour intensive, and the measurement error is large (10% or more). For example, to assess the overall heterogeneity of the structure of a welded seam, it is sufficient to trace the nature of the signal amplitude variation along the length of the welded seam at some given frequency of ultrasonic vibrations without calculating the damping coefficient.

An informative parameter is the amplitude change difference in the joint and outside the joint, $\Delta A_1$. After obtaining the values of the amplitude change difference at two frequencies during the control, Table 1 determines the average grain size in the controlled joint. Welded joints according to the results of manual ultrasonic testing are considered suitable, if the grain size is acceptable in them.

| Frequencies $f_1; f_2$ (MHz) | Grain sizes, $D$, mm | $0.01$ | $0.02$ | $0.03$ | $0.04$ | $0.05$ | $0.06$ | $0.077$ | $0.08$ | $0.09$ | $0.10$ |
|-----------------------------|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $2.5; 5.0$                  |                      | $0$   | $0.3$ | $1.0$ | $2.3$ | $4.6$ | $7.9$ | $12.6$ | $18.7$ | $26.7$ | $36.6$ |

The microstructure of the head of thermally strengthened rails should be a plate perlite, which is 7-8 points in accordance with GOST 5639-82. Thus, considering that the average grain size of the pearlite blocks in the rail steel is in the range from 10 to 50 μm according to [2,5,6], we calculated $\Delta N A$ at $D$ in the range from 10 to 100 μm. Table 2 shows the calculated values of the amplitude difference $\Delta A = - \Delta N A$.

| Grain sizes, $D$ (mm) | $0.01$ | $0.02$ | $0.03$ | $0.04$ | $0.05$ | $0.06$ | $0.077$ | $0.08$ | $0.09$ | $0.10$ |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Ratio of the amplitudes, $\Delta N$, dB | $0$   | $0.3$ | $1.0$ | $2.3$ | $4.6$ | $7.9$ | $12.6$ | $18.7$ | $26.7$ | $36.6$ |
Figure 2. Numbering of measurement points on the rail head: on a flat surface (a); on the surface without visible damage; on the damaged surface (b, c).

Table 3. Calculated values of the average grain sizes in the investigated welded seams.

| The number of the weld joint | The difference between the relationship of the amplitude, $\Delta A_1$, dB | Average grain sizes, $D_\bar{v}$ (mm) |
|-----------------------------|-------------------------------------------------|---------------------|
| 1                           | 31.2                                            | 95                  |
| 2                           | 69.0                                            | 124                 |
| 3                           | 25.5                                            | 89                  |
| 4                           | 17.3                                            | 78                  |
| 5                           | 15.0                                            | 74                  |
| 6                           | 34.0                                            | 98                  |
| 7                           | 25.1                                            | 88                  |
| 8                           | 71.2                                            | 125                 |

Table 4. Results of measurements of the Barkhausen effect amplitude.

| Analyzed surface of rail head | No. of point | Value of mp | Analyzed surface of rail head | No. of point | Value of mp |
|------------------------------|--------------|-------------|------------------------------|--------------|-------------|
| Flat surface                 | 1            | 61.90       | 13                           | 154.40       |
|                             | 2            | 64.50       | 14                           | 184.70       |
|                             | 3            | 286.60      | Damaged                      | 15           | 96.20       |
|                             | 4            | 343.70      | 16                           | 103.40       |
|                             | 5            | 202.30      | 17                           | 57.70        |
|                             | 6            | 268.50      | 18                           | 500.00       |
|                             | 7            | 196.00      | 19                           | 260.50       |
|                             | 8            | 126.00      | 20                           | 139.80       |
|                             | 9            | 149.20      | 21                           | 119.30       |
|                             | 10           | 115.70      | 22                           | 121.10       |
|                             | 11           | 211.70      | 23                           | 147.50       |
|                             | 12           | 72.10       | 24                           | -            |

Measuring Barkhausen effect, the device is controlled via a personal computer with ViewScan...
software. The device is equipped with a measuring sensor that allows one to control flat surfaces. Measurement parameters: magnetizing voltage - 5 V, frequency - 125 kHz. The position of the sensor during measurement on the head is across the rail (see Figure 1, b). Before measurement, the sample was marked out and its control points were numbered (see Figure 2). Results of measurements of the Barkhausen effect amplitude are given in Table 3.

As can be seen from table 4, the values of \( m_p \) vary in a wide range: from 57 to 500 or more units that indicates the heterogeneity of the microstructure of the surface layers. At points 1, 2, 12, 15, 17 – the structure is with a high hardness. At points 3-11, 13-16, 18-23, there was a softening of the steel. At point 18 (\( m_p > 500 \)), a crack (or other damage) was formed in the surface layer. Thus, this method gives a qualitative inconsistency of the structural factor, in contrast to the ultrasonic method.

The proposed control method can be used to estimate the temperature regime of a continuous welded rail operation [7,8]. In connection with the fact that the method is based on a change in the dependence of the Barkhausen effect intensity that arises when the study zone is magnetized, on the magnitude of the mechanical stresses. Structural changes occurring in rail steels during heat treatment [9,10], as well as during operation, affect the intensity of Barkhausen effect that allows one to use the Barkhausen effect method for nondestructive testing of mechanical stresses in the rail chain. The presence of elastic internal stresses in the material of the rail length, their values and nature of distribution influence how the domains determine for themselves the axis of easy magnetization and how they are oriented relative to each other [11], determine the intensity of the generated Barkhausen effect, i.e. amplitude of magnetic noise depends on the internal stresses in the length. That makes it possible to obtain linear dependences of the Barkhausen effect intensity in case of compression strain and tensile strain of the sample under study. Herewith, with an increase in compression strain, intensity of Barkhausen effect decreases, and with an increase in tensile strain, intensity of Barkhausen effect increases.

3. Conclusion

Barkhausen effect method has good prospects for assessing the quality not only after welding the heat treatment rails, but also during the operation of the railroad tracks. The railway length during heating by atmospheric air and sun rays to a temperature, equal to the optimum laydown temperature (35 °C), is in the stretched state, and above the optimal rail neutral temperature (35 °C), is in a compressed state. Thus, it is sufficient to determine the intensity of Barkhausen effect at a length temperature below the optimal rail neutral temperature and above the optimal rail neutral temperature, compare the obtained values, and if the temperature performance of the length is in a satisfactory state, the difference in the obtained Barkhausen effect intensity values will be minimal or close to zero.

References
[1]  GOST R 51685-2013 2014 Rails railway. General specifications. Enter. 2014-07-01 (Moscow: STANDARTINFORM)
[2]  About the statement and introduction in action of the rail Defects Classification, catalog and settings defective and fatal cropped rails : the order of ISC "RZD № 2499r"
[3]  Nikolaeva E P 2013 Izv. Samar. science. the centre Grew. Acad. sciences 15 (6-2) 428-431
[4]  Nikolaeva E P, Gridasova E V, Gerasimov V V 2015 Izv. Samar. science. the centre Grew. Acad. sciences 17(2-1) 125-132
[5]  Balanovskii A E, Grechneva M V, Van Huy Vu, Zhuravlev D A 2017 IOP Conference Series: Earth and Environmental Science 92003
[6]  Balanovskii A E, Grechneva M V, Huy Vu V, Zhuravlev D A 2017 IOP Conference Series: Earth and Environmental Science 9200
[7]  Kargapoltsnev S K, Shastin V I, Gozbenko V E, Livshits A V and Filippenko N G 2017 International Journal of Applied Engineering Research (IAER) 12(17) 6499-6503
[8]  Shastin V I, Kargapoltsnev S K, Gozbenko V E, Livshits A V and Filippenko N G 2017 International Journal of Applied Engineering Research (IAER) 12(24) 15269-15272
[9]  Zerbst U, Schödel M, Heyder R 2009 Engineering Fracture Mechanics 76 2637-2653
[10] Mandal N K 2014 Engineering Failure Analysis 40 58-74
[11] Mandal N K 2014 Engineering Failure Analysis 45 347-362