Diagnostics of high-voltage insulation of the railway transport overhead system by the method of spaced antennas

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Abstract. The growth in freight traffic transported throughout the entire network of Russian Railways, and in the Eastern Polygon in particular, is constantly growing, so an increase in train traffic reduces the time for technological work at railway infrastructure facilities. Consequently, it is necessary to develop methods for assessing the state of infrastructure facilities virtually without using “track possession”. In this regard, the article proposes to improve the existing remote method for diagnosing high-voltage insulation of the overhead system (registration of ultraviolet and thermal radiation with a special device), enhancing it with additional measurement. The proposed solution is to assess the state of high-voltage insulation by measuring electromagnetic radiation, which will increase the accuracy of diagnostics. As for a technological solution – to record a signal (partial discharges and surface partial discharges) with three antennas (induction electrometric converters), it is aimed at improving the accuracy of localization of a faulty string of insulators.

1. Introduction
On electrified railways, much attention is given to the diagnostics of high-voltage insulation, since when it breaks down during operation, a dangerous failure can occur, which results in a failure of the train schedule, which ultimately leads to losses. Due to the constantly growing number of trains that pass through the railway section per day, it is extremely difficult to isolate the track possession for diagnostics. Therefore, in recent years, remote methods have been developed that allow conducting studies of the state of high-voltage insulation in motion without using a track possession. Currently, a method based on the registration of ultraviolet and thermal radiation from a faulty insulation is widely used [1, 2]. At the same time, when diagnosing high-voltage insulation of the overhead system, the measuring equipment is installed directly into the laboratory car [3]. Observations of ultraviolet radiation can only reveal discharges that are formed on the surface of the insulation, so-called surface partial discharges (SPDs). Internal discharges or partial discharges (PDs) cannot be identified by this method, and it is these discharges that gradually “destroy” the insulation from the inside. This was previously mentioned by many researchers [4–9]. The thermal imager is good at detecting a fault in the event of a current flowing through the insulation that heats it. At the initial stage, defects of high-voltage insulation inside are insignificant, the current is small in the presence of PDs and does not cause an increase in temperature recorded by the thermal imager. At the same time, there is already pulsed electromagnetic radiation of the PDs. In this regard, we propose to apply a comprehensive diagnosis, i.e. to supplement the results of observations of ultraviolet and thermal radiation by recording electromagnetic radiation of the PDs.

Earlier, the authors have already proposed using remote acousto-electromagnetic diagnostics of the state of linear isolation of an AC overhead system of railway transport [10]. In this work it is proposed to use the recording of electromagnetic radiation by several spaced sensors to determine the location of the source of the PD.

2. Experiment
To demonstrate the possibility of determining the time delay of an electro-magnetic pulse on spaced antennas, an experiment was conducted, where the radiation source is an electric discharge, and its recording was performed by a digital two-channel oscillograph using two induction electrometric
converters (IECs) of the same size [12]. The antennas are connected to the first and second channels of the oscillograph, respectively. The experiment diagram is represented in Fig. 1.

**Figure 1.** The experiment diagram, $r_1$ and $r_2$ are the distance between the discharge and the IEC.

In standby mode, the oscillograph records a signal, for example, through the first channel (Fig. 2). It is first necessary to determine the response level of the measuring device to eliminate electromagnetic interference. The experiment showed that with the same distance $r_1$ and $r_2$ (the length of the measuring coaxial cable is also the same), the signals are identical to each other, i.e. the amplitudes and pulse recording time coincide (Fig. 2).

**Figure 2.** Oscillograms of signals recorded from IEC1 (the first channel, the upper oscillogram), from IEC2 (the second channel, the lower oscillogram). Scale: on the X axis – 10 ns / div, on the Y axis – channel 1 and 2 – 10 mV / div.

**Figure 3.** Waveforms of signals recorded from IEC1 (the first channel, the upper oscillogram), from IEC2 (the second channel, the lower oscillogram). Scale: on the X axis – 10 ns / div, on the Y axis – channel 1 – 5 mV / div and channel 2 – 10 mV / div.
If the distances $r_1$ and $r_2$ are not equal to each other, then there are changes in the amplitude and, most importantly, the delay of the recorded pulses relative to each other. This effect can be clearly seen in Fig. 3.

The formed delay time must be correlated with the distance, i.e. in the future, the authors of the article propose to conduct a series of experiments to bind the delay of the pulses relative to each other and the distance to the radiation source.

It should be noted that the registration of such pulses is possible with an oscillograph that captures signals in the frequency range of more than 300 MHz. When using an oscillograph with a smaller measurable frequency range, there is a high probability of recording distorted parameters of PD pulses (the temporal shape of the signal, as well as the time of its registration), which makes it impossible to determine the location of a faulty high-voltage isolation. Also, the reliability of the experimental results is affected by such a characteristic of the digital oscillograph as the frequency (rate) of the sampling of the measured signal. In our case, acceptable results were achieved only when using an Agilent Technologies oscillograph with the sampling frequency (rate) of each channel equal to 2 GSa/s.

It is also possible to increase the information content of the experiment using a second two-channel oscillograph (in this case, it is necessary to make one oscillograph the main one and start the second oscillograph from the external synchronization channel), or a four-channel oscillograph. In this case it becomes possible to connect three or four antennas, which will improve the accuracy of determining the location of the radiation source.

The shape of the signals and its polarity depend on the location of the IEC, therefore, when registering pulses of a similar shape, but of different polarity, it is necessary to adjust the position of the IEC in space. The IEC consists of two metal copper plates that are placed in parallel. The dimensions of the plates are 12x3.7 cm, the plates are placed at a distance of $h = 8.5$ cm. The IEC is shown schematically in Fig. 4, its equivalent circuit is shown in Fig. 5.

![Figure 4. An induction-electrometric converter](image)

![Figure 5. An IEC equivalent circuit](image)

The IEC is made according to the recommendations [13]. The logarithmic amplitude-frequency characteristic of the transfer function of the IEC, manufactured according to the above dimensions, was...
published in [12]. In this case the operating frequency range of the IEC ranges from 100 kHz to 100 MHz, which allows for reliable measurements of the PD and SPD, most of which are concentrated in this range (rather than anywhere else).

This was previously reported by researchers in their works [5, 9]. It should be noted that a number of researchers have observed the PD and SPD at frequencies above 100 MHz. During the experiment, each IEC must be located equally in space. This will eliminate the change in polarity of the signals observed by means of the IEC, as well as distortion of the signal waveform.

3. Conclusion
In practice, it is proposed to conduct an experiment by installing two three-channel recorders on the rolling stock, which will capture the same pulse and determine the location of the radiation source, i.e. in this case, the insulator of the overhead system design. The complexity of the method lies in the exact binding of the train location and the measurement time. It is also necessary to take into account that a number of powerful electromagnetic interferences are present on the railway, which interfere with the measurement [16–18]. To increase the signal-to-noise ratio, it is necessary to increase the size of the IEC, which, unfortunately, will somewhat limit the operating frequency range of the measuring complex. To do this, it is necessary to make additional calculations of the IEC [13]. It can be assumed that combining the methods of ultrasonic, thermal and electromagnetic control will significantly increase the information content of diagnostics, which will ultimately reveal a dangerous failure and prevent the failure of the train schedule.

References
[1] Vikhrov M A 2015 Khimicheskaia tekhnika 15
[2] Plotnikov Y I, Skorokhodov D A, Gerasimov V P, Fedorishin Y M, Grachev V F 2005 Energetik 4 46-48
[3] Kutsenko S M, Fedorov M E 2014 Sovremennye tehnologii. Sisternnyi analiz. Modelirovanie 44 107-110
[4] Vdoviko V P, Ovchannikov A G, Pospelov A I 1995 Energetik 16-18
[5] Ovchannikov A G 1999 Nauchnyi vestnayk NGTU 5 123-136
[6] Rezinkina V V, Rezinkin O L 2001 IEEE International Conference on Conduction and Breakdown in Solid Dielectrics 404-407
[7] Rezinkina V V, Rezinkin O L, Nosenko M I 2001 Technical Physics 46 (3) 339-341
[8] Kupershtokh A L, Stamatelatos C P, Agoris D P 2006 Technical Physics Letters 32 (8) 680-683
[9] Kuchinsky G S 1979 Energiya. Leningr. otd-nie 224
[10] Kutsenko S M, e.a. A method of remote acoustoelectromagnetic diagnostics of the state of linear insulation of the AC overhead system of railway transport. Patent RF, no. 2365928, 2013
[11] Bazanov V P, Spirim M V, Turayev V A 2000 Energetik 4 16-17
[12] Kutsenko S M, Bashkuev Yu 2014 Datchiki i sistemy 3 (178) 7-9
[13] Panin V V 1987 Energoatomizdat 120
[14] Kutsenko S M, Klimov N N, Muratov V I 2006 Izvestiya TPU 2 82-87
[15] Kutsenko S M, Muratov V I, Klimov N N 2011 Sovremennye tehnologii. Sisternnyi analiz. Modelirovanie 30 146-149
[16] Klimov N N, Cheremisin S V, Shurygin S A, Kutsenko S M 2018 International Conference on Aviamechanical Engineering and Transport (AVENT) 186-189
[17] Kutsenko S M, Bashkuev Yu B, Muratov V I 2013 Sovremennye tehnologii. Sisternnyi analiz. Modelirovanie 37 167-170
[18] Matayev Yu S 1997 Avtomatika, telemekhanika i sviaz 9 23-24.