Reliability analysis of power equipment of traction rolling stock within the Eastern region

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Annotation. One of the most loaded structures, and at the same time, the weakest elements of the power equipment of traction rolling stock, is isolation. The analysis of the operation of power equipment of electric locomotives from the negative impact of climatic factors on it has been made. It was revealed that to ensure reliable and safe operation, a system of maintenance and repair of rolling stock is necessary, taking into account the zonal conditions of operational features. The necessity of creating adaptive systems to maintain optimal values for temperature and humidity conditions for the insulation structures of electric locomotives is shown.

1. Introduction
The reliability of traction rolling stock is one of the main tasks of the railway industry. The economic well-being of the whole country depends on its smooth operation. The weakest link in rolling stock equipment is insulating structures. Insulation is significantly affected by heat and moisture. In the framework of the state task of research and development on the topic “Improving the reliability of power equipment of traction rolling stock” (№AAAA-A19-119010990009-3), an analysis was made of the reliability of power equipment of electric locomotives within the Eastern region.

In the process of operating the power equipment of electric locomotives, from the negative impact of climatic factors on it, natural and artificial influences can be distinguished. Moreover, natural influences depend primarily on external conditions that are characterized by current weather: temperature, humidity, atmospheric pressure, precipitation, wind. In turn, artificial influences are formed in the process of the direct operation of power equipment and other objects located nearby [1, 2]. From considering the influence of climatic factors on the reliability of insulating structures of power equipment, natural climatic influences are of the most significant interest.

To maintain electric locomotives in working conditions and ensure reliable and safe operation, a system of maintenance and repair of rolling stock is necessary, taking into account the zonal conditions of operational features. This study based on a long-term analysis of statistical data on the reliability of extremely loaded electrical equipment of electric locomotives operating on the railways of the Eastern region. Long-term analysis indicated the need for a systematic approach to the analysis of reliability and development of the scientific foundations of the technical maintenance system for electric locomotives, taking into account the zonal features of operation even within the boundaries of the same road or region of circulation [3-5].
2. The zonal feature of the influence of climatic factors

The objectives of the study include assessing the zonal features of the influence of climatic factors of the Eastern region on the operation of power equipment of electric locomotives. Climate analysis is carried out in the areas of four railways in the region: the Krasnoyarsk Railway, the East Siberian Railway, the Trans-Baikal Railway, the Far Eastern Railway.

The climate of most of the Krasnoyarsk Railway is sharply continental. Moreover, the climate itself is very heterogeneous due to the vast extent of the edge in the meridional direction. Thus, the climate in the northern part of the Krasnoyarsk Railway is exceptionally severe, which is expressed in long winters with significant negative temperatures. In the central and southern parts of the Krasnoyarsk railway, the climate is much milder. These zones belong to the zone of the temperate climatic zone [6]. Moreover, due to the significant remoteness of the entire region from the seas and oceans, the climate here is more severe than in other regions located at similar latitudes.

The climatology of the East Siberian railroad in the central zone is characterized by moderate temperature and a relatively high relative humidity of the surrounding air because of the macroclimatic regulator for this zone of operation of electric locomotives is the largest lake in the world, Lake Baikal. The geographical location of Lake Baikal leaves its mark on the northern direction zone, where during the so-called “Epiphany frosts,” the ambient temperature reaches −59 °C.

The Trans-Baikal Territory occupies a central position; however, its distance from the oceans is not the same. The seas of the Pacific Ocean – the Okhotsk and the Yellow are 850-1000 kilometers away from the Trans-Baikal Territory. The nearest of the seas of the Arctic Ocean – the Laptev Sea is 1700 kilometers away from the region.

The climate in the Far East is monsoon, with characteristic cold winters and humid hot summers. Climatic conditions vary significantly with the nature of the relief, proximity to the sea, and from north to south. For example, the average January temperature in continental regions ranges from −22 ºC– in the south, to −40 ºC – in the north; on the sea coast – from −18 ºC to −24 ºC. The average July temperature in the south is +20 ºC, in the north +15 ºC.

To assess the distribution of climatic features throughout the Eastern region of circulation, we reduce the average temperature values for the years under consideration by one histogram (Figure 1). The analysis of the presented histograms shows that in April and October, all the sections under consideration show different sign temperatures, which can negatively affect the insulation of the power equipment of electric locomotives.

![Figure 1](image)

**Figure 1.** Histogram of average values of air temperature in the Eastern region by climate zones for 2012-2018. (the Krasnoyarsk Railway – KRR, the East Siberian Railway – ESR, the Trans-Baikal Railway - TBR, the Far Eastern Railway road – FER).
Terrain changes are one of the characteristics of the territories of the Eastern region. The influence of the relief affects cloudiness, air temperature, rainfall, and the isolation of mechanisms. Humidity is one of the critical factors from the negative impact on the reliability of the insulation structures of power equipment of electric locomotives. A certain amount of water vapor is almost always present in the air, which is extremely variable. This number may increase or decrease depending primarily on air temperature. This fact causes large fluctuations in the degree of air saturation, depending on the day and year time. Also, humidity significantly depends on the amount of precipitation.

A clear comparison of the distribution of annual precipitation in the Eastern region is presented in the diagrams. Figure 2 shows the total histogram of climatic zones. Figure 3 presents a summary histogram of annual humidity values in the Eastern region by climate zones for 2012-2018.

**Figure 2.** A histogram of average values of total annual precipitation in the Eastern region by climate zones for 2012-2018.

**Figure 3.** A histogram of average total annual humidity values in the Eastern region by climate zones for 2012-2018.
Changes in air humidity contribute to the formation of a layer of water on the material. At low humidity, a monomolecular layer of water forms on the surface of the material. At higher humidity, a polymolecular layer begins to form, the thickness of which increases sharply with the relative humidity approaching 90%. At humidity above 90%, the layer of adsorbed water is in a liquid state. The process of adsorbed condensation, i.e., the formation of the thinnest moisture layer associated with the surface by adsorption forces precedes the process of pure physical condensation and may occur at a relative humidity below 100%.

The annual variation in the moisture content of surface air layers depends mainly on local evaporation. In this regard, the first half of the growing season is of the most significant importance. At this time, comparatively little rainfall still falls, and the moisture reserve in the soil after the melting snow cover is small [7]. In this regard, in some years in the central regions, especially along broad river valleys, humidification is insufficient. Atmospheric humidification is closely related to the features of the thermal regime, atmospheric circulation, and the nature of the underlying surface. At an air temperature of 25-40 °C, with a temperature increase of 2-3 °C, relative humidity decreases from 100 to 90%, with a temperature increase of 5 °C – from 100 to 75-85%, with an increase of 10 °C – to 55-60%.

3. Distribution of failures of insulation of power equipment

Issues of wetting the electrical equipment insulation of electric locomotives always require great attention. Particular attention to the issues of moisture resistance of electrical insulation connects with the development of railway transport. The moisture resistance of equipment is associated with an increase in electrical equipment failures due to the breakdown of insulation.

The impact of extreme negative temperatures on the insulation of power equipment leads to an increase in its resistance, a decrease in leakage currents, and a decrease in return voltages. These residuals contribute to a slower discharge rate. The cyclic effects of negative and positive temperatures lead to irreversible changes in the insulation resistance and a decrease in its breakdown voltage.

Electrical equipment of electric locomotives, by the nature of their work, is in high humidity for a significant part of the year. Moisture penetrates the pores and capillaries of the insulation, worsening its dielectric properties. Even newly manufactured and impregnated insulation absorbs moisture no worse than the old insulation [8].

A significant amount of precipitation, together with the shortcomings of the ventilation systems for cooling the traction engines of electric locomotives, leads to the fact that moisture settles directly on the insulation surface (Fig. 4). Moreover, with a higher degree of probability, a sharp wetting of the insulation can occur, which, in turn, leads to electrical breakdown [9].

![Figure 4](image_url)

**Figure 4.** The presence of snow on the collector-brush assembly (left) and the magnetic system (right) of the electric traction motor of the locomotive

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Studies have shown [10] that moisture penetration into insulation can co-occur at several levels: at the molecular, intermolecular, and capillary levels. The last of them is of the most significant interest since most insulation systems used in the construction of electrical equipment, especially after the long-term operation, pores, microcavities, and through channels, are formed. Their occurrence is mainly due to the shortcomings of the existing technology for repairing insulation using convective electric furnaces. In this case, in the process of surface heating with hot air, a crust forms on the insulation surface, through which fumes of evaporation of volatile organic substances later breakthrough. During operation, under the constant influence of vibrational forces on the polymer insulation, microcavities can pass into microcracks, forming channels connected.

The presence of microcavities is due to the cracks occurrence and the insulation delamination, the material shrinkage during aging. Voids and channels can also appear in the process of applying insulation to the conductors, in particular when using tape materials, which form folds, layers, and loosely join. Significant voids are also observed between the ground conductors of the windings of auxiliary electrical machines. Impregnating varnishes, which contain about 50% of volatile substances, do not fill the formed space. With high humidity, such channels can be excellent conductors of moisture, which can penetrate the depth due to the capillary effect. Under the influence of these forces, the surface of the liquid is covered by a uniformly strained thin film, which tends to give the fluid shape volume with a minimum surface. The surface tension forces develop a molecular pressure in the liquid, typical to its surface, which leads to the penetration of moisture through microcavities.

Figure 5 presents the number of insulation faults of traction electric engines of locomotives in the Eastern region of the distribution of railways. Figure 6 shows the failure rate; that is, the failure rate of the insulation of the power equipment of the traction rolling stock.

![Histogram of failure of insulation of traction electric motors of locomotives in the Eastern region for 2017](image-url)
In many cases, premature failure of the insulation of electric transport equipment can be prevented by systematically monitoring the moisture content of the insulation and drying it if necessary [10]. Given the above, it is clear that with the combined effect of all climatic factors, the primary indicator of the reliability of insulation, the dielectric properties, deteriorates to a certain extent. Climatic factors are determined by annual, seasonal, daily fluctuations in temperature and relative humidity, as well as the number of days and the intensity of precipitation in the form of snow, rain, fog. Thus, it is necessary to improve diagnostic methods and tools, as well as maintenance and repair technologies, to reduce the degree of influence of climatic conditions on equipment reliability.

4. Conclusion

As study shows, according to the leading climatic indicators in the Eastern region, the most demanding conditions for the operation of power equipment in the "northern" direction. Long-term monitoring of the operation of the power equipment of electric locomotives showed that the parameter of the flow of their failures in the breakdown of insulation is more significant in some areas of the operation of electric locomotives, in others – less, especially in winter. It is necessary to create adaptive systems to maintain optimal values for the temperature and humidity conditions for the insulation structures of electric locomotives to increase the reliability of the insulation structures of electric locomotives operating in various areas of operation on the railways of the Eastern region.

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