Assessment of the technical condition of electric contact joints using thermography

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I. INTRODUCTION

The rapid growth of the technical complexity of modern industrial systems and the great variety of their operations have led to the fact that the rational implementation of measures to ensure the reliability of technical systems has become an extremely difficult but important issue for the proper functioning of modern industry [1,3].

The conducted studies and data processing from the operation of electrical equipment show that approximately one-quarter of electrical equipment failures are related to faults in the electric contact joints (connections). Such malfunctions often lead to fire and can have serious consequences. It is therefore clear that electric contact joints are essential components of the equipment for which high levels of operational reliability must be guaranteed [6].

Each electric connection (except for the non-detachable ones) can be considered as a tribotechnical system, having its specificity, deriving from the type and purpose of the electric connection. This specificity is expressed in the requirements for the materials of the contact parts, their coatings, geometric dimensions and shape, the lubricants used, and the field of application of a given contact joint.

At the same time, during their operation, the electric contact joints are inevitably influenced by the interaction of friction and electrical processes, which leads to a change in the quality of the contact.This applies not only to sliding (roller) contacts, but also to fixed electric connections (terminal connections, bolted busbar connections, pin connections, etc.) that experience normal and tangential micromovements during operation.

There are two main approaches to assessing the reliability of technical systems, including electrical contact joints. The first is based on a statistical analysis of sample data, such as reliability function, mean time between failures, gamma-percentage resource, etc. In the second approach, the remaining (residual) useful life (RUL) of the contact joint is predicted based on its actual state at that particular time. In this case, its service life and residual useful life can be determined precisely for a particular contact joint under the given specific operating conditions.

The problem of predicting the remaining useful life of electrical connections can be solved if there is a possibility for continuous monitoring of the changes of key (resource) parameters until reaching their critical values, considered as criteria for failure.

It is well known that temperature is one of the most important parameters showing the technical condition of the equipment. Therefore, monitoring the temperature of contact joints is undoubtedly one of the best methods for estimating remaining useful life and organizing systems for predictive maintenance[4].

II. AGING OF ELECTRIC CONTACT JOINTS AND METHODS FOR ASSESSING THEIR CONDITION

A. *Aging of electric contact joints*

The aging of closed electrical contacts that are not exposed to arc erosion (especially the case of terminal and busbar connections) is mainly due to the reaction of metals with the environment in the area of the contact surface.

Similar to the other elements of the electrical equipment, the condition of the contact joints can be represented by changing a given value that characterizes the technical condition of the connection over time. The general view of the aging curve of contact joints, representing the change of the contact resistance, is shown in Fig. 1.

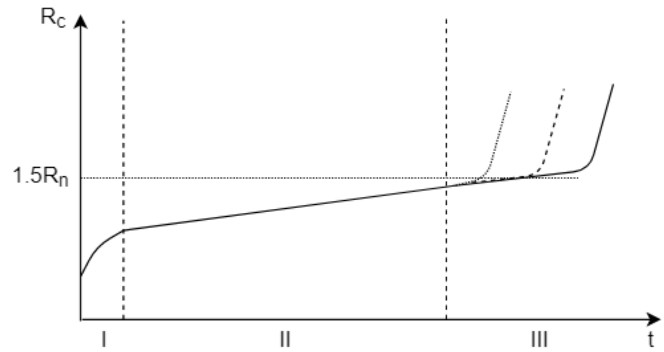

Fig. 1 *Aging curve of electric contact joints*

The aging process of contact compounds develops in three typical stages:

- I stage - an adjustment period with a short duration in which the value of the contact resistance increases;
- II stage - period of normal aging. This period is characterized by a continuous but smooth change of the contact resistance due to the change of the physicomechanical properties of the elements.
- III stage - period of intense aging. Predicting the development of malfunctions and the remaining service life in the stage of intense aging depends on too many factors and therefore it is not possible to predict the time of failure in this period.

The aging process of electrical terminal connections depends on many factors, which should be considered in more detail.

B. Methods for assessing the condition of contact joints

The assessment of the technical condition of electrical connections can be performed on the basis of many parameters. The methods of control of the contact resistance, the temperature of the electric connections, and the voltage drop on the electric contact joints have found the widest practical application. In some of the normative documents concerning the testing of contact compounds, it is proposed to introduce the so-called defect coefficient, which is determined based on the measured parameter.

Measurement of contact resistance is the most appropriate (accurate) method for assessing the condition of the contact joint, as it determines a quantity that depends directly on the contact conditions [2].

On the other hand, the measurement of the contact resistance is associated with significant difficulties - performing the measurement with a current much lower than the normal operating current for the respective connection can lead to incorrect values of the controlled parameter. Also, the voltage of the test apparatus must be sufficient to destroy any possible surface layer without exceeding the operating voltage of the tested equipment. In addition to these disadvantages is the fact that the contact resistance cannot be measured remotely and without interrupting the normal operation of the equipment.

The assessment of the technical condition of the electrical connections in this method is performed directly from the readings of the contact resistance values or by the coefficient of defect, which in this case is defined as:

$$k_d = \frac{R_{c.j.}}{R_{c.j.\_ini}} = \frac{R_c}{R_{c\_ini}}, \quad (1)$$

where: $R_{c.j.}$ and R_c are the measured values of the contact joint resistance and the contact resistance;

$R_{c.j.\_ini}$ и $R_{c.j.\_ini}$ - initial values of the contact joint resistance and the contact resistance.

III. Assessment of the technical condition of electric connections by measuring the temperature

In fact, the temperature of the contact joints is an indirect characteristic of the technical condition, as it is an indication of the condition of the outer surface of the connection, instead of the contact spots. Therefore, the temperature of the outer surface of the contact joint can be used as a key parameter. This greatly simplifies the determination of the technical condition as the temperature allows non-contact measurements.

The temperature of the current-carrying parts depends on the load and is directly proportional to the square of the current flowing through the part of the circuit. This allows the temperature of the contact joints to be determined by the following dependence:

$$T_{c.j.} = T_0 + \Delta T_1 + \Delta T_2 + \Delta T_3, \quad (2)$$

where T_0 is the ambient temperature;

ΔT_1 - temperature rise of the current-carrying part (the conductor) over T_0;

ΔT_2 - temperature rise of the contact area over T_0;

ΔT_3 - temperature rise of the contact spot over T_0.

When including the thermographic technique to assess the technical condition of the contact connections, the latter can be determined on the basis of many criteria depending on the design features and operating conditions [5]:

- normalized value of temperature with respect to ambient temperature (temperature rise);
- defect coefficient;
- on the analysis of the dynamics of temperature changes over time;
- comparing the measured temperature values between phases or individual sections.

In this case, the defect coefficient is the ratio of the measured temperature rise of the electric contact joint to the temperature rise measured over the entire section of the conductive part (conductor or busbar) ΔT_{cond} at a distance of at least 1m from the connection:

$$k_d = \frac{\Delta T_{c.j.}}{\Delta T_{cond}} = 1 + \frac{\Delta T_2 + \Delta T_3}{\Delta T_1}. \quad (3)$$

Prognosis of the increase in the temperature of the electric contact joint allows predicting of the moment when the temperature will exceed the permissible limit, i.e. the moment of occurrence of a parametric connection failure. In this way, the remaining useful life of the respective contact compound can be calculated.

IV. Conclusions

Aging of electric contact joints is a complex physical process that depends on many operational factors.

Increasing the surface temperature of the contact joint can be used as a key parameter to assess its technical condition. Periodic monitoring of this parameter can be used to predict the residual life of contact joints.

The successful application of the thermographic technique for the prediction of the remaining useful life of contact joints requires appropriate measurement tools and software for processing a large volume of diagnostic information.

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