

Possibilities of diagnosing the condition of contact wire in terms of thermal wear

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Abstract. The paper considers the negative consequences of thermal softening of the contact wire material under the action of an electric arc, which is thermal wear. In order to determine the degree of softening of the contact wire in real time, the methodology for assessing the condition of the contact wire of electrified railways by the value of thermal wear is presented. The presented method is based on the criterial approach. The criteria for softening the material of the wire and the transition of the material to the liquid state are introduced. By comparing the amount of heat entering the wire in the event of an electric arc (with these criteria), the contact wire is diagnosed in terms of thermal wear. Calculations have been made using the proposed method; graphical dependences of the amount of heat entering the wire element on the current intensity of the electric arc for various times of its influence on the contact wire are constructed. A device for diagnosing the condition of the contact wire in terms of the amount of thermal wear is proposed, designed to record the place of occurrence of the electric arc, to collect and transmit the necessary initial data. The operating principle of the device is described and its structural diagram is given. The use of the method for assessing the condition of the contact wire in terms of the amount of thermal wear and the diagnostic device will make it possible to quantify the degree of thermal softening of the contact wire material in order to further determine its residual life.

1 Introduction

The contact wire plays the most important role in the traction power supply system. Its main function is the transmission of electrical energy from the traction substations to the electric rolling stock. Various damages of the contact wire can lead to emergency situations on the railway through to the stop of traffic, so an important task for today is to diagnose the condition of the contact wire and to predict its service life in operation.

During operation, various climatic factors act on it. It is also necessary to add the thermal processes that arise when the traction current flows through the network elements, the mechanical action from the current collectors, the electrocorrosion processes, the tension forces, etc. Thus, the contact wire experiencing colossal loads must reliably perform its functions.

Most of the damage to the contact wire is due to wear. Wear is usually divided into mechanical and electrical [1, 2]. It is proposed in papers [3, 4] to introduce the concept of

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“thermal wear” of a copper contact wire. Thermal wear refers to the process of thermal softening of a certain volume of wire under the action of heat pulses. Such heat pulses appear when the current collector (pantograph) of the electric vehicle is bouncing from the contact wire and is caused by the flow of load currents through the electric arc. With sufficient power of the electric arc and the time of exposure, the released heat may be sufficient to melt and even vaporize the material of the contact wire. All the changes that occur in the wire accumulate in its internal structure, and the negative consequences are manifested in a short period of time. Repeated reheats will occur during the next passage of the pantograph's slide, which will gradually lead to further softening. The accumulation process occurs as a result of rest, polygonization and recrystallization of the wire material. The recrystallization temperature is not a fixed value and varies depending on various factors. The result of thermal wear is a decrease in the strength characteristics of the contact wire, which negatively affects its operation.

Nowadays, the state of the contact wires is assessed mainly by the residual area of the conductor cross-section [5, 6]. Monitoring the condition of the contact wire consists in visual inspection of its working surface, detection of arson, mechanical damage or factory defects, as well as in the measurement and analysis of wear. Wear measurements of the contact wire are carried out to prevent a dangerous reduction in its cross-section and to analyze the nature and characteristics of the wear process, to study the influence of certain factors that determine the service life of the wire.

To date, there are many different methods and devices for measuring mechanical [2, 7-9] and detecting electrical wear [10, 11].

Thermal wear of the contact wire is similar in its negative effects to mechanical wear. The softening of the wire material is equivalent to reducing its cross-section to a state at which the breakage is possible. In this case, thermal wear can occur without any visible changes in the cross-section of the wire, which complicates its detection.

The cross-section of the contact wire for mechanical and thermal wear is shown in Fig. 1. In both cases, the wear area is excluded from the area of the cross-section of the contact wire, thereby increasing the probability of its breakage [12].

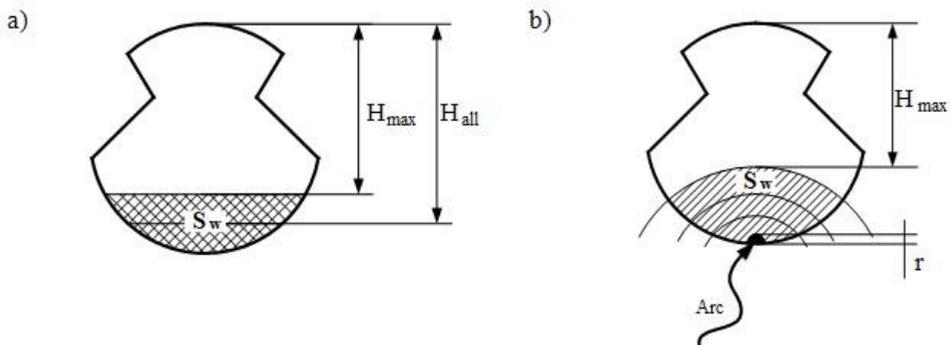


Fig. 1. Cross-section of the contact wire: a - with mechanical wear, b - with thermal wear; S_w – the area of wear, H_{max} - the height of the wire cross-section at maximum wear, H_{all} - the height of the wire cross-section with allowable wear, r - the cross-sectional size of the wire heating area.

2 Materials and methods

Nowadays, the problem of monitoring the condition of the wire remains relevant. Nondestructive testing of the contact wire on its entire length is very expensive, so it is first suggested to find the sites where the local softening spots are most likely to occur. Because

of the rapid development of high-speed and heavy traffic, the urgency of the problem of determining the degree of softening of the contact wire increases, thereby determining its residual resource.

To determine the degree of softening of a certain volume of the contact wire material, a method for assessing the condition of the contact wire in terms of thermal wear was developed. This method allows real-time monitoring of the state of the contact wire at various sections of electrified railways.

The method was based on the research of scientists from FESTU [13] in the field of thermal wear of the contact wire. According to these studies, the solution of the problem is represented as a sum of thermal effects from a moving point source:

$$T(x,t) = 2q \cdot \Phi + T^0 = \int_0^t 2 \cdot q(t') \cdot \Phi(r', t-t') dt' + T^0 =$$

$$= \int_0^t \frac{2 \cdot q(t')}{c \cdot \rho \cdot (4 \cdot \pi \cdot \chi(t-t'))^{3/2}} \cdot \exp\left(\frac{-r'^2}{4 \cdot \chi(t-t')}\right) dt' + T^0, \quad (1)$$

where T^0 – initial steady temperature distribution, °C;

Φ – fundamental solution of a problem; $r' = |x - x'|$ – distance of the point under consideration $x(x_1, x_2, x_3)$ to the base of the movable arc, cm;

t – time of action of a point source, s.

The heat capacity of the arc absorbed at the contact is determined by the equation:

$$q(t') = q(x', t') \cdot S(t') = U_{\Sigma} \cdot I_m \cdot \sin \omega(t_p + t'), \quad (2)$$

where S – area of the arc base, mm²;

U_{Σ} , I_m , ω , t_p – voltage drop, instantaneous value of current, frequency, and time from the previous current transition through zero until the moment of contact opening ($t' = 0$).

In the method of assessing the condition of the contact wire in terms of the amount of thermal wear [14, 15], a criterial approach is used. The criteria for softening the material of the wire (Q_{CRIT1}) and the transition of the material to the liquid state (Q_{CRIT2}) are introduced. The proposed criteria can take different values depending on the radius of the heating area of the contact wire and the speed of the electric arc.

When the electric arc arises, a certain amount of heat (Q_{ENT}) enters the wire when the pantograph of the electric vehicle loses contact with the contact wire. This amount of heat depends on the current intensity of the electric arc and on the time of its action.

The method for assessing the degree of thermal softening of the contact wire material is based on comparing the amount of heat entering the wire in the event of the electric arc with the given criteria.

3 Results

As a result of calculations using the proposed method, the dependences of the amount of heat entering the wire on the current intensity of the electric arc and on the time of its action were obtained.

Fig. 2. shows the result of calculations for the given parameters of the cross-sectional size of the wire heating area $r=0.02$ cm and length $L=3$ cm.

Softening of the contact wire does not occur if $Q_{ENT} < Q_{CRIT1}$. Thermal softening (thermal wear) occurs when the value of Q_{ENT} exceeds the value of Q_{CRIT1} . When the value of Q_{ENT} exceeds the value of Q_{CRIT1} , electrical erosion occurs (the transition of the wire material into a liquid state). With a significant excess of incoming heat, the power of arc is sufficient for instantaneous breakage (burnout) of the contact wire.

Thus, for an electric arc moving at a speed of 60 km/h with a current intensity of 300 A during the burning time $t = 0.01$ s, $Q_{ENT} = 1.254$ cal of heat enters the wire element with the cross-sectional size of the heating area $r = 0.02$ cm (see Fig. 1) and length $L = 3$ cm. In this case, $Q_{CRIT1} = 0.273$ cal, $Q_{CRIT2} = 2.717$ cal. Thus, the condition $Q_{CRIT1} < Q_{ENT} < Q_{CRIT2}$ under which the process of softening the material of the contact wire in a given volume occurs is satisfied. When the speed drops to 20 km/h, melting of the contact wire material in the same volume is observed, which leads to the formation of defects on the wire.

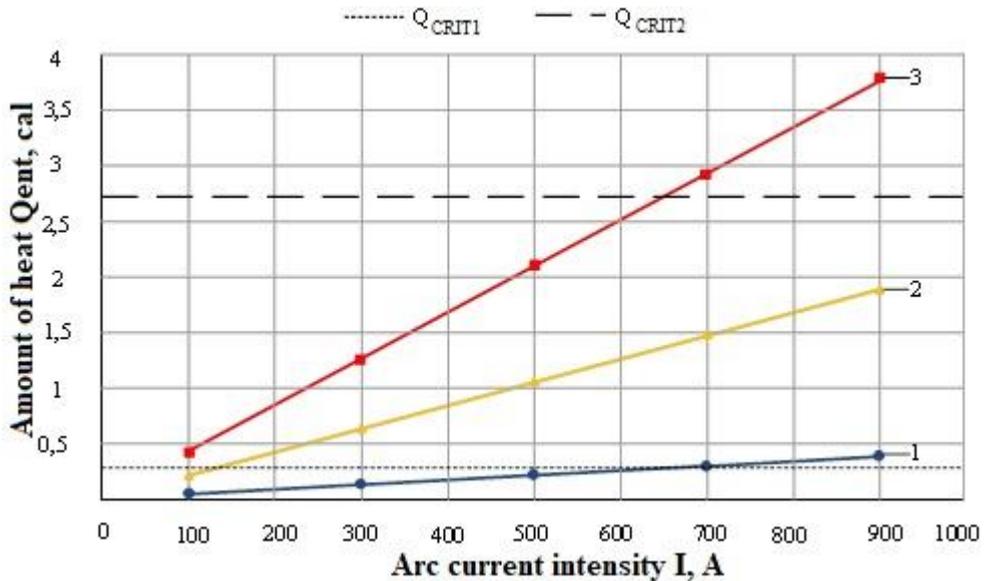


Fig. 2. The graph of the dependence of the amount of heat entering the wire element on the current intensity at $r = 0.02$ cm: 1 – Q_{ENT} with $t = 0.001$ s; 2 – Q_{ENT} with $t = 0.005$ s; 3 – Q_{ENT} with $t = 0.01$ s.

To diagnose the condition of the contact wire in terms of thermal wear, it is necessary to know the current intensity of the electric arc and the time of its action. It is also important to record the place where the arc occurred. For these purposes, a device is proposed for determining the degree of thermal wear in real time.

The device for determining the degree of thermal wear of the contact wire is divided into several blocks. The structural diagram of the device is shown in Fig. 3.

This device consists of a registration unit of the pantograph bounce from a contact wire installed on the roof of an electric locomotive, a signal processing unit, a GPS device, and a data transmission unit. After obtaining the necessary data, the degree of thermal softening of the contact wire is calculated according to the proposed method.

The device works as follows. During the movement of an electric locomotive in the event of a pantograph failure and the occurrence of an electric arc, the registration unit of the pantograph bounce detects the bounce and transfers the electrical signal through a galvanic isolation to the signal processing unit. The signal processing unit serves to enable the recording of the required parameters upon receipt of a signal from the registration unit of the pantograph bounce and disconnect the data recording when the action of the electric arc stops. The current, time and speed measurement units are designed to measure the relevant

parameters that are used in the calculation procedure. The GPS module records the coordinate of the place of the pantograph bouncing from the contact wire. All received data is transferred to the data transmission unit and transmitted to the data center via wireless communication. In the data center using the necessary software, the degree of thermal wear of the contact wire is calculated and assessed according to the above method. The results of the calculations are collected in the database, which in turn allows seeing the complete picture of the condition of the contact wire on the network of electrified railways. In addition, there is the possibility of predicting possible breakages of the contact wire due to heat wear, which contributes to the reduction of economic damage from down time of trains.

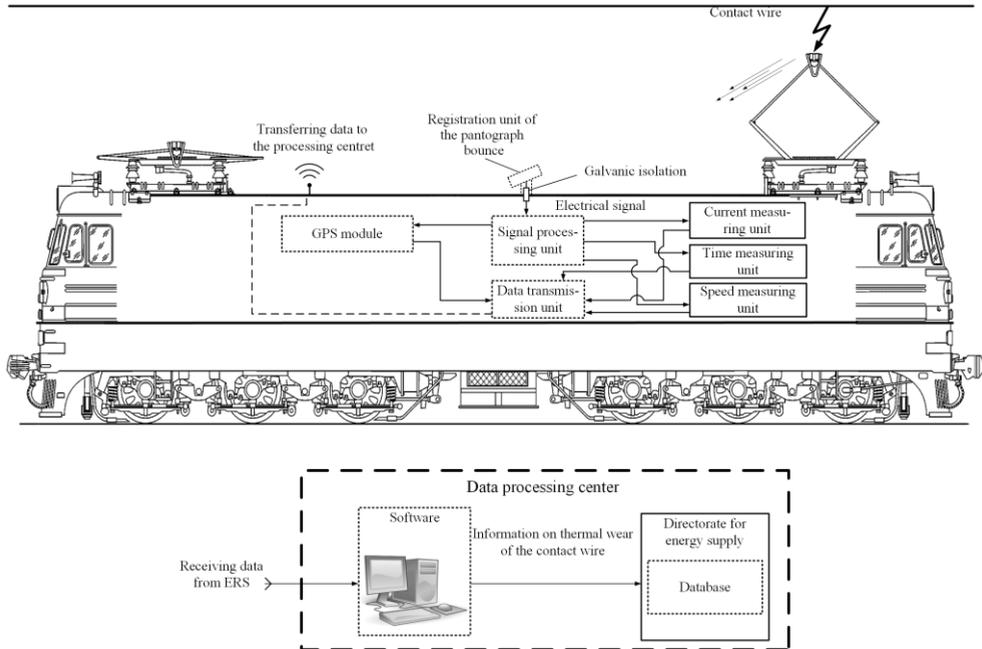


Fig. 3. Structural diagram of the device for determining the degree of thermal wear of the contact wire.

4 Conclusions

To date, the diagnosis of the state of the contact wire is traditionally based on the determination of its residual cross-section, i.e. on the determination of mainly mechanical wear. The conducted researches have shown that it is necessary to diagnose the state of the contact wire in terms of thermal wear. To determine the degree of thermal wear of the contact wire, the criteria of softening and transition of the material to the liquid state, which formed the basis of the diagnostic method, were introduced. To quantify the degree of thermal softening of the contact wire material, a device is proposed to collect the data necessary for the calculation. When summarizing the results of calculations using the proposed method in the database, it becomes possible to assess the residual life of the contact wire.

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