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CONTROL OF THERMAL MODES OF TRACTION MOTORS AND SPEED MINE ELECTRIC LOCOMOTIVES

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Abstract. Analysis and evaluation of quality indicators and functioning of existing control devices and temperature gauges speed mine electric locomotives, which are used in Electromechanical systems, traction motors DC series excitation in modern mines that are listed in the article. The authors found the main reasons for their low reliability. The method of non-contact control and protection of traction motors from impermissible exceeding of the temperature level in the cells, which requires creating the appropriate temperature sensors was proposed. The issues of speed control mine electric locomotives with the aim of improving health and safety of miners in underground transport were considered. The authors reviewed existing speedometers that are directly or indirectly connected with the rotary elements of the locomotive. The authors proposed a method for the contactless control and protection of traction motors from overheating and sensorless meter speed mine locomotive, the operation of which is based only on the electrical parameters of the electric traction motors.

Keywords: thermal modes, traction motors, speed mine, electric locomotives

Introduction. Iron ore raw materials (iron ore) produced from domestic mining enterprises, providing up to 70% of annual revenue is a significant component of the replenishment of currency reserves of Ukraine [1].

Meanwhile the cost of production of iron ore raw materials grows every year, which endangers this strategic competitiveness for the domestic economy of the export product [2]. The main component of the aforementioned odious process is the rising energy costs that make up more than one third of the total cash costs of iron ore, for all cycles of the technology of its production and delivery, regardless of the method of mining: open pit or underground (mining) [2]. Thus, unlike the pit, mining is characterized by the fact that electricity costs they make about 90 %, including up to 16% is the energy consumption for mine transport, a park which has about four thousand locomotives with outdated energy inefficient equipment.

Meanwhile, the second, no less important negative fact in the process of operation the school itself continued increase in material costs of mining enterprises for repair of electric rolling stock [2]. As follows from the analysis of damage items current operated Electromechanical traction systems (ETS) mine contact types of electric locomotives (Fig. 1 and Fig. 2), the dynamics of their injuries has evolved over the years.

It is important that the material costs for the repair of their components - traction electric motors (TEM) in the last decade the mines of Kryvyi Rih (so and other similar enterprises) increased almost 4 times and constitute more than 90% of all costs for repair of traction electric equipment [2].

This situation dictates the requirements for the need for additional analysis of this process and of developing sound and simultaneously real and modern proposals for withdrawal from defined position [3; 4].

Materials and Methods. Bringing the above-mentioned inefficiencies in the functioning ETS preferably to the optimum values by increasing its operational reliability, and trains in general, possible only with the construction and application of modern management systems with the capabilities of monitoring the condition of electrical and technological parameters of traction equipment. It should be understood that the traction electromechanical complexes of electric locomotives, as a basis for the structure of electrical equipment in general, and mine species in particular, are complex multifunctional systems, which have a significant number of parameters that must be controlled [3 - 10]. Based on the same results of failure analysis of the components of the traction electromechanical systems mining electric locomotives and "severity" of the consequences of these moments, nevertheless the first step in building a control system parameters of the traction elements of the complexes should be the issue of control of those parameters that are most likely to cause damage to the traction components of electromechanical systems including TEM, and, therefore, the incapacity of the locomotive as a whole [6, 9 - 11].

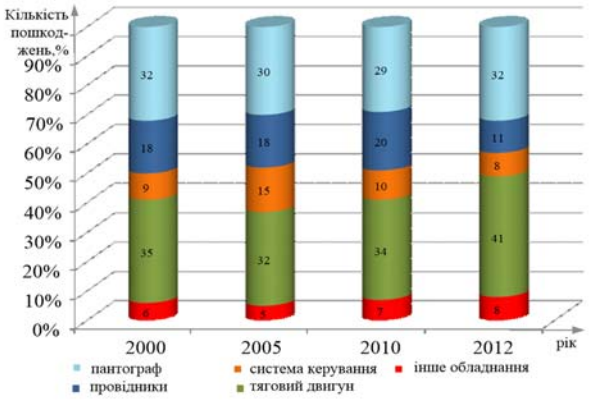

Figure 1. Dynamics on aggregate indexes of quantities of damage of the main elements of the traction electric equipment mine electric locomotives K14 used in iron ore mines of Kryvyi Rih iron ore basin

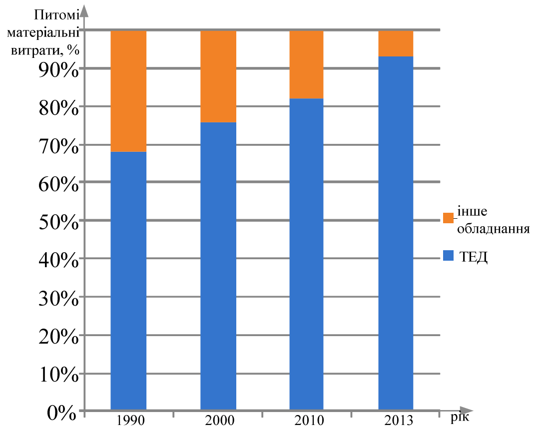

Figure 2. Change in unit material costs for the repair of traction electric equipment mine electric locomotives in the mines of Kryvyi Rih iron ore basin

In [5, 8] is proposed to control the temperature regimes of TEM. To do this, the author presents circuit solutions. In turn, in [9] present a new without touch method of speed control of train movement in the underground conditions in order to avoid exceeding the regulated value. Meanwhile, the desired efficiency of the above funds for the conditions of the mining electric locomotives will be quite effective only when applied.

Consider each of the methods separately. This will stick to the tactics of building methods in order to determine the necessary parameters on the basis of already controlled in the structure ETS [10 - 13].

In turn, these parameters are the values of current, voltage and resultant heating elements TEM. As proved in [5, 9 - 10], it is based on the control values of the first two of the above components can be monitored and the third temperature TEM in the operation of the locomotive in flight cycles [11].

This sequence of approach to the tactics of the structure of the control system is based on the results of the analysis of the causes of the damage TEM during operation of the locomotive. And this is the influence of the superheat temperature [10] on the components of TEM, one of the anchors winding (Fig. 3). As the Fig. 3 shows, the temperature of the TEM with the work of the locomotive increases, which in conditions of lack of control that, will definitely lead to overheating of the windings and their subsequent destruction.

Second important parameter to control is the speed of the locomotive, which is governed by the applicable "Rules of safety" [10], and the excess of which leads to serious technological accidents and threatening the life of the miners. Meanwhile, for mine electric locomotives, with the specifics of their operation in underground mining, the solution vector of the above problems with their complexity lies in the direction of the development of control systems on the basis, primarily, of without touch funds [9, 10].

Study and development of circuit design efficient and reliable operation of sensorless control of thermal conditions of traction electric motors of direct current and the speed of mine electric locomotives.

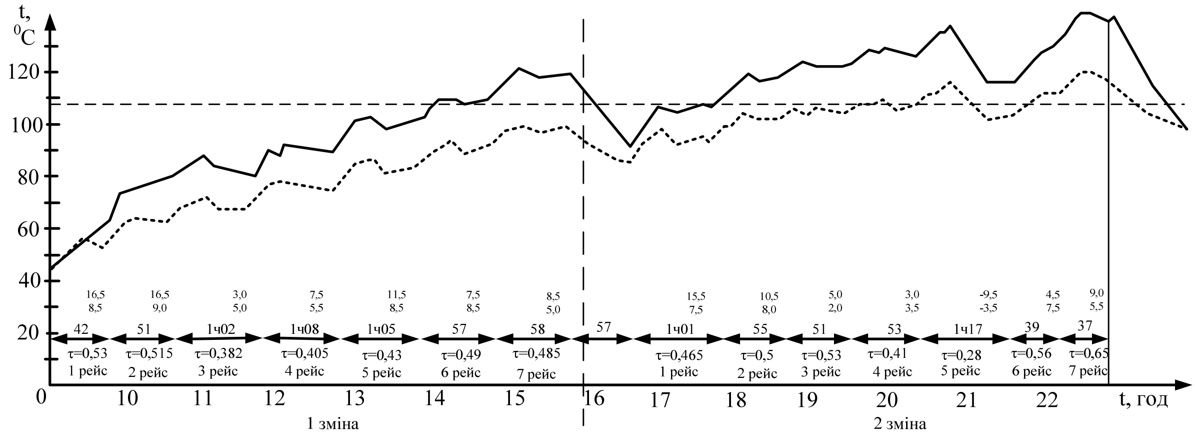

Figure 3. Chart of temperature change of the armature winding of the traction motor DST-45/27 for two shifts of operation of the locomotive K14 (horizon 1045 m of Batkivshina mine, PJSC "Krivorizkiy Zalizorudniy Kombinat")

Results. As the experience of the operation of electrified ground transport and treatment system for continuous temperature control modes of operation TEM reduces failure 30 – 35 % , failure manifolds 2,6 – 3,3 times, all-round lights in them 3,1 – 3,7 times when there is a general decrease in headers 2,8 – 3,4 times [3]. In turn, the operation of TEM without the control systems of thermal regimes increases the number of their failures is 1,5 – 3,5 times [3].

Possible ways of temperature control TEM and build appropriate protections are:

- installation to the engine temperature sensors;
- the use of thermal relay;
- indirect assessment, which is based on the measurement of the resistance of the motor winding or the calculations of losses in the engine.

The most accurate, and now most often used, method is to measure directly the temperature of the windings or become active with the help of temperature sensors [13]. The main disadvantages of the method are:

- the necessity of embedding sensors in the motor windings that under operating conditions without dismantling;
- the necessity of output of the engine additional conductors, that in conditions of severe vibration may cause damage and failure of the protection system.

Second modern direction can be a thermal relay which, as research has shown, is rational to apply when defending TEM with constant or changing loads [13]. In excess currents continuous duty thermal relay trigger too quickly, which can cause a "race machine".

In addition, these relays are unsuitable to protect TEM from overheating, which is most typical for engines operating under ETS of mine electric locomotives [10].

Meanwhile, according to the studies of the authors [5; 9; 11], calculation of energy losses in TEM by analyzed period of time allows an indirect but fairly accurate assessment of the process of its heating.

When applying this method, the period of operation of the TAM is divided into intervals during which the current can be considered constant. In modern microprocessor on-board control systems of electric locomotives it is possible to implement direct assessment of energy losses by determining the equivalent current according to the expression:

$$I_{екв} = \alpha \sqrt{\frac{1}{T}\int_0^T I^2 dt} \,. \qquad (1)$$

where α – is a coefficient taking into account the deterioration of the cooling of the engine at low speeds taken in the range 1,15 – 1,4 [5].

If the value exceeds the rated current continuous mode protection is triggered, feeding the signal to shut off the traction electric drive.

The average temperature of the winding TED can be determined from the magnitude of its resistance. The method is based on the real property changes in the resistance of the windings TED as a function of temperature change. The temperature of the winding is determined by the expression [10]:

$$t_2 = \frac{R_2 - R_x}{R_x}(k + \tau_x) + \tau_x, \quad (2)$$

where R_2, R_x – are support the windings, measured respectively in hot and cold conditions; τ_x – winding temperature in a cold state; k – is a coefficient of 235 for copper windings and 245 for aluminum windings.

As research has shown [3, 7, 10], the most dangerous and intense heat is generated in the armature winding TEM, but control its temperature accompanied by certain difficulties associated with brush contacts, since their resistance is unstable and can change dozens of times depending on the brand of brushes, burnishing, surface conditions of the reservoir and its temperature, speed, etc. To the same brush cover several collector plates. Therefore, a sufficiently accurate determination of the temperature of the anchor winding of the resistance is impossible.

However, there is another way to control the temperature on the resistance of the excitation winding (EW). This is possible based on the following considerations: the field winding of the traction motor is connected in series with the armature winding, and it is the same current flows; the windings are located in the same machine, so their heating and cooling related. This allows for temperature EW to accurately determine the temperature of the armature. Study the temperature distribution is carried out by the authors on a real bench, showed that while the maximum allowable temperature of the armature winding is heated at 25^{0}C higher than EW. Taken into account that the allowable temperature of the armature winding of the traction motor insulation of class F is 155^{0}C, and the maximum allowable for heating is 130^{0}C.

Therefore it seems only logical that despite the fact that the EW and allows a higher temperature, overheat protection TEM shall be activated when the temperature of the coil 130^{0}C. The temperature corresponds to the level of resistance [11]:

$$R_{130}^{Cu} = R_x \frac{365}{235 + \tau_x}. \quad (3)$$

Fig. 4 shows a variant implementation of the protection circuit of the traction motors from overheating.

The average voltage U is removed from the EW through the circle, consisting of $R1 - R2$ and *C* that limits the voltage pulses at switching in the power range of the device that is being protected. The average value of the current *I* which flows through the EW, determined using a shunt *RS*. Configuring protection for a certain resistance and carry out the appropriate temperature adjustment resistor *R3*. Block protection device contains analog integrated divider which performs the function of division U_{cep}/I_{cep} - that is, continuously determines the amount of resistance of the windings. When the resistance value that corresponds to a temperature of EW about130 ^{0}C, the protection is triggered, the temperature of the armature winding reaches a temperature of 155 ^{0}C. The scheme does not require installation in TEM because temperature sensors directly EW on the TEM is a sensor. This makes the protection of TEM is simple and reliable. In this structure as a real option divider for practical implementation can serve as chip 4-Quadrant Multiplier/Divider AD734 © Analog Devices, Inc. The scheme supports two modes of the analog division. It is recommended for use as an analog divider, which operates in the direct voltage regulation. This mode is more accurate, flexible and allows increasing the frequency of the chip. The second argument, which should be subject to control, is the speed of train. As you know, this option is strictly regulated by the Rules of safety in mines [11] differentiated by the technological parts of the underground route of movement of the locomotives. The most important safety factor is to limit the velocity of the ERC according to the condition of the allowable stopping distance for the carriage of goods should not exceed 40 m, and for the carriage of personnel 20 meters. Braking distance the ERC calculated in terms of the worst case - load downhill to the trunk. This phase is the most dangerous, the speed limit on it up to 10 km/h, although (for traction) the train can reach a much higher speed.

In different time periods of development types of mine locomotives have been developed and are in operation until the present time, a line of speed controls locomotive including mining [5, 14].

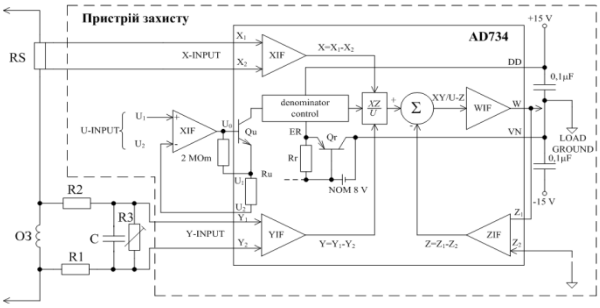

Figure 4. The protection circuit of the traction of the mining electric motor from overheating using chip AD734

Thus, in [5] the list of speed measuring devices installed at the mine electric locomotives type 10KR, 14KR production of the Alexander engineering plant (Russia) is presented. Double system in the first block, the sensor comprises a permanent magnet generator, generating a current whose value is proportional to the speed of rotation of the rotor. The second block magnetic tachometer that produces these currents and shows the speed of the locomotive on the remote control operator. The sensor is mounted on the gear cover traction transmission of the locomotive and connected to the gear reducer using your own gear. According to [14], for mine locomotives LG type manufactured by ASEA (Sweden) to control the speed of movement of the locomotives use two options. In the first sensors mounted on the gear shaft of the traction transmission, the second structurally inserted into TEM. Both methods have the same drawbacks as in the previous case.

To control the speed of movement of domestic transport currently used in a number of ways, based on a control of the rotational speed of the traction motor or wheelset with subsequent peterosborn in the speed of the train [5, 13]. However, if conditions electrolocation that operate on the ground, the variants of these systems of control in varying degrees are acceptable for the conditions of their use underground achieve the necessary efficiency of such methods is problematic [10]. According to the authors, the reliability of the speed meter can be repeatedly increased by means of the method of sensorless control using only the electrical parameters TEM. It is known [14] that for TEM sequential excitation current and voltage uniquely determine the speed of rotation. In the general case, the rotational speed TEM is [14]:

$$\omega = \frac{U_я - IR_я}{C_\omega Ф}, \qquad (4)$$

where *Uя*– the tension on the anchor; *I* – the current of TEM; *Rя* – the resistance of the armature winding; *Ф*– magnetic flux; *Cω*– constructive ratio.

In electric mode it is common to use linear speed

$$v = \frac{U_я - IR_я}{C_v Ф}. \qquad (5)$$

As is known [14], for TEM series excitation magnetic flux is a function of current $Ф = f(I)$, then the expression (5) would have the following form

$$v = \frac{U_я - IR_я}{C_v f(I)}. \qquad (6)$$

Despite the complex dependence of the magnetic flux from the current (due to saturation of steel) it can be expressed by a hyperbola with the exponent $x < 1$, that is $Ф \approx I^x$. Then the expression (6) will be

$$v = \frac{U_я - IR_я}{kI^x}. \qquad (7)$$

Using real Electromechanical characterization of TED and setting a current value to determine the appropriate speed v and to calculate the value kI^x. Calculations show that for different characteristics of the exponent *x* is in the range 0,4 – 0,6. If value is defined *x*, then the value of the coupling coefficient *k* is equal to

$$k = \frac{U_я - IR_я}{vI^x}. \qquad (8)$$

The structure of the proposed speed meter shown in Fig. 5.

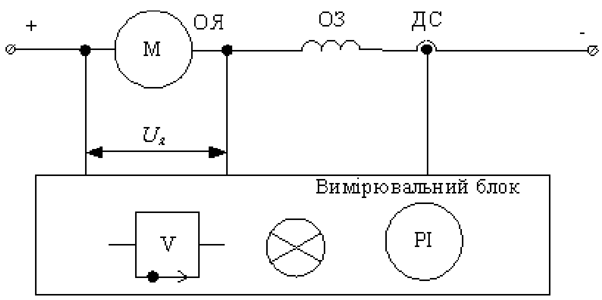

Figure 5. Speed meter structural diagram:

M, ОЯ – respectively, the armature and field winding of the traction electric motor; DC - the current sensor

The value of the armature voltage and current of the motors is applied to the input of the measuring unit that calculates the current speed of the locomotive and produces a value on a display device registration. In excess of the speed above the permitted value, the warning lamp lights up. In addition, the display and the memory device are output values of the motor current to inform the driver about the current load, as in the present tense, and if you want to play in the future.

Conclusions. The quality indicators of functioning devices, temperature monitoring and speed measuring devices, which are used in traction electromechanical systems with TEM DC series excitation modern mine electric locomotives are analyzed and evaluated. The main reasons for their low reliability are founded and the direction of improvement - sensorless control methods is simultaneously determined. The results of the studies suggested the functional and structural schemes of the probes that are recommended for implementation.

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