TROUBLESHOOTING OF TRANSVERTER OF ELECTRIC TRAIN UNDER OPERATION CONDITIONS

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ABSTRACT

The authors assess the existing system of operation and maintenance of railway rolling stock in Russia; identify its main disadvantages and challenges. They argue that it is crucial to organize reliable monitoring of technical state of the most critical equipment. Following the description of the features of transverter of electric train, they suggest a method of its troubleshooting which is based on monitoring of parameters of spectrum of three-phase alternating current. The method refers to both operational and pre-accident conditions of devices. Adequacy of the procedure is tested and confirmed on the basis of data obtained during the operation of the experimental plant.

ENGLISH SUMMARY

Background. *Improvement of operational reliability of multiple units (hereinafter refered to as MU) by early detection and elimination of defects has always been a priority task for maintenance and repair system of railway technics [1].*

The current situation, in which the rolling stock is maintained in good technical condition due to the system of preventive maintenance and repair, involves a large amount of resources spent to carry out regulated works, regardless of the actual state of a device of MU section. In other words, the hidden nature of nucleation of defects and malfunctions leads to unplanned repairs and as a consequence – to additional costs.

The identified problems can be solved with the help of on board monitoring system of technical condition, providing real-time evaluation of each device and compiling of objective information about possibility of its further operation. The effectiveness of such a system is ensured by in its continuous operation, i. e. diagnosing with the period, which is many times smaller than the period of development of the fault to the critical (limiting) state [2], which makes it possible to focus on the actual technical condition of the rolling stock instead of resource-intensive planning and preventative repair system.

Objective. *The objective of the authors is to introduce a method of diagnosing the parameters of transverter of electromotive rolling stock with the help of data obtained during the operation of experimental plant.*

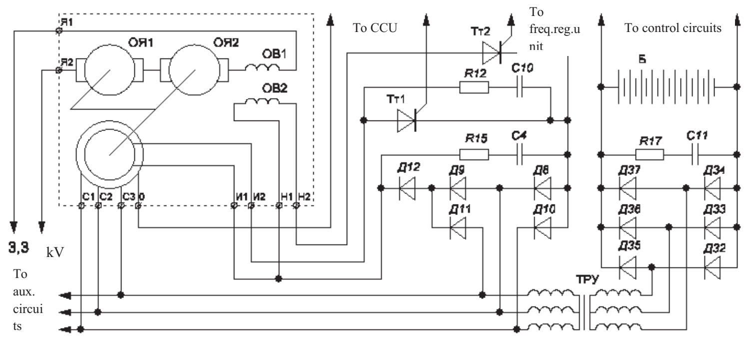
Methods. *The authors used mathematical method, analysis and experimental method using special experimental plant.*

Results. *One of the tasks for the implementation of the mentioned system of operation is the development of methods of troubleshooting of the technical condition of equipment of MU auxiliary circuits.*

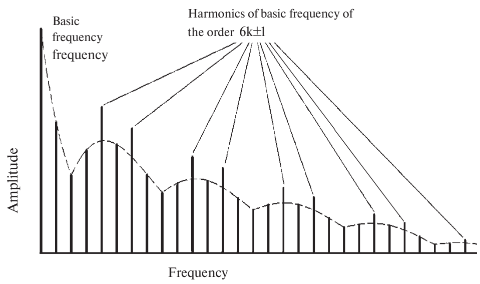
Existing techniques for functional troubleshooting of electrical equipment based on parameters of the spectrum of an electric current imply that during the inspection equipment is operating in a steady mode, and the structure of the electrical circuit does not change over time [3]. Meanwhile, auxiliary circuits of modern trains have a complex topology and variable structure, consisting of a high-voltage part – DC circuit with 3,3 kV voltage, which provides start, supply and protection of a rotary converter, as well as supply of high-powered heating furnaces and a low-voltage part – three-phase AC circuit with linear voltage of 220 V and frequency of 50 Hz generated by rotary converters or transverters for electric power supply of auxiliary equipment, battery charging and supply of drive circuits.

Studies [4], as well as technical analysis of spoilage, malfunctions and unplanned repairs of electric trains [5] show that in the system of auxiliary DC circuits rotary converter or transverter (hereinafter – converter) is the most susceptible to sudden failures.

Converter is a two-machine unit, composed of a DC electric motor and a synchronous generator disposed on the same shaft. Electric trains of ED4M series are equiped wth converter 1.PV.7 since 2011. Its engine is a double-collector DC machine with compound excitation. One of drive windings (series) is connected consistently with the armature winding and the other (independent) during start is powered by a battery, and at a steady mode of operation – from the rectifier unit, powered in turn by three-phase



Pic. 1. Auxiliary circuit diagram of an DC electric train during operation with a minimum load.

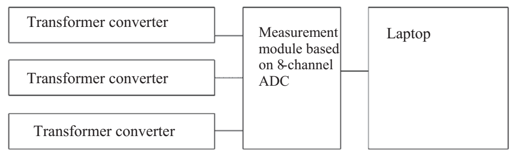


Pic. 2. Model of phase current spectrum of the converter during operation of auxiliary circuits with minimal load.

voltage of the generator. Generator of a converter is a four-pole synchronous machine with salient poles located on the shaft. Excitation of the generator is independent; drive winding is powered similarly to independent drive winding of the engine.

The ends of three-phase generator stator winding are permanently connected with rectifier unit to power drive windings and three-phase transformer, from which 6-pulse uncontrolled rectifier is powered, which provides low-voltage control circuits with rectified current of 110 volts and the battery charge. Other consumers use three-phase AC circuit as needed – compressor unit turns on with a pressure drop in the feed network of electric train below 6,5 kgf/cm ^{2} and it turns off when the pressure reaches 8 kgf/cm ^{2}. Electric motors of enclosed platforms' ventilation and air conditioning system, as well as interior lighting and additional cabin heating, are turned on by locomotive crew [6].

Working conditions of a converter are characterized by a significant variation in feed voltage in the range of 2,7–4 kV, as well as frequent changes in the load from 5–7 A per phase in the mode of feeding of own drive windings and control circuits up to 170 A in the electrodynamic braking mode when controlled semiconductor rectifier receives the current from converter's generator, feeding thus drive windings of traction motors. Working conditions of a converter are influenced, moreover, by fluctuations in temperature and humidity of the environment, significant alternating dynamic loads [7] and, importantly, mishandling. The presence of these factors significantly reduces the resource of a device and may cause its premature sudden failure and related material losses.



Pic. 3. Block diagram of experimental plant.

To effectively diagnose the converter within the framework of the parameters of the spectrum of three-phase alternating current, analysis of three-phase alternating current should be carried out when converter operates with a minimum load. It allows to exclude influence of consumers' currents on the AC waveform of a converter's generator. In this mode, as already noted, almost all of generated power is spent on power supply of drive windings and control circuits. Pic. 1 shows a simplified circuit diagram of auxiliary circuits of an electric train with minimal load.

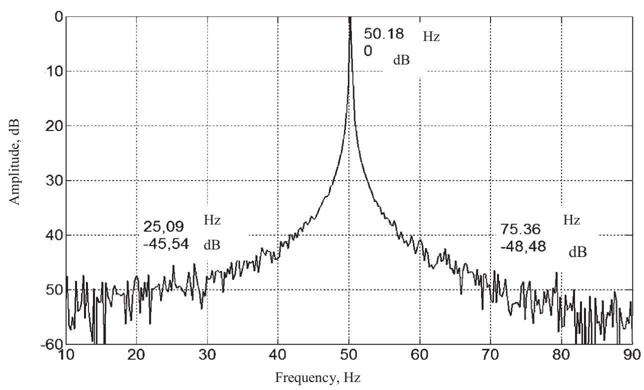
Spectrum of phase current of a converter in this mode (Pic. 2) is quite wide. There are all harmonics of the basic frequency, the presence of which is caused by inclusion of a single-wave rectifier in a three-phase circuit for power supply of converter's drive windings. Their level decreases wavily with increasing frequency similar to function $|\sin(x)|/x$. The exceptions here are harmonics of the order $6{\cdot}k\pm1$ (k is a natural number) generated by a three-phase bridge rectifier, which serves to charge the battery and supply control circuits.

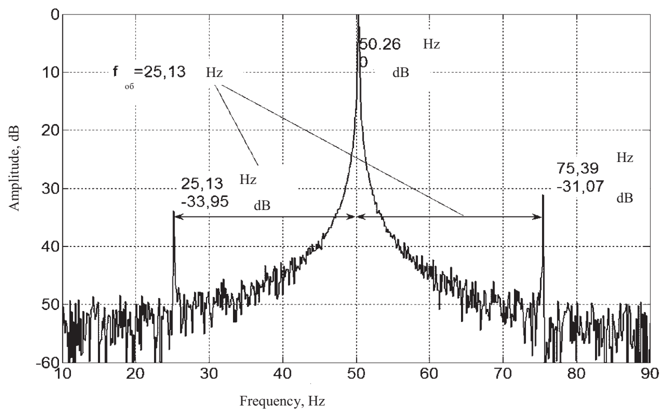
The physical principle as a principle of spectrum-current diagnosis, is that any disturbance in operation of electrical and / or mechanical part of the electric machine leads to changes in magnetic flux in the gap of the electric machine, and consequently to a modulation of the current consumed or generated.

Current spectrum analysis is a diagnostic method in which within the specified time interval instantaneous values of currents, consumed or generated by the machine, are recorded, a fast Fourier transform is produced and the values of the amplitudes at frequencies of defects' appearance are compared with the signal level at current's basic frequency.

For early detection of «problem» machines special attention should be paid to the appearance of rotational frequency in the current spectrum in the form of modulation of harmonics of the basic frequency. Since the converter's generator is a four-pole machine, speed of converter shaft is always equal to half of the basic frequency of current

Pic. 4. Spectrum of phase current of a converter in working order during operation with minimal load.





Pic. 5. Spectrum of phase current of a converter in pre-accident state during operation with minimal load.

and if there is an imbalance of the rotor, sidebands should appear in the current spectrum at 25 Hz on the left and right of the rotational frequency and its harmonics. Thus, when converter shaft rotates at 1500 rev / min and the corresponding frequency of generated current is 50 Hz, reliable diagnostic feature of the imbalance is the presence in the current spectrum of components at frequencies of 25, 75, 125 Hz, etc.

Technique of converters' troubleshooting, based on spectrum analysis of three-phase alternating current, is currently implemented in the form of experimental plant (Pic. 3), consisting of transformer converters connected to the analog inputs of the measurement module based on 8-channel 16-bit delta-sigma ADC and a laptop within a local network with specialized software

In order to obtain experimental data signals of three phase alternating current of converters were recorded at the commissioning stage, as well as the signals of the converters, which were in operation from one to two years, including those, which were in pre-accident state.

As an example, Pic. 4 shows spectral recording of the phase current of a converter in working order, and Pic. 5 does the same for a converter in pre-accident state. Studying Pic. 5 one can easily see the pronounced components of a pre-accident converter with a frequency of 25 Hz and 75 Hz. It is the basic frequency modulation due to the frequency of rotation of the converter. The presence of such a component confirms rotor unbalance [2] of the converter.

Conclusions. *1. The most common cause of failures of rotary converters is connected to rotor and bearing defects.*

2. Rotational frequency is clearly identified within the current spectrum of the generator.

3. It is established that if there is a rotor imbalance of a converter, then one can observe components at rotational frequency within the three-phase current spectrum in the form of modulation of basic frequency harmonics.

Keywords: electromotive, technical diagnostics, troubleshooting, transverter, imbalance, AC spectrum, on board monitoring system, experimental plant.

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