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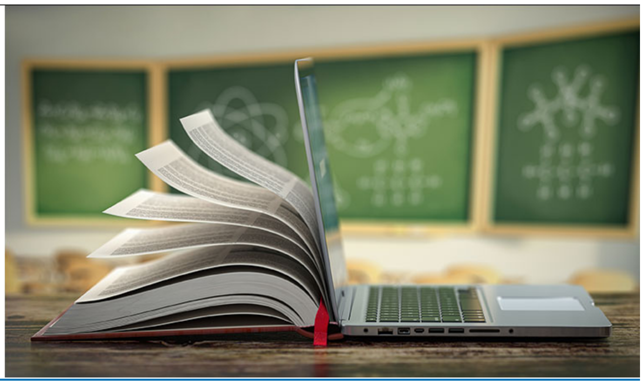

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Adjustable Electric Drive Based On Radiation-Resistant Induction Motors

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Abstract. The object under consideration is an adjustable electric drive based on radiation-resistant DAR induction motors with a power of 0.75 kW and 2.2 kW, with a nominal stator field rotation speed of 1000 rpm and 1500 rpm and an environmental protection method IP 68, designed to use in the equipment for hydrometallurgical processing of spent nuclear fuel (SNF) of the processing module of the pilot demonstration energy complex (PM PDEC). Bench tests of DAR prototypes confirmed that the developed motors in accordance with electromagnetic parameters, energy and starting characteristics fully comply with serial asynchronous motors of similar power and speed and satisfy the requirements of the technical specifications. The control system with the Altivar ATV212/ATV320 frequency converter ensures stable operation of the DAR in the range of 1:50 speed control in the "sensorless" version, the functions and interface of the control system meet the specified requirements. Recommendations are given on expanding the tasks of automation of the technological process, which can be provided by means of the developed control system based on software implementation. An assessment of the thermal state during liquid cooling of engines during operation from the control system.

1. Introduction

For the first time in the Russian Federation in the innovation and implementation center "Electromechanical and Electrotechnological Complexes" (IEC "Electromekhtechnokom") Ural Federal University named after B.N. Yeltsin, together with VNIINM JSC, Uralelectromash CJSC and Rusatom Engineering LLC, as part of the Proryv project area, developed and manufactured radiation-resistant asynchronous electric motors with a control system with a service life of at least 3 years. This will allow us to abandon the traditionally problematic transmission of torque through the biological protection of the premises and place the engines directly in the equipment installation chambers with a high radiation dose level. This will reduce the cost of equipment, construction and installation costs and operating costs. The engines are designed for the technological equipment of the pilot demonstration energy complex (PDEC) for the processing of nuclear waste.

In accordance with the statement of work (SOR), the engines must be capable of long-term operation in PDEC processing modules with a high level of radiation (up to 10^8 rad), in a chemically aggressive environment with nitric acid vapor, the temperature of which reaches + 80° C. Fulfillment of these requirements was implemented by the design of the DAR according to the method of protection against environmental influences - IP 68, which implies complete tightness of the housing structure,

the use of radiation-resistant materials in the design of engines. In accordance with the statement of work, the control system must provide a range of regulation of the engine speed of not less than 1:50. In addition, in accordance with the statement of work, a prerequisite is the use of water-cooled engines to prevent overheating of the medium in PDEC processing modules.
DAR prototypes were made on the basis of the electromagnetic core of serial asynchronous motors of similar power and speed of CJSC Uralelectomash. Other design modifications of asynchronous motors with an asymmetric magnetic core [1,2] or with ring windings [6,7] or an electromagnetic core with ventilation-induction motors of a sensorless control system [3-5,8,9] can be used as an electromagnetic core.

The development of the control system and the manufacture of the control cabinet were carried out at the Electromekhtechnokom IT Center by the departments of Electrical Machines and Electric Drive and Automation of Industrial Installations. Testing of DAR prototypes, including the control system, was carried out in the research laboratory of the Department of Electrical Machines.

To regulate the speed of a new generation of radiation-resistant asynchronous DAR electric motors, the frequency control method was chosen as the most energy-efficient method among the known [11,12]. The engine control system is designed on the basis of a typical serial frequency converter (FC) of the Altivar family of Schneider Electric. To implement operator control functions, solve technological problems of plant automation, driven by the developed electric motor, and provide external access to control the system, it includes an industrial programmable logic controller (PLC) and an operator panel (OP) with touch control. When choosing a set of appropriate equipment, they were guided by its functional characteristics and minimal cost. The Schneider Electric equipment range includes all elements of modern automation systems, has available software and Russian-language operating manuals necessary for design and maintenance, the equipment itself has positively established itself in Russia, and is used in many projects in various industries [10,13].

The problem under considerations was the requirements for the engine control system for equipment for hydrometallurgical processing, namely, providing a control range of 1:50 without a speed sensor, it should be noted that in the characteristics of the inverter for general purposes, such an indicator in its direct representation is absent. The boundary values of the output frequency of the supply voltage are indicated, for example, 0.5 ... 200 Hz, and it does not say what quality indicators (statism of mechanical characteristics, bandwidth in speed) are able to provide an electric motor speed control system. In this regard, the task of obtaining experimental adjusting mechanical characteristics of motors with a selected frequency converter and control system was set in the work [14]. Obviously, to obtain the indicated characteristics, special testing equipment is needed to load an electric machine powered by a frequency converter with a calibrated resistance moment value. The generally accepted solution for such tests is the use of electromechanical stands, in which two electric machines are combined by a common shaft, one of which, for example, the test one, operates in the motor mode, and the second - load, works in the generator mode, creating a braking torque, the value of which is determined by the calculated or evaluated by a torque sensor integrated in the coupling. If it is necessary to evaluate the dynamic properties of the electric drive system, the test list is supplemented by removing the system reactions to stepwise or harmonic input influences, the so-called “control response” and “disturbance response”. It should be noted that at this stage of operation, there were no special requirements for the dynamic performance of the electric drive, therefore, the corresponding items are not included in the test program.

2. Methodology and test results of the electric drive to ensure a given range of speed control

Tests of prototypes of radiation-resistant electric motors, including the control system, were conducted in the laboratory of the Department of EM UralENIN UrFU on an electric machine unit consisting of rigidly connected test engine and a load electric machine (see Figure 1). As a load machine, the 1PH8101 induction motor was used, powered by a frequency converter with an active input rectifier, which provides energy recovery to the network, which makes it possible to obtain a generator (i.e., braking) mode of operation of the machine. The drive was controlled from the control cabinet (see Figure 2).

The engine torque was measured using a TRD-3K type torque sensor integrated in the coupling (nominal torque 3 kgf· m, accuracy class 0.03, manufacturer Dacell, Korea). The rotation speed was measured using an encoder loading machine (2048 pulses per revolution). Electrical quantities (current and voltage) were measured using LEM sensors (at the inverter output: CV3-1000, LA 25-NP, two wattmeter circuit; at the inverter input: LV25-P / SP5, LA 25-NP, two wattmeter circuit). To record signals from sensors, the ADC QMBox17-48 was used.

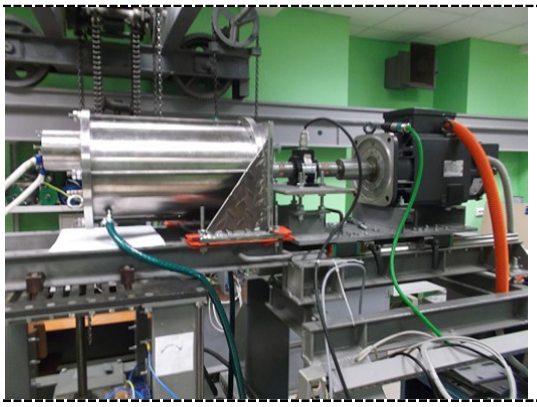

Figure 1. Test bench

Figure 2. Control cabinet for DAR-2.2

The test results showed that the control system with the Altivar ATV212 IF can be recognized as satisfying the requirements of the technical specifications, as ensuring stable operation of the ED in the specified range of speed regulation in the "sensorless" version (without a speed sensor on the shaft), which is illustrated by the mechanical characteristics shown in Fig. 3 and 4.

The problem of the importance in evaluating the performance of an electric drive was considered because of the nature of the load of the production mechanism. In particular, mechanisms with load characteristics of the “fan” type (a group of centrifugal mechanisms), in which the moment of resistance created by them on the motor shaft, is determined by a power-law dependence on speed n: $M_l = f(n^k)$, where $k > 2$, reduce the load on the engine when switching to a reduced speed, which, of course, reduces the requirements for the accuracy of maintaining a given speed.

The clarification of the requirements for the linearity of mechanical characteristics (varying in speed depending on the value of the resistance moment), expressed in absolute units or in fractions of a given value, it may turn out that the obtained characteristics of developed engines with the proposed control system cannot be considered satisfactory. In this case, to increase the overload capacity of the drive with the inverter and expand the speed control range in the "sensorless" version, it is recommended to use the Altivar ATV320 inverter with a power one step higher than the power of the ED.

Comparison between the experimental characteristics shown in Fig. 4 and fig. 5 outlines that Altivar ATV320 provides more stringent mechanical characteristics of the engine. It should be noted that the functions and interface of the control system (controller and operator panel) provide input of the speed task and displays the main variables available in Altivar.

To solve technological problems with the use of DAR and IF, additional information is required on the load characteristics of the working bodies of the mechanisms driven by the proposed electric drive. In this case, the tasks of automation of the technological process can be solved by software using the developed control system when completing the technological equipment with a set of appropriate sensors and actuators and / or devices.

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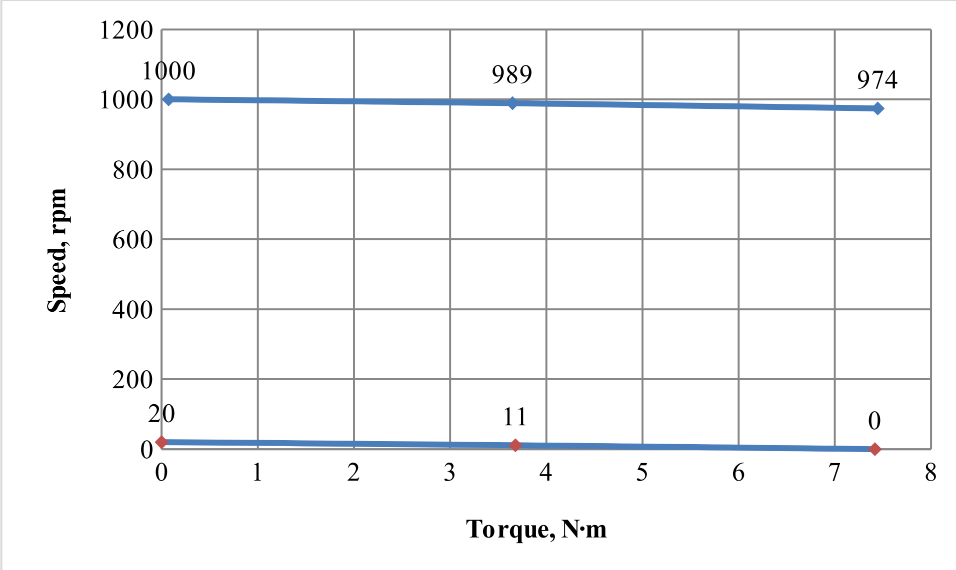

Figure 3. Mechanical characteristics of the DAR-0.75 engine when powered by an Altivar ATV212 frequency converter

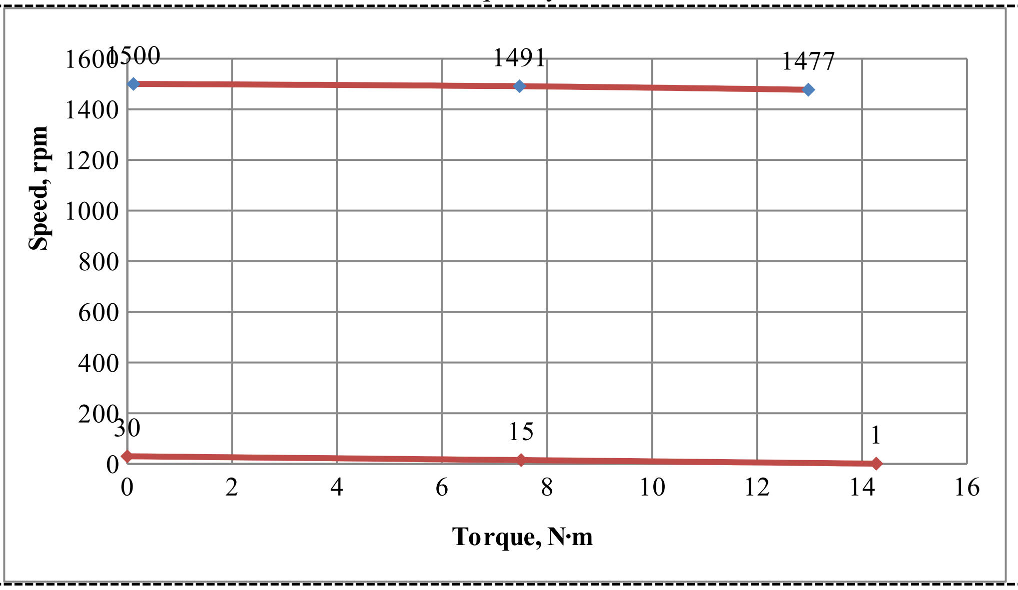

Figure 4. Mechanical characteristics of the DAR-2,2 engine when powered by an Altivar ATV212 frequency converter

3. The results of thermal tests of DAR in the electric drive

Thermal tests of DAR as part of an electric drive were carried out in the research laboratory of the Department of Electric Machines of UrFU:

1) for the DAR 2.2 engine when powered from a mains sinusoidal voltage of industrial frequency;
2) for the DAR 0.75 engine powered by a Schneider Electric Altivar 212 frequency converter.

When conducting a heating test ED DAR-2.2, the temperature of the incoming cooling water is 20 °C. The phase voltage and current in the stator winding corresponded to the nominal load mode. The results are presented in Figure 6.

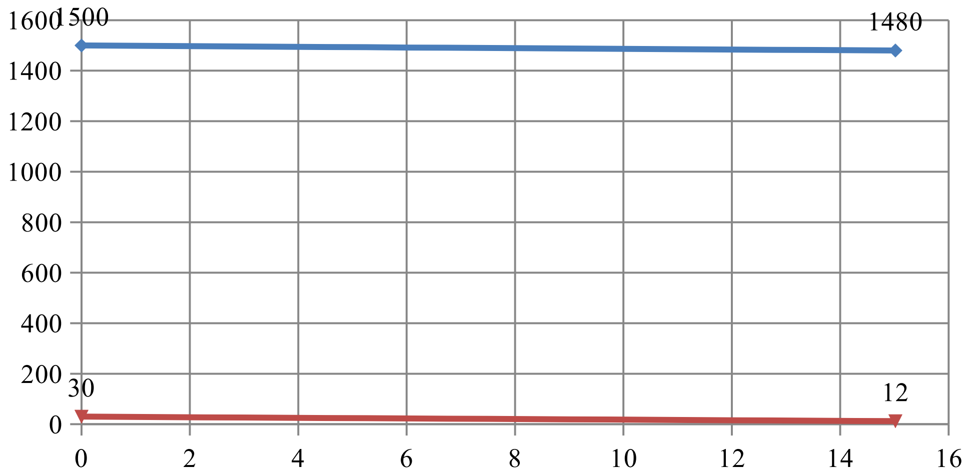

Figure 5. Mechanical characteristics of the DAR-2,2 engine when powered by an Altivar ATV320 frequency converter

Figure 7 shows a thermogram of an experimental sample of DAR-2.2 during heating tests at the test bench of the research laboratory of the Department of Electrical Machines of Ural Federal University. As can be seen from the above thermogram, the temperature of the most heated point on the bearing shield does not exceed the upper values on the color temperature scale on the right. Similar tests were performed for DAR-0.75.

Based on the results of thermal tests, a verification of the thermal calculation method developed to assess the thermal state of the DAR was performed. The technique was compiled using the equivalent thermal circuit method [2,3].

The solution of the ETS system of equations is made in matrix form for 15 nodes in a MathCad environment with 2 reference nodes that determine the ambient temperature and water temperature in the inlet pipe of the cooler. The calculations were performed at ambient and water temperatures and water flow rates in the cooler given in the thermal test protocols. In addition, the calculations used data on steel losses and mechanical losses found during bench tests at CJSC Uralelectromash. Electric losses in the stator and rotor windings were determined by the method of successive approximations by adjusting the active resistance of the windings according to the calculated values of their temperature.

When assessing the thermal state of the engine, we used the dependence of the heat transfer coefficient on the flow rate of cooling water, found as a result of calculating the liquid cooler by a numerical method based on the developed housing design.

Comparison of the steady-state values of the calculated temperatures in the nominal load mode of the experimental DAR samples with the experimental data showed that the developed method gives overestimated temperatures compared with the experiment. In comparison with the established value of the average temperature of the stator winding DAR-2.2, equal to 49.5°C, the excess was 15%, and with respect to the average temperature 49.5°C of the stator winding DAR-0.75, the excess was 5%, which is acceptable in technical calculations. In general, heating of the DAR stator windings does not exceed the values specified in the technical specifications, taking into account the increase in ambient temperature to + 80°C.

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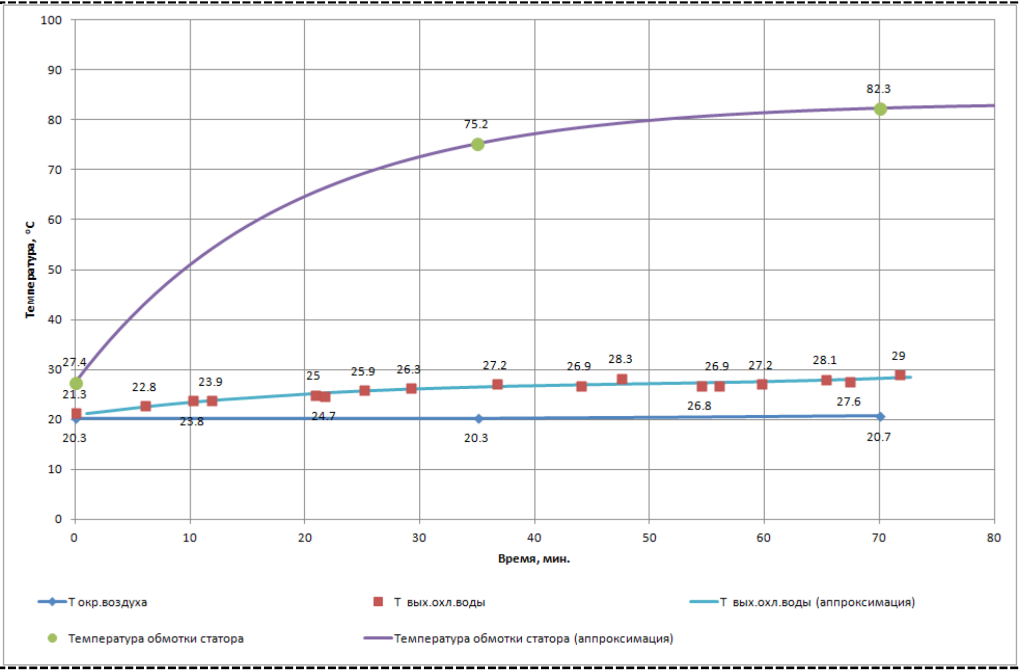

Figure 6. Graphs of temperature changes during the test for heating DAR-2,2

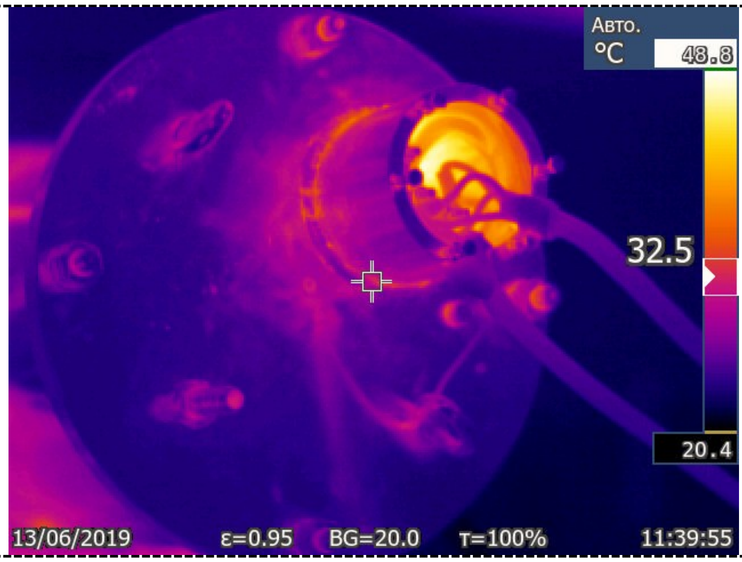

Figure 7. Thermogram of the DAR-2,2 engine. Bearing side view with terminal box

4. Conclusion

Bench tests of DAR prototypes carried out in the testing laboratory of CJSC Uralelectromash and at the Department of EM UralENIN UrFU confirmed that the developed engines with a control system for electromagnetic parameters, thermal, energy, starting and control characteristics fully comply with the technical specifications. They provide a predetermined level of speed regulation and can work in ODEC processing modules with a high level of heating in an aggressive environment.

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