Feasibility demonstration of back-to-back method for induction traction motors testing

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Abstract. The authors present the feasibility demonstration of energy-saving back-to-back test method implementation for induction traction motors testing. The results of theoretical and physical modeling that support the energy effectiveness and usefulness of the proposed back-to-back method are presented in the article. The effectivity ratio of the test circuit has been calculated due to confirm the energy effectiveness and feasibility of the proposed method, and also authors identified a number of advantages of the back-to-back method for high power induction traction motors.

1. Introduction

In the Russian Federation, the fleet of traction electric machines (brushed and brushless) involved in various industries totals hundreds of thousands, while the average power of the traction electric motor is about 1000 kW, which have found their application as traction or auxiliary machines (for example, direct current traction motor EDP810 mounted on a 2ES6 locomotive has a rated power 810 kW, the NTA-1200 asynchronous traction motor set on an EP10 electric locomotive has a rated power 1200 kW). The operational life of these machines enshrined at the design, manufacture and maintenance stages and is about decades, it is economically feasible to carry out scheduled and preventive repairs of these machines, if the machine has not exhausted its lifetime potential. As the cost of such an electric motor is high, therefore, enterprises operating these machines are rarely interested in timely repair based on their actual condition. Often the lifetime resource of these machines is either worked out or close to this.

For the reasons stated above, the replacement of obsolete traction motors with their new modifications is not carried out at a sufficient pace. Which leads to an increase in the number of electric machines failures, as well as to an increase in the repair work and, accordingly, to rise of unbudgeted expenses. According to the global trend, the changeover from the brushed electric drive of railway rolling stock to asynchronous is inevitable, due to the undeniable advantages of these machines. However, in the Russian Federation, according to experts, direct current motors as traction motors will be used for about another 30 years, despite the fact that, the use of asynchronous machines as traction motors has a number of advantages compared to brushed machines [1, 2].

An increase in the share of asynchronous traction electric motors makes it necessary to solve a number of urgent issues related to their operation. Among these issues, we can single out the need to create new or re-equip existing repair bases and test stations, while the test stations must meet modern requirements for reliability and energy efficiency. This can be achieved by introducing modern energy efficient methods and techniques of asynchronous machines diagnosing and testing [3].

While testing traction machines, it is necessary to provide long-term test conditions, which leads to high energy costs. As a solution to this problem, a methodology and test circuit for the traction asynchronous machines according to the back-to-back method can be proposed; this method allows obtaining the largest percentage of energy savings during the test time. The practical application of this method up to the present moment has been limited only to direct current machines, research team of the School of Energy and Power Engineering of Tomsk Polytechnic University have proposed a circuit that implements the back-to-back method for traction induction motors testing [4]. The aim of this work is a theoretical study and practical application of the proposed method for induction traction motors testing.

2. Theoretical study

The selection of circuit for testing of electric machines is determined by parameters of electrical equipment used on test station, all of them can be characterized by range of quantitative and qualitative parameters which include the rated power of auxiliary equipment and the amount of consumed electrical power during the test procedure. The interrelation of these factors can be expressed in terms of effectivity ratio that could be determined as [5]:

$$k_E = \frac{P_1 - P_{test.cir}}{P_1} \qquad (1)$$

where P_1 – power consumed by the tested electric machine; $P_{test.cir}$ – power consumed by the circuit as a whole. The effectivity ratio shows the fraction of electricity required for the motor compared with its rated power.

There are several circuits and methods used for high rated power alternative current machines testing [5], some of them are presented in table 1. All test circuits have sufficiently high effectivity ratio values, thus differ in the number of auxiliary machines included in the test station.

Table 1. Effectivity ratio.

Test Circuit	k_E	Number of Auxiliary Machines
Direct load of traction motor	0.25 ÷ 0.60	5
Circuit with power regeneration to main supply	0.65 ÷ 0.70	6
Circuit with load reversal, power losses covered by booster generator	0.70 ÷ 0.60	5
Circuit with load reversal, power losses covered by direct current generator	0.75 ÷ 0.65	4

As the table 1 shows test circuits have relatively high effectivity ratio values, however taking into account the ratings of modern induction traction motors (power about 1000 kW, efficiency 95 %) the test station must be capable of loading the tested motor with the load that is equal to or greater than the rated value, after that the number of energy conversion levels must be the smallest. The back-to-back test method complies with all of those requirements.

To obtain the numerical value of the effectivity ratio let's consider in detail the power flow of the back-to-back test method for induction traction motors, as shown in Figure 1, where P_{1G} – power generated by the induction machine in the generator mode, P_2 – power output of the tested motor.

The power flow diagrams of the machines being tested, which worked in a generator and mo-tor mode, will be similar to each other, apart from the overall mechanical losses, which will be compensated in the machine under test that works in a motor mode.

The motor and the generator work jointly during test, so they are connected mechanically and electrically, hence, their power flow diagrams represent sequential combination of the machines' diagrams that work in motor and generator modes, as shown in Figure 2.
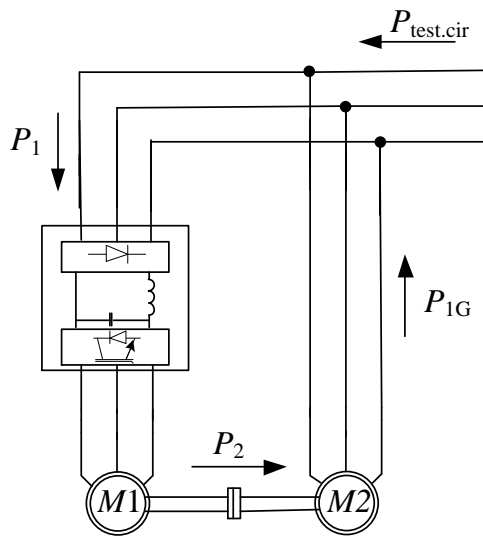
Figure 1. Energy flow in back-to-back test circuit**.**
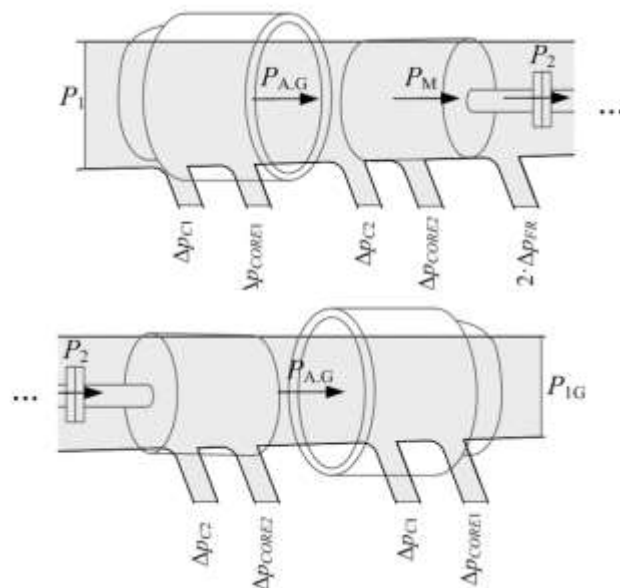
Figure 2. Power flow diagram of the induction motor – the induction generator system.

To determine the power losses during the test with a standard technique was used [6], in the (2) are the power losses taken into account during the experimental studies of back-to-back test method:

$$P_2 = P_1 - \Delta p_{C1} - \Delta p_{CORE1} - \Delta p_{C2} - \Delta p_{C1} - \Delta p_{CORE2} - \Delta p_{FR} - \Delta p_{STR} \qquad (2)$$

where P_2 – output power of the tested motor; P_1 – input power of the tested motor; Δp_{C1} – copper losses in the stator winding; Δp_{CORE1} – stator core losses; Δp_{C2} – copper losses in the rotor winding; Δp_{CORE2} – rotor core losses; Δp_{FR} – summative friction losses; Δp_{STR} – stray load losses. Also Figure 2 contains the following legend $P_{A.G}--$ air-gap power, P_M – converted power or mechanical power of the machine.

For determination of the effectivity ratio we use the expression (1), where power consumed by the tested electric machine could be determined from the expressions for the direct determination of efficiency:

$$P_1 = \frac{P_2}{\eta_M} \qquad (3)$$

where η_M – efficiency of the tested motor.

The power produced by the machine that works in generator mode could be expressed as:

$$P_{1G} = P_2 \cdot \eta_G \qquad (4)$$

where η_G – efficiency of the machine in generator mode.

Then taking into account the power losses occurred in machines the summative power consumption of the test circuit:

$$P_{test.cir} = P_1 - P_{1G} \qquad (5)$$

Substituting (2) and (4) in the expression (5) we obtain the effectivity ratio of the back-to-back test method:

$$k_E = \frac{\frac{P_2}{\eta_M} - P_2 \cdot \left(\frac{1 - \eta_M \cdot \eta_G}{\eta_M} \right)}{\frac{P_2}{\eta_M}} = \eta_M \cdot \eta_G \qquad (6)$$

As the expression shows, the effectivity ratio of the back-to-back test method depends on the efficiencies of the tested machines. The power losses of both machines are covered in the test station due to a main source supply.

3. Experimental study

According to the back-to-back test circuit (Figure 1), a test bench was created that allows testing using the back-to-back method, the data obtained during the test make it possible to evaluate the energy efficiency of the test circuit as a whole [3,7]. A general purpose industrial asynchronous electric motor (6A series, rated power $P_r = 0.55$ kW) is used as the tested electric motor and load machine. Since in laboratory conditions it was not possible to use a real traction machine, the physical test model was implemented using low-power machines, while the similarity theory allows the results to be applied to larger machines with high accuracy. A static frequency converter with a braking resistor (Danfoss VLT 2800 series) was used to provide control and source to the motor under test. Data collection during the tests was carried out using an analog-to-digital converter connected to a personal computer via USB bus (National Instruments NI USB 6009 model). Current and voltage sensors working on the Hall effect (current sensor LEM LA25-P, voltage sensor LEM LV25-P) were connected to the phases of the tested electric motor, as well as to the phases of the electric motor used as a load, these sensors were used as data sources.

According to the law of change of main supply voltage and frequency, the experimental study was performed with increased frequency and amplitude of the main supply voltage, the description can be found in earlier publications [8]. Experimental data for effectivity ratio determination of the back-to-back test method are shown in Figure 3. The principal interest is of dependences that show the energy flow in the system, i.e. the power consumption of the tested motor, power produced by the machine in generator mode and the amount of power taken from the main supply for covering the losses [9].
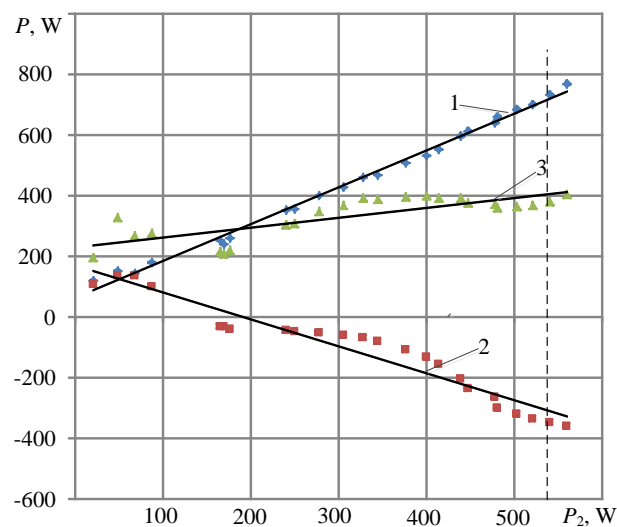

Figure 3. Experimental data.

Figure 3 shows the following experimental data: 1 – power consumption versus power output of the tested motor, 2 – power produced by the machine in generator mode versus power output, 3 – power taken from the main supply for covering the losses versus power output. According to the results obtained by experimental study, it is obvious that in order to achieve the rated mode the tested induction motor needs to consume about 730 W, while the load machine generates 320 W. To cover the losses occurred during the test circuit consumes 400W. Taking into account that efficiency of the tested machines is equal to 0.705, thus for covering the losses circuit consumes about 50% of the power, this theoretically calculated value is confirmed by the value of effectivity ratio, whose value in this particular case is equal to 0.5.

The experimental data confirm the interdependence between efficiencies of tested motors and effectivity ratio. This brings us to the conclusion that the implementation of back-to-back text method makes sense for high rated power induction traction motors testing. As high rated power induction

motors have higher energy characteristics, the effectivity ratio in this particular case is equal to 0.8÷0.9.

4. Summary

Experimental studies performed on general purpose induction motors have shown that the proposed back-to-back test method is efficient. Performed tests confirm that the summative efficiency of the circuit depends on the efficiency of the tested machines and can be used for induction traction motors testing. Energy saving in this context will be up to 90 % of rated power of tested machines.

The analysis shows that the back-to-back circuit possesses a number of advantages:

- the experimental circuit consist of the smallest number of auxiliary machines in comparison with alternatives;

- the test circuit allow testing two motors simultaneously that could not be realized in alternatives;

- due to smaller levels of energy conversion the back-to-back test circuit has the highest effectivity ratio.

However, the final decision on usefulness of back-to-back test method implementation should be based on the number of studies performed in association with enterprises involved in designing, production and repair of induction traction motors, and in the following develop the test procedures, standards and guidelines.

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