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# Redefinition of electromagnetic parameters of induction motors as part of variable-frequency electric drives with technological feedback

***Abstract.*** *The features of taking into account the change in the properties of the main structural units of induction motors with a high mean-time-between-failure when identifying their electromagnetic parameters are considered. It enabled the practical research and substantiation of the method of using the obtained results in systems of the industrial variable-frequency electric drive. The efficiency of the proposed solutions for improving energy parameters and ensuring the necessary quality indicators for the regulation of electric drives of pumping and ventilating equipment provided with technological feedback is confirmed.*

***Streszczenie.***
*Uwzględniono cechy zmienności głównych zespołów konstrukcyjnych silników indukcyjnych o wysokim średnim czasie międzyawaryjnym przy identyfikacji ich parametrów elektromagnetycznych. Umożliwiło to praktyczne badania i uzasadnienie metody wykorzystania uzyskanych wyników w układach przemysłowego napędu elektrycznego o zmiennej częstotliwości. Potwierdzono skuteczność proponowanych rozwiązań w zakresie poprawy parametrów energetycznych oraz zapewnienia niezbędnych wskaźników jakościowych do regulacji napędów elektrycznych urządzeń pompowo-wentylacyjnych wyposażonych w sprzężenie zwrotne technologiczne.* ***(Re-definicja parametrów elektromagnetycznych w silnikach indukcyjnych jako części zmienno-częstotliwościowych napędów elektrycznych ze sprzężeniem technologicznym)***

**Key words:** induction motor, frequency converter, electromagnetic parameters, identification, automatic adaptation.
**Słowa kluczowe:** silnik indukcyjny, przemiennik częstotliwości, parametry elektromagnetyczne, identyfikacja, automatyczna adaptacja

## Introduction

A special feature of modern systems of water and heat supply and ventilation, designed for use in production and the communal sector, consists in the installation of variable-frequency electric drives of pumps and ventilators, which are closed by temperature or pressure technological feedback [1, 2].

Taking into account the fact that induction electric machines (EM) are most often drive motors, frequency converters (FC) of various structures and manufacturers are used as control devices. Depending on the cost and energy efficiency of the systems, this may be the equipment of such firms as Schneider, Mitsubishi, Siemens and others.

At the same time, from the standpoint of controllability, preference is given to manufacturers producing the main actuators, such as DAB and Danfoss. The lines of their converters, in addition to the general functions that are standardly implemented in FC, are characterized by the presence of additional possibilities that facilitate adjustment and increase the efficiency of pumping and ventilating equipment.

The automatic adjustment of the converter to the parameters of a controlled electric machine of a pump or a ventilator is one of these possibilities. Since the algorithms for such adjustment are rather simplified and involve the use of standard methods for identifying the parameters of the equivalent circuit, they are practically inapplicable for induction motors (IM) of pumps and ventilators that have partially exhausted their resource, as well as machines that have been modernized or restored during various types of repairs [3].

Taking this into consideration, the purpose of the paper is to substantiate the method of accounting for changes in the IM electromagnetic parameters when the properties of the main structural elements change during long-term operation and repairs.

## Theoretical provisions

The main scientific and practical aspect of solving the problem is the answer to the question about the efficiency and permissible operating modes of IM as part of pumping and ventilating equipment. To solve it, a comprehensive assessment of the reliability and energy efficiency of the operation of such IMs is required.

Besides, if their reliability indicators, according to [4, 5], directly depend on the excess of thermal and vibration parameters, the energy efficiency indicators are determined by the required power $P_2$ on the shaft under the conditions of redistribution of the components of losses and changes in the efficiency $\eta$ and power $\cos\varphi$.

A feature of IM aging during repairs and long-term operation consists in a general deterioration in the properties of the magnetic system, often interconnected and/or combined with the presence of local damage to the stator winding and bearing assemblies.

These changes form the main percentage of failures and often in combination result in a violation of the electrical and magnetic symmetry of the IM design.

This compels one, along with the assessment of the limiting changes in parameters, to clarify the localization of places of increased heating, to determine the spatial distribution of electromagnetic forces and to carry out a number of additional, rather complex thermal and vibration calculations.

Magnetic symmetry violations are caused by the local deterioration of the properties of laminated electrical steel cores, which form the basis of the IM magnetic system.

As shown in [6], this manifests itself in a shift of the EM operating point to the domain of higher saturation with a general decrease in the saturation magnetic induction, an increase in the magnetic field strength, and a sharp increase in steel losses.

The indicated phenomenon for the case of electromagnetic parameters is taken into account by setting the real dependence of the magnetic permeability on the magnetic field strength, as well as by means of an updated calculation of losses in steel in accordance with [6, 7].

In addition, the occurrence of irregularities in the air gap due to the destruction of bearings, subsidence of bearing assemblies, as well as the influence of various types of imbalance introduced by the rotor, additionally leads to a violation of magnetic symmetry.

This also results in a change in electromagnetic parameters, mainly due to their uneven distribution in phases and around the circumference of the stator [7].

In terms of breaking electrical symmetry, first of all, it is necessary to take into account possible changes in the parameters of the windings, in particular, their electrical resistance $R_i$, arising from the variation in turns number $W_i$ in case of incorrect structural modifications or partial damage, as well as a change in the stator winding maximum temperature $\theta_i$, due to uneven conditions of its heating along the length [8].

Such changes can be taken into account comprehensively only with the correct choice of identification methods and models.

In practice, various groups of methods are used to identify IM parameters. The following should be singled out of them first of all:

– algebraic methods, based on calculations, various types of approximation and interpolation of theoretically or experimentally obtained data, for example [9–13];

– calculation methods that imply obtaining electromagnetic parameters as a result of modeling certain modes of IM operation with or without taking into account the influence of additional phenomena, such as the effect of current displacement in the rotor, saturation of the magnetic system, etc., as shown in [14–19];

– experimental methods, involving the determination of the required parameters as a result of various types of tests of IMs and/or their structural units, based on the results of measurements of integral and / or instantaneous values of a number of electrical and mechanical parameters, such as [20–24];

– predictive intelligent and/or adaptive methods that allow taking into account complex implicit relationships between IM parameters, as systems with cross-feedback, and respond to changes in a number of electromagnetic parameters over time, both due to the effect of heating, and during their redistribution under different operating modes, and control methods [25–31].

The results of the analysis of the above mentioned groups of methods in terms of solving the problem are presented in Table 1.

As follows from the analysis, to solve the problem, taking into account the uncertainty of the initial state of the magnetic system of the drive IM of pumping and ventilating equipment, preference should be given to combined adaptive methods. This approach allows automatically correct or redefine electromagnetic parameters as part of a variable-frequency electric drive in the simplest modes of its operation without additional expansion of the functionality of the information-measuring system implemented in it.

At the same time, a large amount of necessary calculations requires a significant simplification of the models at the stage of practical implementation.

In this formulation, the task can be solved based on typical frequency converters of leading manufacturers due to the presence of the option of adaptation to the parameters of the drive motor.

This function is used to improve the quality of regulation, ensuring the optimization of certain parameters while protecting against the excess of negative factors such as temperature, overvoltage, etc.

IM main parameters, relative to which calculations are performed and indirect measurements are carried out as part of typical FC, include their nameplate data: rated power $P_{2n}$ on the shaft, rated voltage $U_{1n}$ and stator current $I_{1n}$, efficiency $\eta$ etc., as well as a number of electromagnetic parameters of the equivalent circuit, such as resistance $R_1$ and complete $L_1$ inductance, which is for IM the sum of inductances of leakage $L_{s1}$ and magnetizing $L_\mu$ circuit.

The main disadvantage in the implementation of this approach is the practical lack of information on the methods for calculating electromagnetic parameters embedded in the calculators of each separate series of industrial frequency converters.

Table 1. Results of comparative analysis of groups of methods for identifying IM parameters

| Group name | Determined parameters, accuracy of their determination | Advantages of the methods | Drawbacks of the methods |
|---|---|---|---|
| Algebraic methods | Separate parameters of the stator and/or rotor, as well as their groups, 3–7% depending on the power and type of IM | – high accuracy of calculation | – the complexity of accounting for structural changes in IM;<br>– low flexibility and practicality in use;<br>– the need for a large amount of initial information |
| Calculation methods | All parameters, 9–15%, depending on the degree of AP wear | – high functionality;<br>– the possibility to determine the parameters of non-serial IM | – inability to take into account changes in parameters in different operating modes;<br>– low identification accuracy |
| Experimental methods | Separate parameters and/or their groups, 3–15% | – the ability to directly determine the parameters of IM with structural defects | – the need for complex types of tests, including ones under load;<br>– the complexity of accounting for parameters in non-stationary modes;<br>– high requirements for the information content and accuracy of the measuring system |
| Predictive intelligent and/or adaptive methods | All parameters, 7–9% | – flexibility and self-adaptability for various standard versions of serial IM | – a large amount of required calculations;<br>– additional requirements for the volume, reliability and versatility of training samples when using intelligent approaches |

It should also be noted that there is often no practical possibility of correcting the value of the rated shaft power $P_{2n}$ outside the standard range of powers. This can both determine the relative binding of calculations to certain IM catalog data, and limit the calculated adaptation zone in the used methods.

**Experimental research**

The obtained results were tested on IM of a Wilo TOP-S 50/10 pump, operated in a centralized heating system for five years with one major overhaul, powered by a VLT Micro Drive FC-51 made by Danfoss.

The main functions of the pump in this case include ensuring the necessary circulation of the heat carrier in the internal heat supply system of a multi-storey residential building.

This process includes regular dynamic transitions between static modes with different heating temperatures. The parameters of such transitions (limiting temperature difference, heating and cooling rate of the heat carrier, etc.) are regulated by the existing requirements for meeting the sanitary and hygienic norms and standards that limit the permissible temperature change from the standpoint of ensuring the strength of building structures.

In addition, with an intensive consumption of the heat carrier from the supply line, which is typical for low ambient temperatures and the limiting operating modes of heat supply organizations, the pump must compensate for the pressure drop on side of the heat carrier supply.

Thus, the main tasks of the pump include maintaining the hydraulic parameters of the internal centralized heating system (discharge and pressure) when they change in accordance with the time schedule.

This problem is rather effectively solved in the system of a variable-frequency electric drive of the pump, supplied with technological pressure feedback.

However, to ensure the required performance indicators of the system in transient modes, it is necessary to accurately set and determine the electromagnetic parameters of the drive IM.

In this case, it is necessary to take into account the changes in the parameters due to long-term operation and repair of the driven IM of the circulation pump. As shown above, the complexity of this process consists in the need for a comprehensive assessment of changes in the current state of all basic design parameters and elements, including laminated electrical steel. The task was further complicated by the somewhat limited functionality of the VLT Micro Drive FC-51 in terms of the ability to take into account all changed parameters.

The special features of such frequency converters include the availability of a measuring system for phase currents $I_a, I_b, I_c$ and voltages $U_a, U_b, U_c$ of the stator, as well as consumed active power $P_1$, energy $W_1$, efficiency $\eta$ and $\cos\varphi$ of power with the implemented function of indirect determination of the drive motor rotation frequency $n$.

At the same time, the functions of entering nameplate data and basic electromagnetic parameters in the formats corresponding to the above, as well as the automatic motor adaptation (AMA) function, are available for adjustment. The latter makes it possible to refine the electromagnetic parameters based on the results of control measurements with a locked and rotating rotor

As the research has shown, the best results in terms of redetermination of the parameters can be obtained with preliminary manual assignment of refined nameplate data ($I_{1n}$) and electromagnetic parameters ($R_1$, $L_1$), calculated according to [7].

The phase-by-phase unbalance of the winding parameters at the level of 3.47 % observed in this case is the result of the aging of the IM structure and therefore was not assessed separately, but entered the specified parameters as a result of averaging.

To improve the accuracy of identification of the missing IM parameters, the efficiency of the use of the AMA function built into the converter was confirmed. At the same time, it was proved that the same procedures, carried out without taking into account the adjustment of preset parameters or without the AMA function, give significantly worse results in terms of solving the problem, not allowing implementing the necessary quality indicators of transient control in a closed-loop system with technological feedback, as Fig. 1 demonstrates.

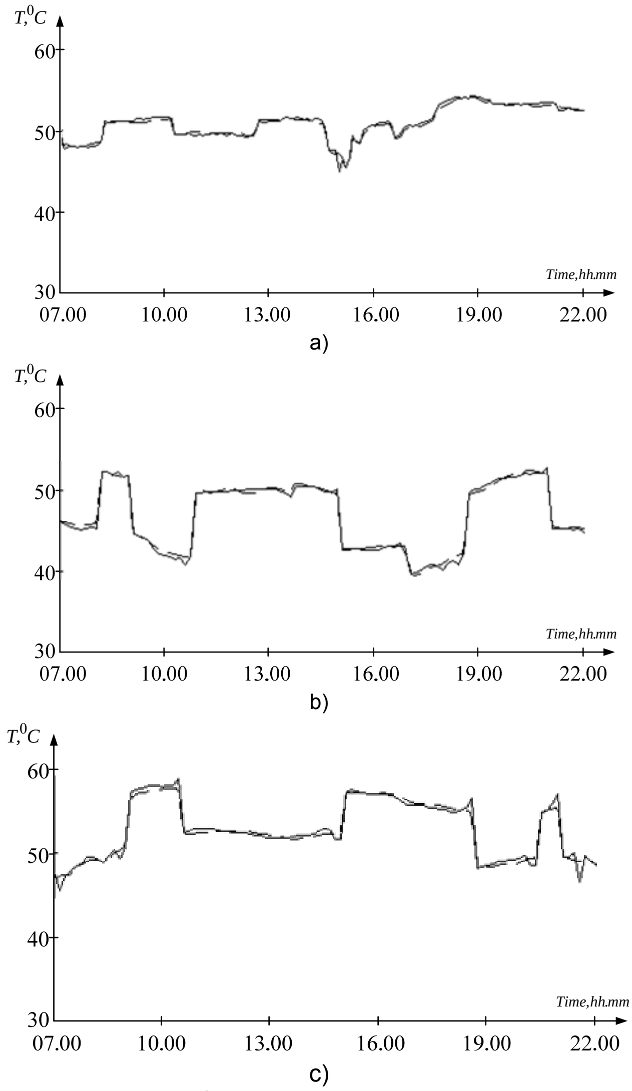


Fig. 1. The graphs of changes in the controlled parameters when setting and stabilizing the temperature of the heat flow of the Wilo TOP S 50/10 pump with VLT Micro Drive FC-51: a) setting parameter change with AMA function; b) setting parameter change without AMA function; c) preservation of original parameters with AMA function (dashed line – setting the parameter, solid line – the results of its processing)

In addition, the proposed modification of the parameter identification method allows increasing the operating values of $\eta$ and $\cos\varphi$ within the ranges of 2.73–4.13 % and 4.47–6.28 % respectively, more efficiently providing the function of the control of the excess of the stator winding temperature by the maximum value of its current.

**Conclusions**

1. A method for taking into account changes in the properties of structural units and elements of induction motors used in heat and water supply and ventilation

systems controlled by a variable-frequency electric drive with a closed technological feedback has been substantiated.

2. The effectiveness of the proposed solutions for improving the accuracy of identification of the main parameters, increasing energy efficiency and providing the necessary quality indicators for the regulation of induction motors of industrial mechanisms with a high mean-time-between-failure has been confirmed.

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