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Solving optimization problems in steady operation of regulated asynchronous motor

Abstract. *This article provides information on how to solve complex problems arising in the design of a variable two-rotor asynchronous motor, and their usefulness for creating optimal engine operating modes, the role of engine characteristics in the stable operation of the machine in various modes: long-term, short-term, repetitive short-term and in mainly when braking. The control system for electrical machines ensures optimal operation of electrical machines, increases productivity, reduces the cost of products and improves their quality. The choice of one or another criterion for an optimal parametric design is considered one of the most important issues, depending on the requirements for the machine when solving a particular problem.As a result of solving the problem of optimizing losses in the IM, according to the proposed conductivity ratio, the dependence of the supply frequency was obtained networks from slipping, according to the condition of minimum losses in stator and rotor windings. The double-rotor IM under study will operate with minimal losses if you change the amplitude of the supply voltage so that so that the blood pressure slip is equal to the calculated value s = 0.06 at a frequency of 50 Hz. The method proposed in the work allows, when regulating the engine speed, to reduce active power losses by 3-5% in the motor windings.*

Streszczenie. *W artykule przedstawiono informacje dotyczące rozwiązywania złożonych problemów napotykanych przy projektowaniu dwuwirnikowego silnika indukcyjnego o zmiennej prędkości obrotowej i ich przydatności w tworzeniu optymalnych warunków pracy silnika, roli charakterystyk silnika w stabilnej pracy maszyny w różnych trybach: ciągłym , krótkotrwałe, powtarzające się krótkotrwałe i głównie podczas hamowania.System sterowania maszynami elektrycznymi zapewnia optymalną pracę maszyn elektrycznych, zwiększa wydajność pracy, obniża koszty produktów i poprawia ich jakość. Wybór jednego lub drugiego kryterium optymalnego projektu parametrycznego jest uważany za jedną z najważniejszych kwestii, w zależności od wymagań stawianych maszynie przy rozwiązywaniu konkretnego problemu. W wyniku rozwiązania problemu optymalizacji strat w IM, wykorzystując zaproponowany stosunek przewodności, uzyskano zależność częstotliwości sieci zasilającej od poślizgu, zgodnie z warunkiem minimalnych strat w uzwojeniach stojana i wirnika. Badany IM dwuwirnikowy będzie pracował z minimalnymi stratami, jeżeli zmienimy amplitudę napięcia zasilania tak, aby poślizg IM był równy obliczonej wartości s=0,06 przy częstotliwości 50 Hz. Zaproponowana w pracy metoda pozwala przy regulacji prędkości obrotowej silnika ograniczyć straty mocy czynnej w uzwojeniach silnika o 3-5%.* (***Rozwiązywanie problemów optymalizacyjnych w pracy ustalonej regulowanego silnika asynchr***onicznego)

Key words: asynchronous motor, adjustable, resistance, additional resistance, optimal solution, two-rotor, Gradient method.
Słowa kluczowe: silnik asynchroniczny, regulowany, rezystancja, rezystancja dodatkowa, rozwiązanie optymalne.

Introduction

The question of improving the static and dynamic parameters of electrical systems of control and regulation of electrical machines participating in the technological process was relevant throughout the history of the development of the theory of automatic control and was solved in different ways.

Engine speed, torque, shaft rotation angle, transmission speed can be adjusted. The main exciting effect is the load moment on the engine shaft. Deviations of network voltage, changes in parameters and characteristics of system elements, etc. can have an excitatory action [1].

Asynchronous electric transmission with adjustable speed uses available energy indicators to evaluate energy efficiency, which are divided into two groups. The first group includes indicators characterizing the operation of an asynchronous motor (AM). It includes full, active and reactive power, which can be used as a consumer of electricity. Indicators characterizing the operation of the engine as an energy converter belong to the second group, which should include: efficiency, power factor, power losses. Considering the listed indicators - parameters (amplitude and frequency) as a function of purposeful adjustment, we can talk about the presence of maximum or minimum points of these functions, which are indicators of the quality of work. The necessary target functions can be determined from the listed quality indicators of the frequency-regulated asynchronous electric transmission, and there is also a need to apply new indicators to solve optimization tasks [2 -5].

The purpose of the work is to formulate the basic principle of the optimal current frequency and control the operation mode of the machine in accordance with the criterion of energy saving. To achieve the goal, it is necessary to determine the control method, the use of which will allow to optimize the mode of operation of the engine according to the criterion of minimal losses. During the study of the dependence of the active and reactive components of the phase currents AM, the law of frequency regulation was adopted in the design of an asynchronous electric motor, which can be used by construction organizations to select shift functions.

Modes of operation of electric motors are characterized by a certain sequence of cycles:

duration and size of load;

cooling conditions;

the frequency of switching on and off;

reverse frequency;

Loss ratios in periods of constant movement and start-up.

Since there are many modes, it is impossible to make engines for each of them, so serial engines are designed to work in eight nominal modes according to the standard. Nominal data are available in the engine passport. Optimum operation of the unit is guaranteed when operating under nominal load and nominal mode.

Basic modes of operation of electric motors [6].

There are three main (long-term, short-term, intermittent) and five additional modes of operation, conditionally designated according to the international classification S1-S8. Domestic electrotechnical plants are obliged to enter nominal data for the main modes in the catalogs and passports of the unit.

The continuous mode (S1) provides long and continuous operation, during which the engine warms up to a constant temperature. It can be divided into two types:

Constant load mode (without temperature change during operation). It contains electric drives of conveyor engines, ventilators and pumps.

Variable load mode (the temperature rises or falls when the load changes). It is used when working with metal-cutting, woodworking and rolling machines.

The short-time operation mode of the electric motor (C2) is characterized by a short period of operation (norms 10, 30, 60, 90 minutes) without heating the engine to a constant temperature with subsequent cooling during the break. In this mode, electric drives of locking devices (valves, gates, shock absorbers, etc.) work. The duration of the working cycle is indicated in the engine passport (for example, S2 – 60 minutes).

Intermittent short-term operation mode (S3) of the electric motor is a mode in which the heating of the engine does not reach a constant temperature during operation and does not cool down to the ambient temperature during the break. It is characterized by a continuous change of the working cycle in the load and idling mode. That's how electric drives of cranes, excavators and elevators work. e. devices of cyclic action [7-11].

Additional modes of operation of electric motors.

Additional modes are indicated by markers S4-S8. They are introduced as a more convenient equivalent of arbitrary modes and for expanding the range of nominal modes.

S4 – intermediate mode under the influence of initial processes. Each working cycle includes:
- a long start-up period, the start-up losses of which affect the temperature of the components of the unit;
- duration of work under constant load without heating to constant temperature;
- a break during which the engine does not cool down to the ambient temperature [12].

S5 – intermediate mode with electric brake. The working cycle includes:
- long-term start-up time;
- duration of work under constant load without heating to constant temperature;
- the cycle of rapid electric braking;
- idle time without cooling to ambient temperature.

S6 – intermittent mode of operation. The working cycle consists of:
- working time with permanent load;
- it breaks.

In both periods, the engine temperature does not reach a constant value.

S7 – intermediate mode with the effect of electric braking and starting processes. Each cycle includes:
- long period of start-up;
- duration of operation of the machine with constant load;
- quick electric brake.

This mode does not allow interruptions.

S8 – intermediate mode with different rotation speeds (2 or more). The period includes the following periods:
- work with constant speed and constant load;
- works on other fixed loads, and each of them corresponds to a certain speed of rotation.

As in the previous mode, there are no interruptions in this mode.

Despite the simplicity of the design, when designing a two-rotor asynchronous motor of adjustable type, it is necessary to solve many complex and contradictory issues, to create an accurate provision of operational characteristics and technical and economic indicators. The functional dependence of initial data and geometric dimensions on magnetic, electrical, thermal and mechanical parameters must be applied when designing and reporting each electric machine. Usually, parameter binding expressions are complex and involve relationships with a large number of second-order parameters. To simplify these relations, it is necessary to carry out a number of transformations over the obtained basic expressions. In this regard, there is a need to establish basic stable functional relationships between the initial data and geometric measurements.

Relevance

As a result, functional connections between fixed data and parameters of a short-circuited asynchronous motor make it possible to obtain the following [1, 2]:
- make a more reasonable selection of basic parameters;
- the possibility of transition from separate thermal and electromagnetic reports to the general solution of problems;
- departure from calculation tools with time-consuming methods of successive approximation;
- to minimize the influence of subjective factors;
- to estimate the basic parameters of AM at the initial stages of the project;
- to make the basis of the optimization of the adjustable two-rotor AM of the new design.

The problem is the goal

The process of optimization generally begins with the selection of constraints on variables and optimization criteria. This, in turn, requires highlighting some features in the design of this construction [3, 4].

Below are the main characteristics of a short-circuited two-rotor asynchronous motor, which is involved in the control of rotating mechanisms:
- the possibility of saving engine power when expanding the adjustment range;
- compliance of the necessary characteristics with the norms in the dynamic modes of engine operation (braking and repeated short-term braking);
- obtaining the maximum long-term operation of the engine in the mode of static load.

When optimizing an asynchronous machine, the optimization criteria are considered:

Maximum stable current maintenance regardless of load.

Minimization of mass, cost, dimensions, loss of power.

Maximization of the cooling system, linearity of static characteristics, operational reliability in all modes of operation of the machine.

The choice of one or another criterion for optimal parametric design depends mainly on the requirements for the machine when solving one or another task [5, 6].

In general, the formulation of the task for the optimal parametric project is as follows: it is required to find the optimal point a^* from the set of optimal variable parameters $(a_1^*, a_2^*, \dots, a_n^*)$ according to the criteria selected as a result of the preliminary expert evaluation analysis. This point is determined by the maximum and minimum values of D_a, M and J within the permissible limits. It determines the (maximum and minimum) value of the criterion of optimality $J\{a^*(r_2'),\ a^*(M),\ a^*(D_a)\}$ in the solution area of the given optimal point. Therefore, it is important to,

$$J\{a^*(r_2'),\ a^*(M),\ a^*(D_a)\} = \text{optimal}; \quad J \in [J_{min}, J_{max}].$$

$$M\{\ a^*(s_{kr}),\ a^*(D_a),\ a^*(J)\} = \text{optimal}; \quad M \in [M_{min}, M_{max}].$$

$$D_a\{\ a^*(\ J),\ a^*(r_2'),\ a^*(M)\} = \text{optimal}; \quad D_a \in [D_{a\,min}, D_{a\,max}].$$

$J \in [J_{min}, J_{max}]$, $M \in [M_{min}, M_{max}]$, $D_a \in [D_{a\,min}, D_{a\,max}]$ – are the minimum and maximum values of input parameters.

Solving the problem

The optimal solution of the specified task is considered the main subject of nonlinear mathematical programming. Multiple methods can be used to solve this problem: Gauss-Seidel, Posenbrok, Hook, Sieves, etc. d. But the gradient method is more effective and effective when optimizing the engine. The gradient method is a fast and time-consuming method with the possibility of obtaining locally optimal results. As you know, the basis of the classification of nonlinear mathematical methods is the search for information and the optimal solution. The solution of the latter leads to the calculation of the derivative criterion of optimality $J\{a^*(r_2^{\prime}),\ a^*(\mathrm{M}),\ a^*(D_ə)\}$ = optimal $(r_2^{\prime})$ according to the variable parameter [7, 8]. Then:

$r_{qq} \in [r_{qq\ min},\ r_{qq\ max}],\ r_2 \in [r_{min},\ r_{max}]$.

In zero-sequence methods, such calculation of the derivative is not required, and the following methods include: Gauss-Seidel, fast copying, parallels; Rosenbrock, Hook and Sieves, relaxation and search for coincidences. The method in the first sequence is based on the calculation of the first derivatives. Among them, the most common are the gradient method - rapid descent of paired gradients, the Polak method and the projection of the gradient vector. In methods of the second order, it is necessary to calculate the second derivatives of the parameters of the parameters. The listed methods are generally considered to be variations of Newton's method. It should be noted that the gradient vector projection method is used when solving conditional parametric optimization problems. Other methods are used to solve problems of unconditional parametric optimization. But the latter can be reduced to priority issues. For such variability in practice, the penalty function method is usually used [9].

The gradient method is more effective in solving optimization tasks of an asynchronous motor with a short-circuited rotor. The gradient method is considered a method for searching for a local optimum. The strategy of the gradient method is based on the search for an optimal solution in a faster time. However, the sensitivity analysis is not applicable for all stages of determining the direction of the gradient search. Preimushestvenno at the point of initial convergence to small values of the criterion of optimization, t.e. в точке rn, M_n, D_n – а не в точке rn-1, M_n-1, D_n-1. In this case, the n+1 st search step will be determined according to the above expression [13-14].

The effectiveness of the adjustable two-rotor AM is in the ability to stably preserve the stability of the rotating mechanisms depending on the operating modes. This type of engine is designed for different operating modes of the mechanism. That is, in each mode of operation (long-term, short-term, repeatedly short-term, braking), the machine must work in a stationary state. We note that in certain cases the usefulness of the engine is based on higher indicators. For example, engine control in braking mode (in the case of s>1) is carried out according to the same scheme as in reverse mode. It is necessary to change the direction of the rotating field so that the car goes into braking mode. If the braking mode is used to stop the engine for a short period of time, then the stability of this mode is not important. There are certain cases when the machine must work in braking mode for a long time (for example, when the crane is the working mechanism). At this time, the presence of additional active resistance in the rotor circuit is necessary for the operation of AM to be absolutely stable.

İn Figure 1. presents the curves $M=f(s)$: 1 – the case with the usual resistance $r_2^{\prime}$ of the rotor winding, 2 – the case of additional resistance (introduced into the stator winding) in the rotor circuit $(r_2^{\prime}+r_{ə}^{\prime})$; where the curve $M_{st}=f(s)$ of the lifting crane is also shown. Thus, with large values of $r_2^{\prime}$ - the dependence $M=f(s)$ is stable in the braking mode and $(dM_{st})/d_s<dM/d_s$. Thus, in order for the engine to have a stable mode of operation in braking mode, a high-resistance relay should be added. As a result, the magnitude of the current in the winding of the rotor and stator will decrease, the performance of the engine will be high.

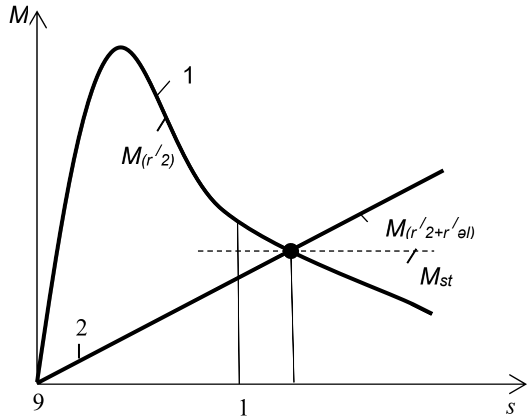

Fig. 1. Steady operation of the car in braking mode

Conclusions

Knowing the characteristics of the starting characteristics of the machine, it is still possible to determine the efficiency of the new design. The starting characteristics of asynchronous motors with a short-circuited rotor (the presence of a large moment and small currents) recommend the operation of the presented AM in short-term and repeatedly short-term modes. In the long-term mode, due to a short circuit with a slightly increased active resistance, the increase in power losses ΔP_2 and the occurrence of overheating can be considered a disadvantage of this type of engine. However, the presence of a constant high level of ventilation (cooling system) inside the engine due to the second rotor eliminates this deficiency and makes the engine work reliable and stable.

Thus, on the basis of the presented studies, the new design of the machine proves the possibility of working in various modes, increasing the productivity of the short-circuit AM and increasing its usefulness.

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