Determination of electromagnetic parameters for improvement of efficiency of special electric drives

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Abstract. The research of electromagnetic parameters for improvement of efficiency of special electric drives is presented in article. The analysis of the received results was carried out. An object of a research were special electric drives with asynchronous motors of cylindrical construction. The studied special electric actuators possess improved mass-dimensional and power indicators due to constructional features and the used control systems. For different industries application of electric actuators with the seized characteristics is a relevant task. For modeling and design of special electric drives it is necessary to create new approaches for determination of electromagnetic parameters or to make significant correction of the existing approaches. On the basis of the offered mathematical model of the electromagnetic system presented in the form of set of electromagnets parameters of the studied electric drives were determined electromagnetic. The analysis of the conducted research shows that the received solution will allow to improve efficiency of the special electric drives used in difficult technological processes of different industries.

1. Introduction
Development of modern technologies in heavy mechanical engineering [1-2], the electric transport [3-4], oil and gas [5-6], steelmaking [7-8], mountain [9-10], pulp-and-paper, easy, textile and other industries [11-12] leads to toughening of production and technical requirements [13] to different mechanisms [14] and the equipment [15-16], their upgrade [17] and creation new [18-19]. Such requirements are imposed also by an electric drives of industrial mechanisms [20-21]. New electric drives should carry out the set technological parameters, technical and economic and mass-dimensional indicators and provide the minimum consumption of electrical energy [22-23]. Standard single-engine electric drives can not always provide everything the criteria of efficiency stated above. The applied modern control devices and automation solve only a part of problems. Application of special electric drives will allow to solve the specified technical and technological problems.

Mathematical modeling, design and creation of special types of electric drives [24] demands significant correction of the existing methods of calculation or creation of new approaches [25-26] with development of elements of an automated design engineering system [27-28].

2. Determination of electromagnetic parameters for improvement of efficiency of special electric drives
The problem of determination of electromagnetic parameters of special electric drives is solved with application of methods of electromagnetic transformation of energy, the law of Ohm for a magnetic
chain and the principle of imposing. Such approach allows to receive analytical expressions for finding of magnetic resistance of the studied special electric drives.

On the example of mathematical model of the operated cascade asynchronous electric drive with motors of low power analytical expressions of magnetic resistance of the set sites of an electromagnetic system are received. The magnetic flux is equal:

\[ \Phi = \frac{Iw}{R_{\mu}} \]

where \( \Phi \) – magnetic flux of the electric motor; \( I \) – the current proceeding on the stator; \( w \) – number of rounds of the coil or winding; \( R_{\mu} \) – magnetic resistance electric motor.

Magnetic resistance is equal:

\[ R_{\mu} = \frac{1}{G_{\mu}} = \frac{1}{\mu_0 \mu S}, \]

where \( G_{\mu} \) – magnetic conductance; \( l \) – length of the power line on the site; \( S \) – the area through which the magnetic flux proceeds; \( \mu \) – magnetic permeability of this site; \( \mu_0 \) – relative magnetic permeability.

The value of magnetic resistance on section of a yoke of the stator is equal:

\[ R_s = \frac{\pi D_{md}s + 2D_{md}s - D - 2h_{ts}}{2 \mu_0 \mu D_s - D - 2h_{ts} l_\delta}. \]

where \( D \) – inside diameter of the stator; \( D_{md}s \) – the average length of the power magnetic line; \( D_s \) – the outer diameter of the stator; \( l_\delta \) – the computational length of a magnetic conductor; \( h_{ts} \) – stator tooth height; \( p \) – number of poles. \( R_s = 73440 \text{Ohm} \).

Magnetic resistance of section of a tooth part of the stator is equal:

\[ R_{ts} = \frac{2h_{ts}}{\mu_0 \mu b_{ts} y l_\delta}. \]

where \( b_{ts} \) – stator tooth width; \( y \) – number of teeth on the coil (winding step).

Results of calculation of magnetic resistances of section of a tooth part of the stator for different angle of rotation are presented in Table 1.

**Table 1.** Magnetic resistance of a tooth part of the stator

| R_{ts} | Angle of rotation ° |
|--------|---------------------|
| [Ohm] | 0  | 2α | 3α | 4α | 5α | 6α | 7α | 8α | 9α | 10α |
| 1     | 4627 | 4639 | 4639 | 4631 | 4643 | 4651 | 4639 | 4615 | 4655 | 4607 | 4627 |
| 2     | 4631 | 4635 | 4635 | 4631 | 4643 | 4651 | 4639 | 4615 | 4655 | 4651 | 4631 |
| 3     | 4627 | 4696 | 4815 | 4627 | 4651 | 4655 | 4635 | 4651 | 4651 | 4651 | 4627 |
| 4     | 4631 | 4635 | 4635 | 4631 | 4643 | 4651 | 4639 | 4615 | 4655 | 4815 | 4631 |
| 5     | 4611 | 4631 | 4623 | 431 | 4651 | 4651 | 4802 | 4561 | 4651 | 4651 | 4611 |
| 6     | 4643 | 4631 | 4631 | 4815 | 4767 | 4651 | 4647 | 4655 | 4651 | 4651 | 4643 |
| 7     | 4734 | 4806 | 4631 | 4659 | 4655 | 4755 | 4635 | 4655 | 4651 | 4651 | 4734 |
| 8     | 4627 | 4639 | 4627 | 4639 | 4651 | 4655 | 4639 | 468 | 4815 | 4647 | 4627 |
| 9     | 4635 | 4639 | 4635 | 4643 | 4659 | 4815 | 4643 | 4667 | 4651 | 4659 | 4635 |

Magnetic resistance of air gap is equal:
\[ R_s = \frac{2\delta}{\mu_0 h_y y l_{s}}. \]  

(5)

where \( \delta \) – stator tooth width.

Results of calculation of magnetic resistances of air gap for different angle of rotation are presented in Table 2.

**Table 2.** Magnetic resistance of air gap

| \( R_s \) [Ohm] | Angle of rotation ° |
|-----------------|---------------------|
| 0 | α | 2α | 3α | 4α | 5α | 6α | 7α | 8α | 9α | 10α |
| 1 | 505400 | 506800 | 505900 | 507200 | 508100 | 508500 | 508500 | 503300 | 505400 |
| 2 | 505900 | 506300 | 506300 | 505900 | 526000 | 526000 | 505400 | 509400 | 508100 | 508100 |
| 3 | 505400 | 513000 | 526000 | 505400 | 508100 | 508500 | 50630 | 508100 | 508100 | 505400 |
| 4 | 505900 | 506300 | 507200 | 505900 | 508100 | 508100 | 505900 | 508100 | 508500 | 526000 |
| 5 | 503700 | 505900 | 505000 | 505900 | 508100 | 508100 | 524600 | 508100 | 508100 | 503700 |
| 6 | 507200 | 505900 | 505900 | 526000 | 520800 | 508100 | 507600 | 508500 | 508100 | 507200 |
| 7 | 517100 | 525000 | 505900 | 509000 | 508500 | 519400 | 506300 | 508500 | 508100 | 517100 |
| 8 | 505400 | 506800 | 505400 | 506800 | 508100 | 508500 | 508600 | 511200 | 526000 | 507600 |
| 9 | 506300 | 506800 | 506300 | 507200 | 509000 | 526000 | 507200 | 509000 | 508100 | 506300 |

Magnetic resistance of a tooth part of a rotor is equal:

\[ R_{t} = \frac{4p h_y}{\mu_0 \mu_r n_r \beta y l_{s}}. \]  

(6)

where \( n_r \) – number of teeth of a rotor; \( \beta \) – relative step of a winding; \( h_y \) – rotor tooth height; \( b_y \) – rotor tooth width.

Results of calculation of magnetic resistances of a tooth part of a rotor for different angle of rotation are presented in Table 3.

**Table 3.** Magnetic resistance of a tooth part of a rotor

| \( R_t \) [Ohm] | Angle of rotation ° |
|-----------------|---------------------|
| 0 | α | 2α | 3α | 4α | 5α | 6α | 7α | 8α | 9α | 10α |
| 1 | 2432 | 2858 | 3455 | 4376 | 5949 | 9286 | 21600 | 1866 | 1866 | 2111 |
| 2 | 2611 | 2608 | 2608 | 2608 | 2595 | 2595 | 2241 | 1977 | 2423 | 2598 |
| 3 | 2611 | 2700 | 2322 | 2034 | 1866 | 1866 | 2063 | 2598 | 2598 | 2598 |
| 4 | 2094 | 1866 | 1866 | 2008 | 2275 | 2641 | 2608 | 2598 | 2598 | 2094 |
| 5 | 1955 | 2212 | 2562 | 2611 | 2598 | 2598 | 2598 | 2598 | 2598 | 2094 |
| 6 | 2618 | 2608 | 2608 | 2604 | 2595 | 2595 | 2595 | 2598 | 2598 | 2598 |
| 7 | 2611 | 2608 | 2611 | 2562 | 2207 | 1945 | 1866 | 2598 | 2598 | 2611 |
| 8 | 2655 | 2283 | 2004 | 1866 | 1866 | 2081 | 2389 | 2598 | 2598 | 2655 |
| 9 | 1866 | 1866 | 2034 | 2316 | 26900 | 2598 | 2598 | 2598 | 2598 | 2655 |
| 10 | 2245 | 2601 | 2614 | 2618 | 2598 | 2598 | 2598 | 2598 | 2598 | 2245 |
| 11 | 2611 | 2608 | 2585 | 2611 | 2628 | 2423 | 2118 | 2174 | 2506 | 2611 |
| 12 | 36200 | 29700 | 2518 | 2181 | 19200 | 1866 | 1923 | 10580 | 6434 | 36200 |

Magnetic resistance of a yoke of a rotor is equal:
\[
R_c = 2\frac{\pi D_{md} + d - 2h_c - D_{sh}}{\mu_0 \mu (d - 2h_c - d_{sh})}.
\]

where \(d_{sh}\) – diameter of a shaft; \(d\) – diameter of a rotor. \(R_c = 3556 \text{Ohm}\)

Results of calculation of a magnetic flux from one coil group for different angle of rotation are presented in Table 4.

**Table 4. Magnetic flux from one coil group**

| \(\Phi_{cg} \) [Weber] | Angle of rotation ° | 0 | 2° | 3° | 4° | 5° |
|------------------------|---------------------|----|----|----|----|----|
|                        | \(6\alpha\)         | 1.046 \times 10^{-4} | 1.041 \times 10^{-4} | 1.043 \times 10^{-4} | 1.042 \times 10^{-4} | 1.035 \times 10^{-4} | 1.027 \times 10^{-4} |
|                        | \(7\alpha\)         | 1.014 \times 10^{-4} | 1.029 \times 10^{-4} | 1.036 \times 10^{-4} | 1.037 \times 10^{-4} | 1.045 \times 10^{-4} |

Calculations on formulas (1-7) can be made for any angle of rotation of a rotor concerning the stator and for any timepoint of turn of a three-phase system of tension. It allows to define values of instant effort on a shaft of the drive and the corresponding instant moment operating on a shaft for a whole turn of a rotor concerning the stator of special electric drives. For more exact determination of these parameters it is necessary to know a picture of real value of a magnetic flux for determination of value of the maximum magnetic flux density. In Figures 1 – 4 pictures of real distribution of the magnetic flux received as a result of work of own software products are presented.

**Figure 1. Distribution of an electromagnetic field at turn of a three-phase system on angle \(\alpha = 0^\circ\).**
Figure 2. Distribution of an electromagnetic field at turn of a three-phase system on angle $\alpha = 1.8^\circ$.

Figure 3. Distribution of an electromagnetic field at turn of a three-phase system on angle $\alpha = 9^\circ$.

Figure 4. Distribution of an electromagnetic field at turn of a three-phase system on angle $\alpha = 23.4^\circ$. 
3. Conclusion
The carried-out analysis showed that to carry out determination of electromagnetic parameters of special electric drives with asynchronous motors of cylindrical construction by the most reasonable using methods of electromagnetic conversion of energy, the law of Ohm for the magnetic circuit and the principle of imposing giving good coincidence of calculation to experimental data. The conducted research allows to determine quite precisely parameters of an electromagnetic system, both in a statics, and in dynamics. The developed software allows to define a picture of real value of a magnetic flux and value of the maximum magnetic flux density, necessary for calculation of force, the moment, electromechanical and mechanical characteristics. The received solution will allow to increase efficiency of special electric drives and to design electric drives with optimum mass-dimensional and power parameters for different industries.

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