LOSSES IN SHIELDS OF HERMETIC SYNCHRONOUS MOTOR EXCITED BY PERMANENT MAGNETS

Prof. Eng. **Tudor AMBROS,** Dr.Sc.[1], Lecturer **Marcel BURDUNIUC**[1]

[1]Technical University of Moldova, Chisinau

REZUMAT. S-au realizat cercetări teoretice şi experimentale în vederea obţinerii unor expresii analitice simplificate pentru calculul pierderilor din cilindrele motorului sincron ermetizat. Expresiile analitice obţinute cu admiterea unor simplificări justificate au permis calculul pierderile din cilindrul statoric inclusiv din părţile frontale ale cilindrului, cele rotorice fiind neglijate.

Cuvinte cheie: motor sincron, magneți, flux, inducție magnetică

ABSTRACT. Theoretical and experimental research was carried out to obtain some analytic simplified expressions for calculating the losses from the cylinders of the hermetic synchronous motor. The obtained analytical expressions allowed calculating the losses from the stator cylinder including the front cylinder parts, neglecting those from inside the rotor, and admitting some justified simplifications.

Keywords: synchronous motor, magnets, flow, magnetic inductance

1. INTRODUCTION

The electromagnetic excitation is repressed by permanent magnets in synchronous machines due to known reasons. Permanent magnets used for such purposes are solving, and, at the same time, imply new problems, such as: asynchronous start of synchronous motors; voltage control of generators, estimation of losses and other problems of constructive and technological aspects.

At the moment, centrifugal pumps driven by hermetic asynchronous motors are, usually, used for pumping aggressive liquids. The stator and rotor package with respective windings in these motors are protected by cylindrical shields manufactured from stainless steel of 0.3 – 0.5mm thickness. These cylinders are increasing the air gap up to 0.6 – 1mm, being manufactured from non-ferromagnetic material. The air gap increase leads to an essential reduction of power factor and increase of losses in cylinder shields.

The transformation of hermetic asynchronous motor into a synchronous one with permanent magnets contributes to the increase of power factor and efficiency. The losses in the rotor cylinder decrease simultaneously due to its synchronous rotation with the rotating magnetic field. It is important to mention, that in addition protection of magnets, the rotor cylinder assures rigid fixation of along rotor perimeter.

Elaboration of hermetic synchronous motor basing on serial production of hermetic asynchronous motor is described in paper [1]. In this case the short circuited of asynchronous motor is replaced with a ferromagnetic massive rotor, on which are mounted rotor poles from permanent magnets, comprised by the protection cylinder (fig. 1).

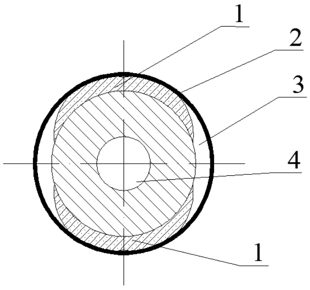


Fig. 1 Rotor of sectioned synchronous motor:
1) permanent magnets; 2) protection cylinder;
3) non-ferromagnetic material; 4) shaft.

The stator package remains unchanged from the geometrical point of view (fig. 2).

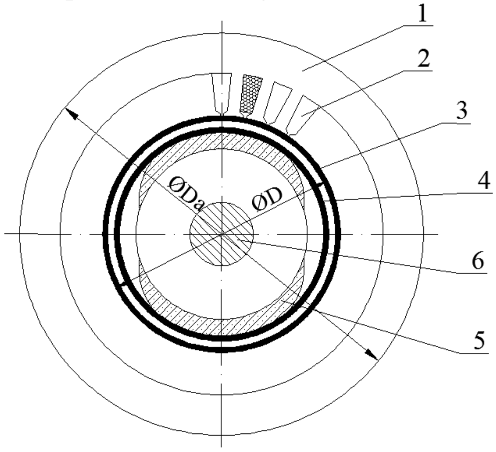


Fig. 2 Transversal section of the stator:
1) stator core; 2) stator slot;
3, 4) protection cylinders;
5) permanent magnets 6) shaft;

Three-phase stator winding can be replaced in some cases, optimizing the motor for reducing the copper consumption used for this winding.

2. ADOPTED ASSUMPTIONS

As it was mentioned above, the stator package and the winding are protected by a cylinder pressed on interior side of the stator, being, also, manufactured from stainless steel (fig. 2).

It follows from the above that the proposed motor is a hermetic synchronous motor and excited by permanent motors. These two constructive particularities influence electromagnetic processes in stationary and transitory regime.

Eddy currents from protection rotor cylinder increase the asynchronous start couple in asynchronous motor start of the synchronous motor, but in synchronous regime this couple becomes equal to zero. The cylinder mounted on the interior side of the stator is still in relation to the rotating magnetic field in stationary operating regime and plays the role of a stalled rotor, through which the eddy currents are closed. These currents provoke losses and contribute to efficiency reduction and motor warming.

Assumptions are adopted for determining the losses from stator still cylinder, which do not influence essentially the obtained results if applying the method proposed in this paper.

The magnetic inductance inside the air gap (fig. 3, a) excited by permanent magnets is considered to be sinusoidal taking into account the following reasons:

- harmonics of magnetic inductance of dental order are excluded from calculations, because the jagged stator package is replaced by a smooth one;
- harmonics of magnetic inductance of impair order are, also, excluded, because the geometry of permanent magnets and the value of magnetic inductance produced by these magnets are selected so that the curve of magnetic inductance inside the air gap would be sinusoidal;
- the component of magnetic inductance that corresponds to the reactive magnetic flow is, also, sinusoidal, because it is produced by the stator sinusoidal currents.

From this it follows that the maximum value along the axis of poles d is (fig. 3, a):

$$B_{m\delta} = \frac{\mu_0}{\delta' + \Delta c_1 + \Delta c_2} \cdot F_{m\delta} \qquad (1)$$

where $F_{m\delta}$ – the value of magnetic force created by permanent magnets;

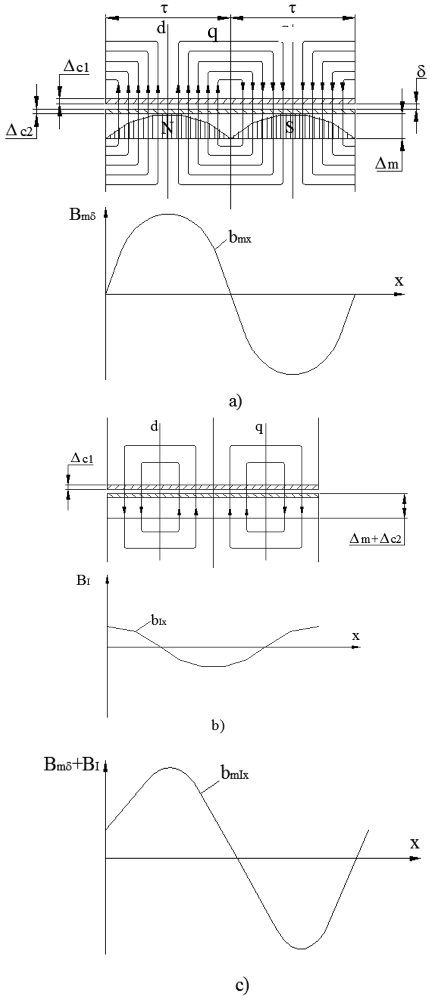
Δc_1, Δc_2 – thickness of protection cylinders.

If the reaction of the induced possesses active character, then the maximum value of magnetic inductance lays on q axis (fig. 3, b) and can be expressed as:

$$B_{mI} = \frac{\mu_0}{\delta' + \Delta c_1 + \Delta c_2 + \Delta_m} \cdot F_{mI} \qquad (2)$$

where F_{mI} – amplitude of magnetic force of reaction produced by stator currents;

Δ_m – thickness of permanent magnets.



a)

b)

c)

Fig. 3 Closing lines of magnetic flows and curves of magnetic inductance variation inside the air gap.

a) magnetic inductance flow and curve produced by permanent magnets;
b) flow of the induced for the active charge and the curve of magnetic inductance;
c) resulting magnetic inductance curve inside the air gap.

According to figure 3, the component of the curve of magnetic inductance variation inside the air gap b_{mx} and reaction of the induced b_{ix} can be written as:

$$b_{mx} = B_{m\delta} \cdot \sin\frac{\pi}{\tau} \cdot x \quad (3) \qquad b_{ix} = B_{mi} \cdot \cos\frac{\pi}{\tau} \cdot x, \quad (4)$$

and the resulting curve (fig. 3, c)

$$b_{mix} = b_{mx} + b_{ix} = B_{m\delta} \cdot \sin\frac{\pi}{\tau} \cdot x + B_{mi} \cdot \cos\frac{\pi}{\tau} \cdot x \qquad (5)$$

3. DETERMINATION OF LOSSES FROM STATOR CYLINDER

The losses from protection cylinders pressed on the stator and rotor in hermetic asynchronous motors of serial production consists about 25% of total loss. These losses are provoked by closed currents through both of protection cylinders. Losses from rotor cylinder are neglected in synchronous motor.

The second generalized Maxwell rule is applied fro determining the losses provoked by eddy currents inside the stator cylinder:

$$\left[\nabla \overline{E}\right] = -\frac{\partial \overline{B}}{dt} + \left[\nabla\left[v\overline{B}\right]\right] \qquad (6)$$

The first term from the right part of Maxwell equation represents the electromotive force, induced at the variation of magnetic inductance in time and is named as the force of transformation. This process occurs, for example, inside the windings and laminations of the magnetic system of transformers.

The second term corresponds to the movement of magnetic wave, named as motion, for example, inside the windings and laminations of the magnetic system of electric machines.

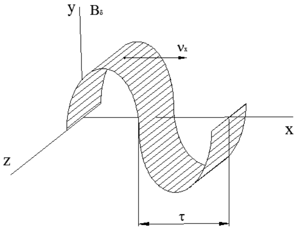


Fig. 4 Spatial wave of magnetic field

Equation (7) is applied as in transformers as in electric machines [2, 3]:

$$\left[\nabla E\right] = -\frac{\partial B}{dt}, \qquad (7)$$

which does not strictly and correctly correspond to the theory of rotating magnetic field.

It is known that if the magnetic field with a flow density B moves with a V speed in relation to environment, then the electromotive force appears inside the environment:

$$\overline{E} = \left[\overline{V}\overline{B}\right]. \qquad (8)$$

It means that:

$$\overline{V} \times \overline{B} = E\,. \qquad (9)$$

The multiplication between the V and B vectors can be expressed in a coordinate system x, y, z at sinusoidal variation of magnetic inductance inside the air gap of the electric machine:

$$\overline{E} = \begin{vmatrix} i & j & k \\ v_x & v_y & v_z \\ B_x & B_y & B_z \end{vmatrix} \qquad (10)$$

Of course, the rotating magnetic field possesses a single spatial motion direction (along x axis) (fig. 5), $V_y = V_z = 0$. Then:

$$\overline{E} = \begin{vmatrix} i & j & k \\ v_x & 0 & 0 \\ B_x & B_y & B_z \end{vmatrix} = k v_x B_y - j v_x B_z \qquad (11)$$

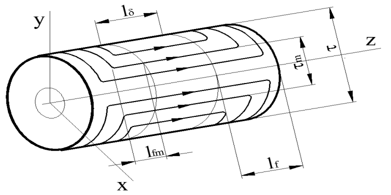


Fig. 5 Movement of magnetic field along x direction

The component of electromotive force induced in Δc_1 can be considered null, because cylinders' thickness c_1, Δc_2 is much smaller than the calculus length l_δ of stator package.

The magnetic field inside the air gap does not posses the component of magnetic inductance along z axis, as a result $B_z = 0$ and the expression (11) can be written as:

$$\overline{E} = k v_x B_y \qquad (12)$$

By multiplying the left and right part of the equation (12) by k one can obtain the following expression for the electromotive force induces inside the stator cylinder:

$$E = E_z = v_x B_y\,. \qquad (13)$$

It means that:

$$E_z = E_{c1} = v_x B_\delta\,. \qquad (14)$$

As B_y is the maximum value of magnetic inductance inside the air gap, we obtain:

$$E_{c1} = v_x B_{my} = v_x B_{m\delta}\,. \qquad (15)$$

Power losses in one volume unit are:

$$P_v = E^2 \gamma = E_{c1}^2 \cdot \gamma_{c1}\,. \qquad (16)$$

Considering that:

$$v_x = \omega R = \omega \frac{2\pi R}{2p\pi} = \omega \frac{\tau}{\pi}, \qquad (17)$$

and substituting (15) in (16) we obtain:

$$P_v = \left(v_x B_\delta\right)^2 \gamma_{c1} = \left(\frac{B_{m\delta}}{\sqrt{2}} \cdot \frac{\omega\tau}{\pi}\right)^2 \gamma_{c1}\,. \qquad (18)$$

If $\omega_1 = 2\pi f_1$, then the losses in one volume unit are considered to be:

$$P_v = 2B_{m\delta}^2 \cdot f_1^2 \cdot \tau^2 \cdot \gamma_{c1}\,. \qquad (19)$$

Power losses from cylinder volume V_{c1} covered by the stator package with $l_{c1} = l_\delta$ length can be written as:

$$P_{c1} = 2B_{\delta}^2 \cdot f_1^2 \cdot \tau^2 \cdot \gamma_{c1} \cdot V_{c1}, \tag{20}$$

where $V_{c1} = 2\tau \cdot l_{\delta} \cdot \Delta_{c1}$.

It follows that:

$$P_{c1} = 2B_{m\delta}^2 \cdot f_1^2 \cdot \tau^2 \cdot \gamma_{c1} \cdot 2\tau \cdot l_{\delta} \cdot \Delta_{c1} \tag{21}$$

or

$$P_{c1} = 4B_{m\delta}^2 \cdot f_1^2 \cdot \tau^3 \cdot \gamma_{c1} \cdot l_{\delta} \cdot \Delta_{c1}. \tag{22}$$

In some sources [2, 4] the authors admit that the resistance of front parts of cylinder is calculated by applying the elements of the theory of boundary effect, this way admitting an error in calculating the losses from stator cylinder.

According to figure 4, the eddy currents closed through the cylinder part placed under the stator package can be, also, closed through frontal parts. The eddy currents from the part covered by stator package are, also, closing through the frontal parts. These currents are replaced by an equivalent current I_{cE} that corresponds to the frontal parts.

The power losses from the frontal part will be:

$$\Delta P_f = I_{cE}^2 \cdot r_f, \tag{23}$$

where r_f is average resistance of frontal parts of the cylinder:

$$r_f = \frac{1}{\gamma_{\Delta c}} \left(\frac{2\tau_m}{l_f \cdot \Delta_{c1}} + \frac{4l_{fm}}{2\tau \cdot \Delta_{c1}} \right) \tag{24}$$

The power of total losses from the frontal zones can be expressed as (25), because the electric losses occur in both frontal parts under each p poles.

$$\Delta P_f = I_{cE}^2 \cdot \frac{2p}{\gamma} \left(\frac{\tau_m}{l_f \cdot \Delta_{c1}} + \frac{l_{fm}}{\tau \cdot \Delta_{c1}} \right) \tag{25}$$

The calculation made according to the expressions (22) and (25) had demonstrated that the losses inside the stator cylinder of the synchronous motor are lower down to 11% in relation to those similar for the asynchronous motor.

Table 1 shows the calculated results of the efficiency and power factor for the synchronous motor with permanent magnets and, respectively, those experimentally obtained for the asynchronous motor of same power in serial production.

Table 1

Theoretic and experimental results

Motor types	Power and techno-economic indexes of the motors			
	P_n, W	ΣΔP	cosφ	η
Synchronous	3000	832	1	0.78
Asynchronous	3000	1046	0.81	0.74

4. CONCLUSIONS

The obtained formula for calculating losses have sufficient accuracy for motorer calculations and correspond to static processes of asynchronous motor with permanent magnets.

The calculation results realized according to the expressions proposed in the paper for synchronous motor had proved that the total losses are 20% lower in relation to those from asynchronous motors that are actually in serial production.

5. REFERENCES

[1] **T. Ambros**, *Convertizoare electrice şi electromecanice speciale, Ed. Tehnica-Info, Chişinău, 2008, p.148-154.*

[2] **V. M. Kuţevalov**, *Voprosy teorij rascheota asinhronnyh mashyn s masivnymi rotorami,* Iz. Energhija, Moskva-Leningrad, 1966, p. 302.

[3] **E. G. Kaşarschii**, ş.a., *Poteri i nagrev v masivnyh rotorah sinhronnyh mashyn*, Iz. Nauka, Leningrad, 1968, p. 199.

[4] A. I. Bertinov, Electricesckije mashiny aviatsionnoj avtomatiki, Oboronghiz, 1961, p. 320.

About the authors

Prof. Eng. **Tudor AMBROS**, Dr.Sc.
Technical University of Moldova
tudorambros@gmail.com

Currently is a professor at the Department of Electromechanic and Metrology, Energetic Faculty, Technical University of Moldova. Scientific activity is related to special electromechanical converters. He has published books, monographs and scientific papers dedicated to power converters, and cosmic electromechanic.

Lecturer **Marcel BURDUNIUC**
Technical University of Moldova
marcburduniuc@gmail.com

He graduated the Technical University of Moldova, Department of Electromechanics, Energetic Faculty in 1999. After graduation was motorer, assistant lecturer, senior lecturer at the Electromechanics Department of the Technical University of Moldova. Has published scientific papers and teaching in the field of electric machines.