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IMPROVING THE STABILITY OF ROTATION RING ROTOR WITHOUT MECHANICAL SUPPORTS

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Summary. The ways to improve the stability of rotation of the rotor ring without mechanical bearings by using no radial groove disk stator induction motor are developed. Considered three designs of slots of the stator: inclined, combined and break. Method for compensation of the errors of manufacturing of the structural components of the electric machine is proposed.

Keywords: synergy, rotor, stabilizing force, destabilizing force.

INTRODUCTION

Currently, there are many devices and machines that have working units in the form of the flat ring, rotating around the axis of symmetry. Examples might serve gyros rotors, working wheels of dynamic pumps and circular saws in the processable machines. Traditionally, ring-working body set in rotation, held in a space and accepts a payload and the resistance through spindle hub or shaft. The shaft receives the rotation from a separate electric motor and, in most cases, through an intermediate gear.

Reserve for increasing the efficiency of such machines is a synergetic association working body functions and secondary elements of the electrical machines, such as a disk induction motor (DIM) [4, 7]. This principle is realized by transferring torque to the rotor and held it in space by magnetic force that rotates. In that case mechanical connection completely exclude from the energy value chain. The basic idea of creating machines with direct drive without mechanical bearings described in the works [16, 2, 15].

In [15, 17] found that the stability of rotor rotation takes place at the vanishing of the tangential component of the main vector of forces, i.e. $F_\tau = 0$. It was shown that this condition is achieved by changing in wide range geometrical parameters of DIM and magnetic induction in the working gap. However, it should be noted that if the angle of elementary electromagnetic force $d\overline{F}$ along the groove does not change (for example, groove performed on a Archimedes spiral) [10], and provided $F_\tau = 0$, the stabilizing radial force F_r equals zero. At the same time rotor will be in a state of indifferent equilibrium, and therefore wouldn't resist external radial forces.

The condition of stationary work of the device which is developed on the basis of DIM is the creation of such a system of forces in what the shift of the rotor from the center should not result to the emergence of destabilizing force $\overline{F}_\tau$, and caused only a stabilizing force $\overline{F}_r$ that returns it to the center [17, 18].

This condition can be achieved if the law of change of force $\overline{F}_\tau$ along the radius does not coincide with the law of change of the force $\overline{F}_r$. In this case, angle of inclination of stator slots ψ must functionally depend on the radius, that in general, reached by production of a curved groove, eliminating the Archimedean spiral.

As was shown in [17, 18], that at a bias e of the rotor into the engine working area formed the outer and inner asymmetric areas, and central area, that has axial symmetry. The width of the outer area is e_H, and the inner – e_B. The central part of the DIM working zone only involved in the creation of torque $M_{o\tau}$, and does not affect on the stability of the rotor. Stability of the last one depends on the value and the correlation of forces F_r and F_τ, which greatly simplifies the problem, since it suffices fulfillment of the condition $F_\tau = 0$ only in the peripheral regions.

The purpose of this study is to develop ways to ensure the stable rotation of the rotor ring without mechanical bearings. In acting on the rotor of technological load, which shifts its center of mass, the rotor must, by means of electromagnetic forces resist this load, and when removing it - to return to equilibrium.

Below we consider the constructive variants of DIM providing stable rotation of the rotor.

APPLICATION OF AN INCLINED SLOT OF STATOR

Great influence on the stability provided the angle ψ that determines the slope of the normal of stator slots in DIM in relation to the radius. In [13, 9, 14] showed that for the inclined slots the main vector has a radial $\overline{F}_r$ and tangential $\overline{F}_\tau$ components.

Assume that the three-phase stator winding [13, 5, 6], which has an outer R_{CH} and inner R_{CB} radiuses, formed by straight grooves, the direction of which does not coincide with the directions of the radiuses [19]. In Fig. 1 groove within the working area created by the rotor with internal R_{PH} and external R_{PB} radiuses and the stator, has a length *BC*, and the *AC* - the axis of the groove. We assume that the magnetic induction, which operates along the groove, is permanent ($B_H = B_B = B = const$).The groove *BC* at different points makes with the radius vector different angles and at the ends taking specific values ψ_H and ψ_B at that $\psi_H \neq \psi_B$. Moreover, from Fig. 1 follows that $\psi_B < \psi_H$. Tangential component of the electromagnetic force $dF_{\tau H}$ on the outer contour of the rotor is greater than the force $dF_{\tau B}$ acting on the internal circuit.

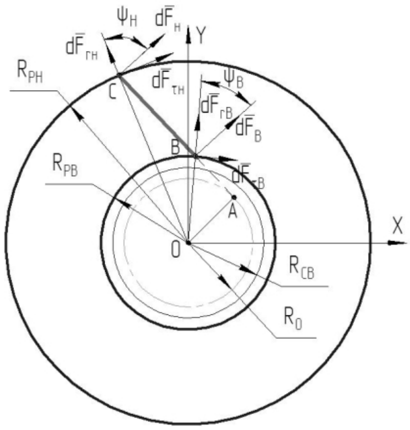

Fig. 1. The scheme of constructing of stator slot

Fulfillment of the conditions $F_\tau = 0$ is possible under $R_{CH} = R_{PH}$ and $R_{PB} - R_{CB} > e$ [17]. In this case, for the external and the internal areas following relation holds $e_B = 2e_H = 2e$, then the condition of stabilization is presented in the following form [18, 19]:

$$\sin\psi_H = 2\alpha_0^2 \sin\psi_B, \tag{1}$$

where: $\alpha_0 = R_{PB}/R_{CH}$.

Since the grooves BC on the stator are symmetrical center, the axis AC will have one point near the center. These points lie on a circle called base circle.

Axis of slots AC are tangents to this circle. In this case, there are always right-angled triangles *ΔOAC* and *ΔOAB*, built on a common leg R_0, of which we find:

$$R_0 = R_{CH}\sqrt{(4\alpha_0^4 - 1)/(4\alpha_0^2 - 1)} \tag{2}$$

Condition of zero destabilizing force, is not running for any size ratio of the rotor and of stator. From (2) follows that if $R_0 \geq 0$ it $\alpha_0 \geq 1/\sqrt{2}$. Suppose that $R_0 = R_{CB}$, then $\alpha_0 = 1$. So to ensure a steady rotation when $B_B = B_H$ the parameter α_0 should be chosen within the $1/\sqrt{2} < \alpha_0 < 1$.

APPLICATION OF THE COMBINED SLOT OF STATOR

Electromagnetic forces acting on the rotor, directed perpendicular to the groove. If the groove is oblique, these forces have the tangential $d\overline{F}_\tau$ and radial $d\overline{F}_r$ components [9]. In [18] showed that at a bias of the rotor into the working area of the electric motor axially symmetric and two asymmetric crescent-shaped areas are formed. In axisymmetric areas sum of the projections of the electromagnetic forces on the coordinate axes is zero, and therefore $d\overline{F}_\tau$ create only torque $M_{o\tau}$, and $d\overline{F}_r$ is counterbalanced. [18, 12, 11]. With increasing angle of inclination of the groove $d\overline{F}_\tau$ decreases, which leads to a decrease of the $M_{o\tau}$.

If in the peripheral areas provide $F_\tau = 0$ and $F_r \neq 0$ the rotor rotates stably. To do this slots near the external and internal contours of the stator must be tilted relatively to the radius. Thus, the groove is combined of three parts. The design of the groove is illustrated by pattern in Fig. 2

The groove is marked by a broken line $ABCD$. Part of the groove AB (located between the circles R_{CB} and R_{C1}), as well as part CD CD (located between the circles R_{C2} and R_{CH}) run at an angle to the radius. The purpose of the slope – the creation of a stabilizing force F_r. The central part of the groove BD creates only torque.

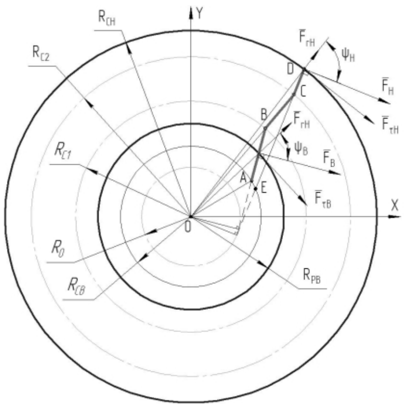

Fig. 2. Scheme of the combined slot of stator

Because of the small magnitude of the shift e assume that angles ψ_H and ψ_B have constant value. In such case for $B_H = B_B = B = const$, the condition $F_\tau = 0$ will correspond to (1)

APPLICATION OF A BROKEN SLOT OF STATOR

Fig. 2 shows that the increase of inclination angles groove ψ_H and combined groove ψ_B leads to an increase of the moment $M_{o\tau}$ [12]. When $\psi_H = \psi_B = 90°$, the moment $M_{o\tau}$ takes its maximum value, but the force $F_r = 0$. The force F_r increases with decreasing ψ_H or increasing ψ_B [18]. Consequently, for the simultaneous growth of the $M_{o\tau}$ and F_r it is necessary to increase the angle ψ_B.

Consider the extreme case when the angle ψ_B is equal to its maximum value $90°$ and $\psi_H < 90°$. This groove is called the broken one, its scheme is shown in Fig. 3 [20].

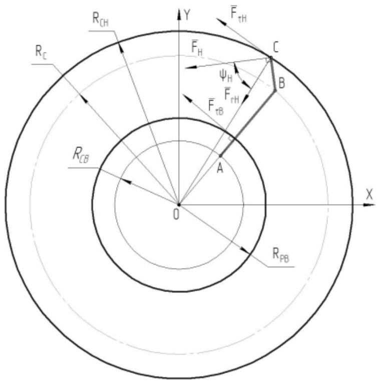

Fig. 3. Arrangement of a broken groove

Circle R_C divides the stator with an outer radius R_{CH} and inner radius R_{CB} in two regions: the outer bounded by the circles R_{CH} and R_C, and the inner one defined by the radiuses R_C and R_{CB}. Radius $R_{PH} = R_{CH}$ and $R_{PH} - R_C = e$.

Radial part of the groove AB is the source of the tangential forces $d\overline{F}_{\tau B}$, and creates only a torque. Part of the inclined of the groove BC, located in the outer areas of stator forms a forces $d\overline{F}_H$. Their tangential projection $d\overline{F}_{\tau H}$ increases the moment on the rotor of the motor and the radial projection $\overline{F}_{rH}$ provides stabilization of the rotor in radial direction.

The main condition for the stabilization of the rotor is the implementation of the equation (1). When $\psi_B = 90°$ equality (1) will be:

$$\sin\psi_H = 2\alpha_0^2 . \tag{3}$$

The angle of the groove and the dimensions of the rotor and stator can be chosen from the condition $0 < \alpha_0 < 1/\sqrt{2}$. Consequently, the use of broken groove ensures stable rotation of rotors larger area than with the two previously discussed methods, ceteris paribus increases the torque.

COMPENSATION OF ERRORS BY UNEVEN DISTRIBUTION OF MAGNETIC INDUCTION IN THE WORKING GAP

Discussed above methods of creating stable circular rotation of the rotor are based on strict observance of geometry DIM. Since in the production always have place the size errors [8, 3], the real fulfillment of the condition $F_\tau = 0$ is problematic. Therefore, the DIM should be possible to compensate for inaccuracies of the parameters affecting the stability of the rotor. In similar cases in machine and instrument manufacture used movable and regulated compensators.

Compensation of errors of geometrical parameters can be accomplished by abandoning conditions $B = const$. In contrast to the geometric dimensions the magnetic induction can be regulated in the final product. Its value can be changed, both due to electrical and mechanical parameters, such as changing the current in the respective windings, or by changing the value of the working gap [9, 1].

Let the magnetic induction in the internal circuit B_B is not equal to stator magnetic induction in the external circuit B_H .When $R_{CH} = R_{PH}$ and $R_{PB} - R_{CB} > e$ the condition of asymptotic stability ($F_\tau = 0$) takes the form [18]:

$$B_H^2 R_{PH}^2 \sin\psi_H = 2B_B^2 R_{PB}^2 \sin\psi_B . \tag{4}$$

Thus, the left side of the equality (8) can always be aligned with the right one, by adjusting the magnetic induction on the external and (or) on the internal circuits of stator.

One way of changing the distribution of magnetic induction in the working area of the electric motor is to use magnetic core located over the internal area of stator. The working gap determines the magnetic induction B_B .

By changing size of working gap can be offset not only the error performance of the radial dimensions of the rotor and stator, but also, according to (8), inaccuracies in the slope of the grooves $\psi_H \neq \psi_B$.

CONCLUSIONS

1. Analyzed the influence of the slope of slots in DIM's stator on the stability of rotation of the rotor without mechanical supports. Stability of rotation is increased when the stators with sloping slots. Determined the conditions under which a stabilizing force F_r takes the maximum value.

2. Proved that the presence of the radial section of the groove in the central region of the stators increases the torque on the rotor of the motor and does not affect on its stability. Sloping groove sections provide a presence of a stabilizing force, and are also involved in the creation of the moment.

3. Proved that eliminate influence of an error of production in DIM on the stability of the rotor can be achieved by changing the magnetic induction on internal or external contour of stators. Why is proposed motor design with an adjustable magnetic core in which the distribution of magnetic induction given by the radial dimensions of the magnetic circuit and the magnitude of the working gap.

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ПОВЫШЕНИЕ УСТОЙЧИВОСТИ ВРАЩЕНИЯ КОЛЬЦЕВОГО РОТОРА БЕЗ МЕХАНИЧЕСКИХ ОПОР

Сергей Ерошин, Сергей Мирошник

Аннотация. Разработаны способы повышения устойчивости вращения кольцевого ротора без механических опор за счет применения не радиального паза статора дискового асинхронного двигателя. Рассмотрены три конструкции паза статора: наклонный, комбинированный и ломанный. Предложен способ компенсации погрешностей изготовления конструктивных элементов электрической машины.

Ключевые слова: синергетика, ротор, стабилизирующая сила, дестабилизирующая сила.