Non-conventional rule of making a periodically varying different-pole magnetic field in low-power alternating current electrical machines with using ring coils in multiphase armature winding

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Abstract. The paper presents methods of making a periodically varying different-pole magnetic field in low-power electrical machines. Authors consider classical designs of electrical machines and machines with ring windings in armature, structural features and calculated parameters of magnetic circuit for these machines.

1. Introduction

As it is known there are two ways for making of periodically varying different-pole magnetic field in low-power alternating current machines [1].

First of them is connected with case when environment for formation of the magnetic field is homogeneous in magnetic position and the specific magnetic permeability at each point of the considered region is, for example, one.

In this case, the formation of a periodically changing different-pole magnetic field is carried out by means of conductors with a periodic alternation of current directions in adjacent conductors, which are placed, for example, on an imaginary cylindrical surface, that is fixed in space. Conductors with counter-directed movement of electrons are connected in turns, coils, coil groups, forming a phase.

In the general case, the turns with current can have any shape (boat, rectangle, trapezoid, circle, etc). Current loops can be located on a closed or unclosed surface stretched over an imaginary cylinder (sphere, cone, screw, etc.)

When an electric current flows through the phase, different-pole induction changes of the magnetic field of a given direction with given amplitude at each point of the surface are formed. This principle is used in synchronous machines of general industrial execution with the purpose of creating an excitation field.

Conductors with a current can be placed on a plane, for example, along an arbitrarily curved line. Conductors with counter-directed movement of electrons are connected in turns, coils, coil groups, forming a phase. When an electric current flows through the phase, an alternating change in the magnetic field is formed. This method of placing phase coils is used to create an excitation field in synchronous machines, for example, linear performance.

If conductors with current are placed in a plane but along an imaginary circle, and conductors with counter-directed movement of electrons are connected into turns, coils, coil groups, forming a phase, then when the current flows through the phase an alternating different-pole change of the end-face type magnetic field is formed. This method of placing the phase coils is used to create an excitation field in synchronous machines of the end-face performance.

If one ring coil is placed on an imaginary cylindrical surface so that the geometrical axis of the coil coincides with the rotation axis of an imaginary cylindrical surface and the projection of the current density vector in each element of the coil conductor to the rotation axis of an imaginary cylindrical surface is zero, unipolar magnetic field is generated relative to imaginary surface.

If several coils of the ring type are placed on the imaginary cylindrical surface with alternating current directions in the coils, then it is known that a magnetic field is generated. The field is unipolar with respect to the imaginary surface and alternating with respect to the axis of rotation.

The second principle of obtaining periodically varying different-pole magnetic field relative to imaginary cylindrical surface refers to the case when the environment for formation of the magnetic field is non-uniform and the specific magnetic permeability at each point of the region is determined. In the region under consideration, volumes are identified where the specific magnetic permeability is one, for example air, and volumes where the specific magnetic permeability is greater than one (magnetic masses), for example, electrical steel.

There are known designs of magnetic systems of low-power electric machines in which alternating variation of the different-pole magnetic field of a given direction at each point with given amplitude is obtained with the help of a single ring-type coil and magnetic masses covering the current coil [1]. The magnetic system is claw-shaped. The geometric axis of the magnetic system and the geometrical axis of the coil coincide with the axis of an imaginary cylindrical surface, relative to which a different-pole magnetic field is created.

2. The traditional principles of the formation of a periodically varying different-pole magnetic field moving with respect to an imaginary cylindrical surface

According to the first principle of forming a periodically varying different-pole magnetic field in alternating current electric machines, for making of different-pole magnetic field moving around the rotation axis of imaginary cylindrical surface (m-1) additional phase must be placed on the same surface (m-number of phases).

The constructions of the turns, coils, coil groups and connections of neighboring phases are geometrically symmetrical and identical. The geometric axis of each coil of the phase coincides with the axis of symmetry of the magnetic field created by this coil and is perpendicular to the rotation axis of an imaginary cylindrical surface.

The geometric axes of the first coils of adjacent phases are shifted in space relative to each other by an angle of $360/m$ electric degrees. The currents in the additional phases are shifted relative to each other also by $360/m$ electric degrees by a current source, for example, an m-phase synchronous generator.

This way of forming a periodically varying different-pole magnetic field moving with respect to an imaginary cylindrical surface is used for creating a rotating magnetic field, for example, in induction motors of general industrial design.

The minimum possible number of coils in this windings is pm, where p is the number of pairs of poles. This winding is called a winding of the drum type.

A drum winding deployed on a plane along an imaginary line is used to create a linearly moving excitation field in linear AC machines.

For the organization of different-pole magnetic field moving along an imaginary cylindrical surface, obtained by placing a single coil of the ring type and alternating the geometry of the magnetic mass of a claw-shape form, the movement of the magnetic field relative to the imaginary cylinder can be created in a conventional method, for example, by rotation. The method for creating a different pole magnetic field is used, for example, in low power synchronous generators to create an excitation field moving relative to the stator, with the goal of creating an electromotive force in alternating current windings.

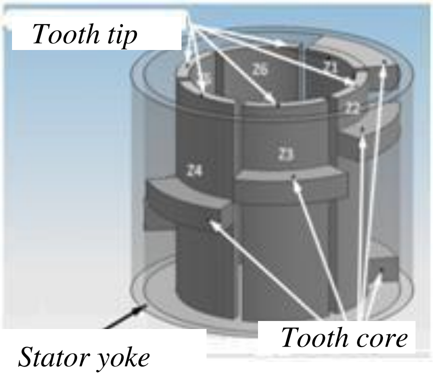

Figure 1. Geometric forms of magnetic masses in space and the order of their conjugation for p=1

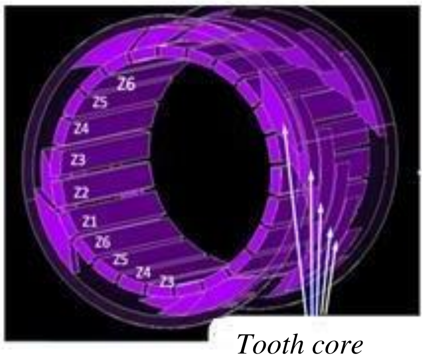

Figure 2. Geometric forms of magnetic masses in space and the order of their conjugation for $p = 4$

3. The non-traditional principles of the formation of moving magnetic field in armature of low-power electrical motors with using ring coils in multiphase armature winding

For low-power electric motors having "strewed" windings, the principle of creating of the different-pole magnetic field moving around rotation axis of imaginary cylindrical surface is observed in [2]. This way is connected with placing 2m ring coils and with alternating of the magnetic masses geometry of different configurations. The geometric axes of all the coils of the ring type of the armature multiphase winding according to [2] coincide with the rotation axis of the imaginary surface, relative to which a moving different-pole magnetic field is created. Magnetic masses cover each of the coils and have a different configuration.

The rule of the magnetic masses placement in space relative to current conductors in ring coils of armature winding and the order of magnetic masses conjugation are directed to a step-by-step transformation of the type of displacement of the magnetic field of the armature with respect to an imaginary cylindrical surface (rotor), namely, the spiral movement of the magnetic field in the stator yoke into radial screw motion in the zone of the tooth cores and in circular motion with respect to the imaginary surface in the zone of the tooth tips.

Figures 1-2 show the geometric forms of magnetic masses, the placement in space and the order of their conjugation for the case when the number of pole pairs is $p = 1$.

Geometric forms of magnetic masses have the following types: hollow cylinder (stator yoke), curved prism (tooth core), and segment of hollow cylinder (tooth tip).

According to figure 1, the second tooth core is shifted relative to the first tooth core by 60 electric degrees and by one sixth of the axial length of the stator. The third tooth core is shifted relative to the second tooth core by 60 electric degrees and by one sixth of the axial length of the stator, and so on. The upper (first) and lower (seventh) tooth cores are shifted relative to each other by 360 degrees.

The first tooth tip, the first tooth core, the stator yoke and the seventh tooth core are conjugated and form a short-circuited magnetic ring. The second tooth tip is shifted relative to the first tip by 60 electrical degrees. The internal surfaces of the tooth tips are conjugated with an imaginary cylindrical surface, relative to which a moving periodically varying different-pole magnetic field is formed. The inner surfaces of the tooth tips are equal.

Figure 3 shows the placement of phase ring coils with respect to magnetic masses. The connections scheme of ring type coils is shown in figure 4.

IOP Conf. Series: Materials Science and Engineering **313** (2018) 012002 doi:10.1088/1757-899X/313/1/012002

For this case and for any number of poles pairs, the minimum number of coils of a three-phase armature with ring coils is six when constructing a sixty degree phase winding zone.

It is should be noted that in the stator of an classical low-power electric motor with a single-layer three-phase armature winding, the minimum number of coils placed in the stator slots is a function of the number of pole pairs: f (p) = 3*p*.

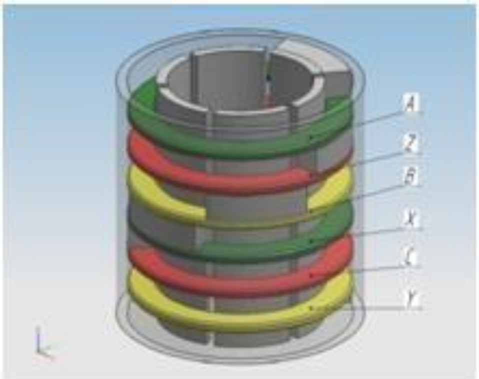

Figure 3. Placement of phase ring coils with respect to magnetic masses

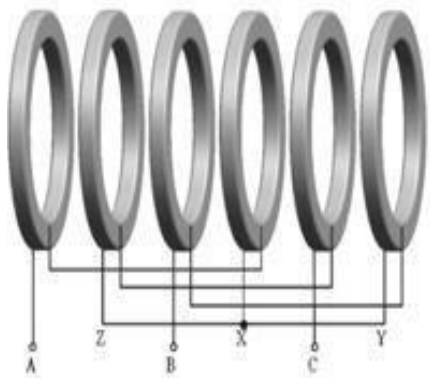

Figure 4. Connections scheme of ring type coils

4. Distribution of magnetic flux in the magnetic system of induction motor with ring windings during flow of three-phase sinusoidal currents system along armature winding

The field lines of mutual induction of a two-pole induction motor of general industrial design with the number of poles $2p = 2$ and the number of slots per pole and phase $q = 1$ are presented in simplified form in figure 5.

The magnetic field is created by the phase currents of the three-phase armature winding of the stator of an induction motor of general industrial design for the case when the current in phase A is equal to the current in phase B and equal to ½ of the current of phase C.

The field lines of mutual induction of a two-pole induction motor of general industrial design with the number of poles $2p = 2$ and the number of slots per pole and phase q = 6, when the current in phase A is equal to the current in phase B and equal to ½ of the current of phase C are presented in simplified form in figure 6.

Magnetic field vectors of a two-pole induction motor with ring windings with the number of poles $2p = 2$ and the number of slots per pole and phase q = 1 and when the current in phase A is equal to the current in phase B and equal to ½ of the current of phase C are presented in simplified form in figure 7.

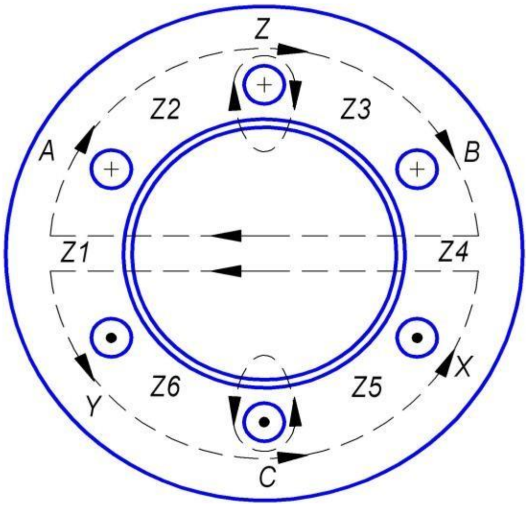

Figure 5. Field lines of mutual induction for $2p=2$, $q=1$

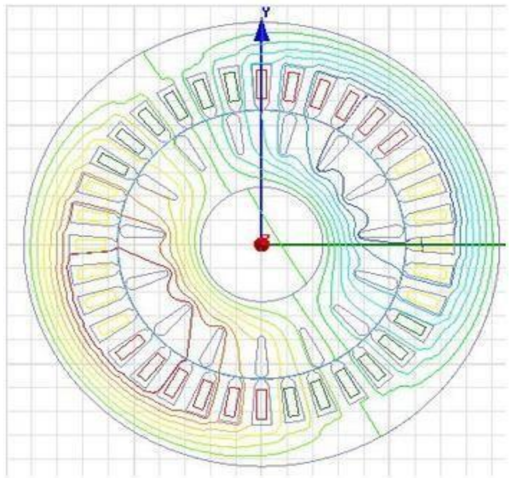

Figure 6. Field lines of mutual induction for $2p=2$, $q=6$

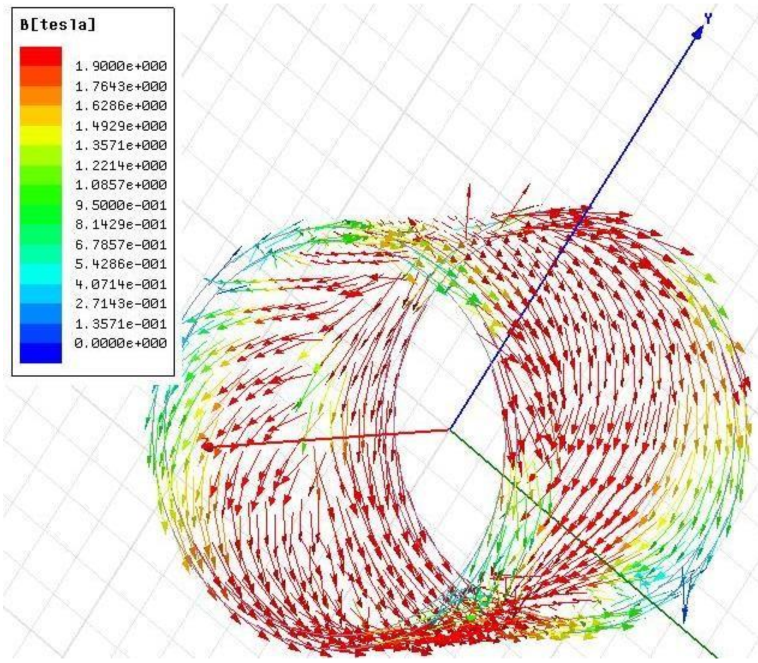

Figure 7. Vectors of magnetic field for $2p=2$, $q=1$ and for ring windings of armature

As it is known, the magnetic field in the magnetic system of stator and rotor of the classical design induction motor is axis-symmetric (figures 5-6).

You can see from figure 7 the magnetic field in the stator of an induction motor with ring windings in the stator yoke zone and the tooth cores has a helical shape along the axis of rotation. The helical character of the magnetic field distribution is given by the helical character of the magnetic masses distribution (see figure 1, figure 4).

Using "ELCUT" program, we determine the distribution of the flow in the working air gap of the induction motor with ring windings. The AO2-32-6 motor was chosen as the prototype design. In the calculation model of the induction motor with ring windings, the grade of electrical steel, the number of turns in the phase of the stator armature winding, the geometric dimensions of the rotor, the size of the mechanical gap were assumed to be equal to the corresponding values of the prototype. Unlike the prototype, for which the number of slots per pole and phase is two, in the design model of the induction motor with ring windings, the number of slots per pole and phase q in the first stage of calculating the flux induction distribution in the air gap along the rotor was assumed as q = 1. The current in phase A is assumed to be the no-load current of the prototype. The design of the magnetic system is collapsible. The additional air gap $\delta\Delta$ between the tooth core and the tooth tip is assumed equal to the value of the mechanical air gap: $\delta\Delta$ = 0.3 mm. The areas of all six tooth tips on the side of the air gap are equal to each other.

We define the planes that cut the magnetic system along the axis of rotation as shown in figures 8 a, b, c. For each section we construct a calculation model using the capabilities of "ELCUT" (figure 9.) And then we will perform and present the calculations.

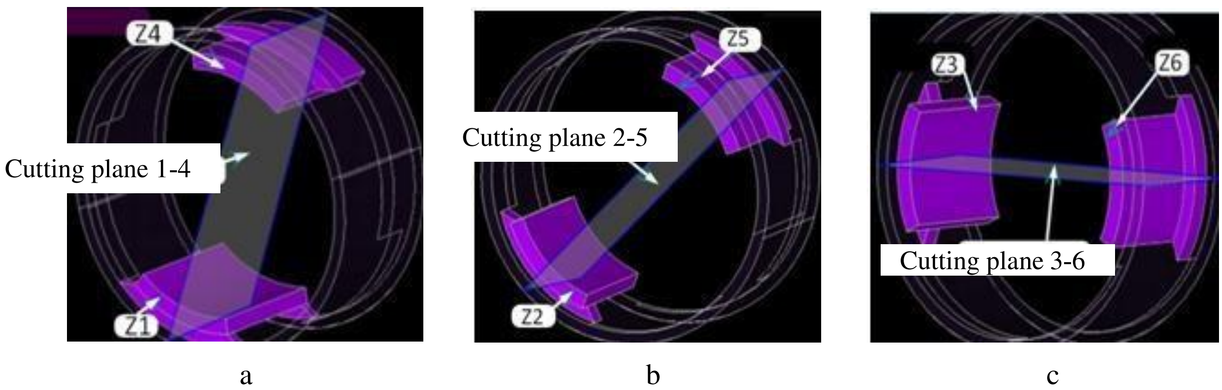

Figure 8: a, b, c. Magnetic system cutting by special planes

We construct the graphs of the induction change along the cutting planes in the air gap. Let us consider a plane passing through the tooth tips Z1 and Z4 (figures 8a). Figure 9 shows the calculation model corresponding to the longitudinal section of the magnetic circuit shown in figure 8a. Graphs of the induction change in the air gap along the rotor on the side of the tooth tips (respectively, Z1 - Z4) are shown by figures 11-12.

According to figures 9-10 you can see resulting direction of the magnetic flux lines in the air gap from the tooth tip № 4 to the tooth tip № 1 for given values and directions of the phase currents and placement of the phase coils in the magnetic system along the axis rotation, indicated in figure 9. It is presented for simplified image of magnetic circuit in cross-section.

As you can see from figures 11-12, the average value of the induction Bav.z1 in the gap under the tooth tip Z1 is equal to $B\delta$av.z1 = 0.237 T. The average value of induction $B\delta$av.z4 in the gap under the tooth tip Z4 is equal to $B\delta$av.z4 = 0.247 T, which is less than 5% more than the average value of induction $B\delta$av.z1 in the gap under the tooth tip Z1. The inequality of the average values of the inductances in the gap under the tooth tips Z1 and Z4 is due to the assumptions made when replacing the three-dimensional model of a two-dimensional magnetic system.

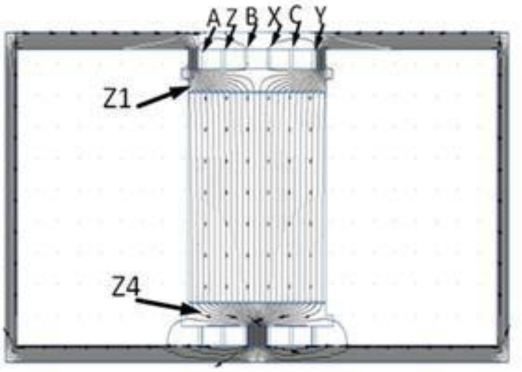

Figure 9. Calculation model corresponding to the longitudinal section of the magnetic circuit

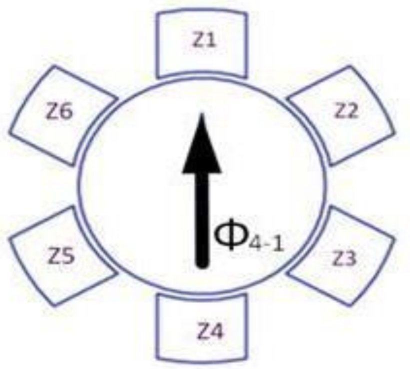

Figure 10. Resulting direction of the magnetic flux lines in the air gap from Z4 to Z1

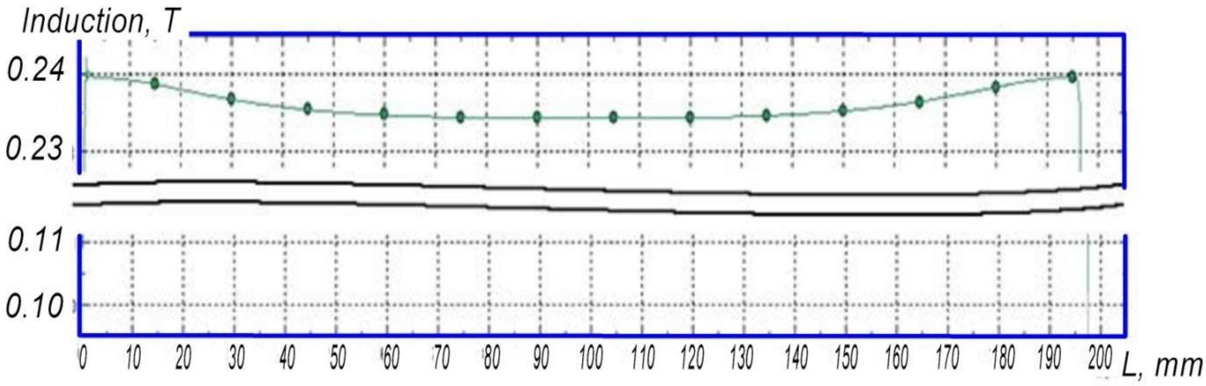

Figure 11. Induction change in the air gap along the rotor on the side of the tooth tips

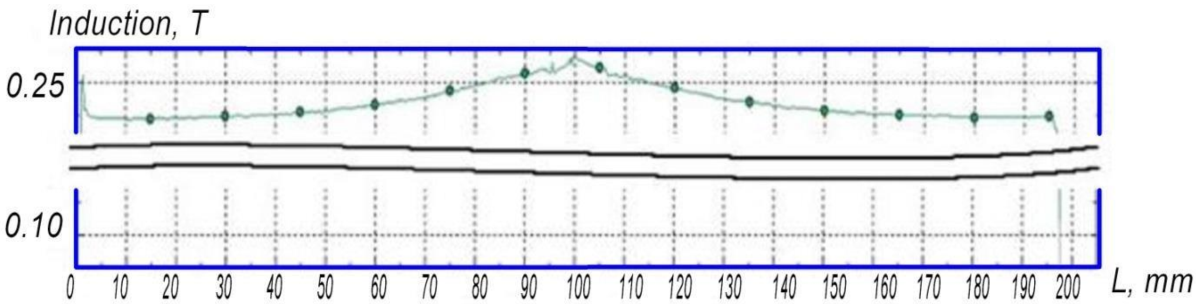

Figure 12. Induction change in the air gap along the rotor on the side of the tooth tips

Considering in a similar way the changes in inductions along the planes indicated in figures 8b and 8c, we obtain the flux directions according to figures 13 a, b.

At the indicated values of the phase currents relative to the rotor, the tooth tips Z6, Z1, Z2 create the North Pole. Accordingly, tooth tips Z5, Z4, Z3 create the South Pole. With an error of less than

2%, we can assume that the average values of the inductions under tooth tips Z6, Z2 are equal to each other. Also, with an error of less than 2%, we can assume that the average values of the inductions under tooth tips Z5, Z3 are equal to each other too.

When the phase current values change symmetrically according to sine law by an angle α in electric degrees, for example, by 60 electric degrees, the field symmetry axis is shifted by 60 geometric degrees, etc. When the phase sequence changes the rotation direction of rotation of the magnetic field changes too.

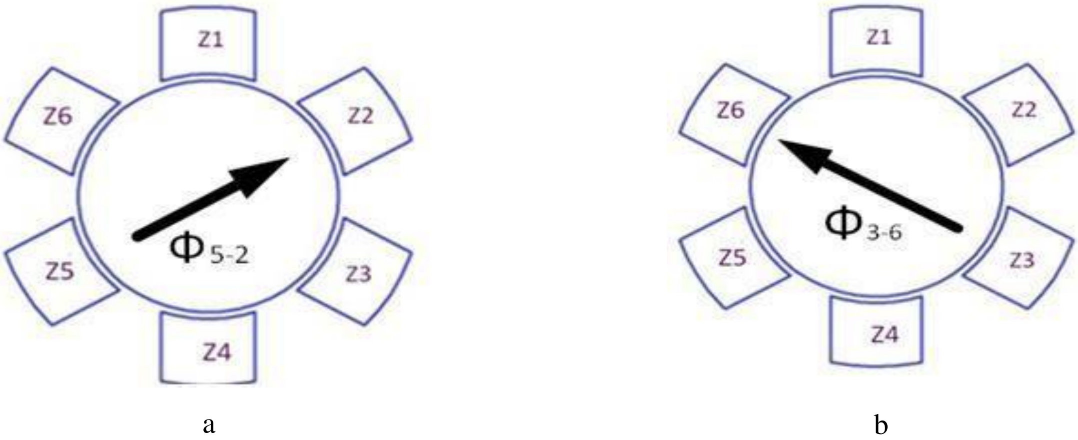

Figure 13. Resulting direction of the magnetic flux lines in the air gap:
a) From Z5 to Z2; b) From Z3 to Z6

Figure 14 shows a photograph of a laboratory sample performed for $m = 3$, $p = 5$, $q = 1$.

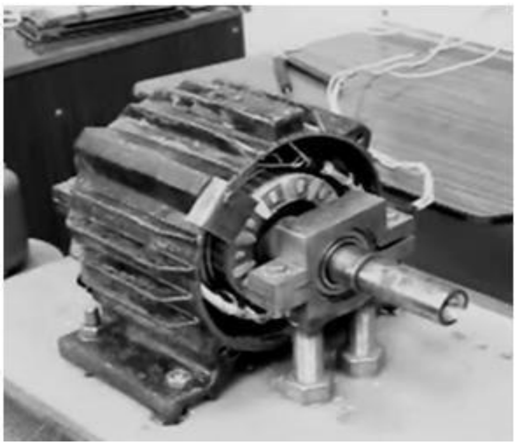

Figure 14. Laboratory sample of a motor with ring windings

The tests carried out due to the laboratory sample of the induction motor with ring windings have showed that:

1. The induction motor with ring windings has starting and maximum torques.
2. The direction of rotor rotation of the induction motor with ring windings does not depend on the starting angular position of the rotor. The change in the direction of rotation cans be obtained by changing the phase sequence of the supply voltage.

3. The synchronous rotational speed of the rotor for the prototype of the induction motor with ring windings is n = 600 rpm, which corresponds to a calculated number of pole pairs p=5.

4. Investigation of the harmonic composition of the magnetic field in the gap showed that the field in the gap has the same harmonic and amplitude series as for a classical machine with a classical winding with the number of slots per pole and phase q=1 and the diametric step.

5. Conclusion

1. With an error of less than 5%, we can assume that the considered principle of the formation of a periodically changing different-pole magnetic field moving relative to an imaginary cylindrical surface, which consists in a staged transforming the type of movement of the magnetic field of the armature with respect to an imaginary cylindrical surface (rotor) by means of a different configuration of magnetic masses and the distribution of coils of the armature winding, it is possible to create a symmetric field of mutual induction similar to the field created by the drum winding in induction motors of classical design.
2. The principle of making the number of pole pairs that is presented in [2] is valid. With the minimum possible number of coils of the stator winding equal to six and the number of phases m = 3, we can obtain any number of pole pairs.
3. Each stator coil of the induction motor with ring windings performs the function of the p-sides of the coils of the classical design machine.

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