Possibilities of Improving the Transformers and Reactors on the Basis of Multiple Counters of the Rods

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Abstract—**Technical solutions of transformers and reactors improvement by structural conversion of the elements of the active part are considered. Such conversion consists in the replacement of the traditional circular forming contours of the rods and winding coils by hexagonal and octagonal configurations. The decrease of material consumption and labor intensity of production as well as the increases of electrodynamical stability of the mentioned induction static devices are achieved.**

Keywords—transformer, reactor, rod, winding, contour, durability.

I. Introduction

In the 21st century, the main tasks of the development of electromechanics and electric power systems are the integrated energy and resource saving and the achievement of 100% reliability of electricity supply. Such problems are solved by the maximum reduction of losses and specific material consumption, as well as by the increase of unit capacity and electrodynamic stability (EDS) of single electromechanical aggregates [1-3]. At the same time, the possibilities of improving transformers and reactors based on the achievements of materials science, methods and means of optimization design, are limited by the physical properties of materials and constructive-structural features of traditional static electromagnetic systems (EMS) [3-8]. Therefore, there is a need to increase the indices of the above induction static devices (ISD) by non-traditional methods [3, 9, 10].

II. Analysis of main achievements

The majority of medium and high power ISDs [4, 8] with planar and spatial EMSs are based on circular forming contours (FC) of rods and winding coils. Single-phase and three-phase EMSs of ISDs with the specified structural features are unchanged for many decades. The traditional design solutions for increasing the EDS are: hardening of the conductor material and their gluing, crimping of coils in the axial and radial directions, installation of rigid support cylinders and balancing of coils and phase coils along the height of the rod [4, 8]. However, in the overall failure rate of transformers, the proportion of damage caused by insufficient EDS exceeds 14%

[3-6]. One of the non-traditional ways of improving the ISD is to transform the FC and the structures of active and constructive elements [3]. Variants of this transformation are six and eight-faceted FC active elements [3, 9].

III. Purposr of research

Review and analysis of non-traditional design and technological solutions of EMS with n≥6-faceted FC rods and winding coils.

IV. Method and research results

The circular form of the coil of the winding of a static EMS complicates the technology of producing magnetic circuits [3, 8]. A high coefficient of filling of the circular FC K_{fc} = 0.927...0.931 is achieved by the arrangement in the circumference of 28-32 packages of electrotechnical steel (ETS) of various widths (Figure 1).
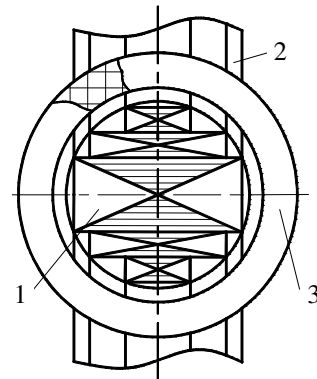

Fig. 1. Fragment of the core zone of the static electromagnetic system of the traditional design: 1-rod; 2-yoke; 3-winding.

It was established theoretically and experimentally [4] that the bending deformations and internal residual stresses σ_b arising in the curvilinear winding (Figure 2, a) of the turns add up with the stress σ_{ed} from the electromagnetic forces. The imposition of deformations of the two mentioned factors creates total stresses along the entire circumference of the loop and reduces the EDS of the ISD [3, 4].

$$\varepsilon_\Sigma = \varepsilon_b + \varepsilon_{ed}.$$

From [3] follows a method for increasing the EDS of an ISD, which consists in forming coils of windings based on n ≥ 6-faceted OC turns [9]. A feature of such coils is the presence of sections of turns formed by straight lines intersecting at obtuse angles of bending of windings $\alpha_B \geq 120°$ (Figure 2, b). In contrast to the circular turns (Figure 2, a), on the straight sections which constitute the main part of the length of the polyhedral turn, the components of deformations and stresses caused by the bend are excluded. These components, according to [4], as well as possible damage to the wiring insulation during bending, are concentrated in the zones of turns on the axes of the vertices of the polyhedron. Therefore, in these areas, insulation should be reinforced and the mechanical fastenings of the winding concentrated, in particular, horizontal pillar posts and sewn laths. To maximize the electrical strength and EDS of the winding, additional vertical gaskets must be installed in the corner areas of the edges between the turns (Figure 2, b). Vertical gaskets and slats, as well as holes and recesses for them in horizontal gaskets, can be made with a shape that corresponds to internal r_B and external r_N radii of fillet winding rounds [9].
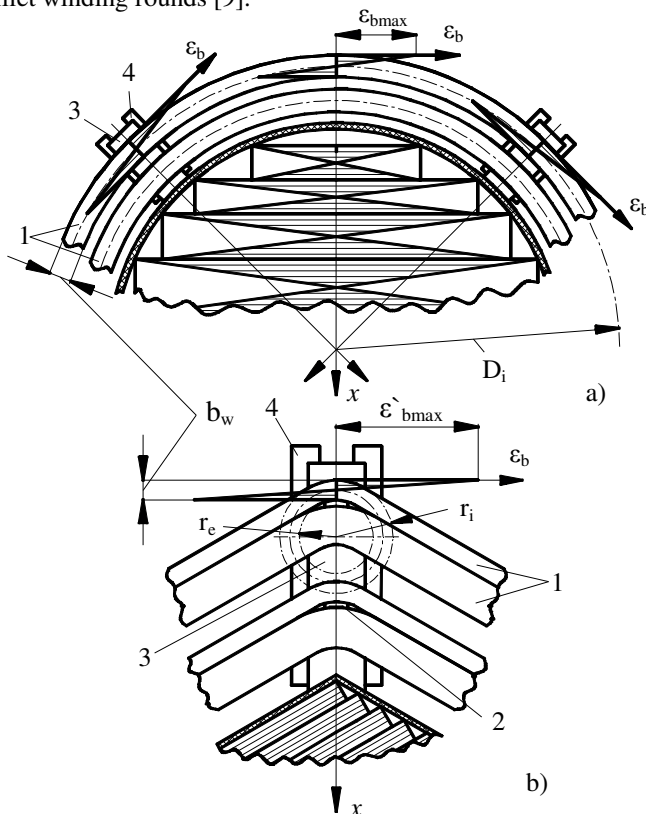

Fig. 2. Bending and deformation of the initial bending of the conductor along the circular contour of the winding (a) and the concentration of bending deformations in the angular zones of the polyhedral contour of the revolution (b):1 - conductor; 2 - vertical gasket; 3 - piercing rake; 4 - support gasket.

The number of faces of the FC winding turns (Figure. 2, b) should correspond to the cross-sections of the cores of magnetic cores with structural and technological solutions that satisfy the requirement of constructive "wastelessness", that is, the non-waste production of elementary layers of the magnetic circuit from the rectangular strip (tape) being the fraction of the standard rolling roll ETS.

During the duration of the short-circuit, the stresses σ_Σ must not exceed critical values with a certain margin, which is the condition of the EDS of the ISD. According to [4], the use of EDS calculation methods without taking into account σ_b results in (100...500)% errors.

The replacement of circular FCs with hexagonal ones makes it possible to substantially simplify the production of jointed magnetic cores structures (Figure 3, a, Figure 4, a). Simplification is achieved by completely filling the cross-section of the rods when identical ETS layers are located at angles of 120° (Figure 3, b, Figure 4, b, c).
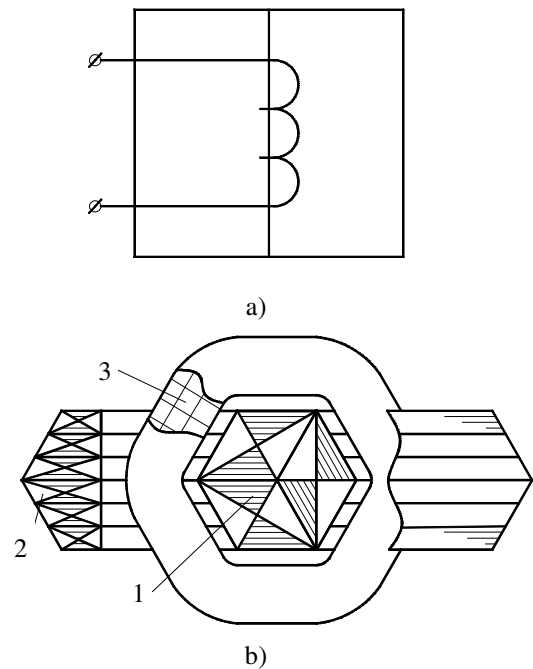

Fig. 3. Structural (a) and constructive (b) scheme of a single-phase planar armored electromagnetic system: 1-rod; 2-yoke; 3-winding.

The assembly of the rods EMS (Figure 3, b, Figure 4, b, c) from ETS plates with a thickness of 0.35 mm and a width (0.1...1) m creates filling of the hexagonal FC with the coefficient $K_{fc} = 0.998...0.9998 \approx 1$ [9]. It is possible to reduce the material consumption and losses of windings relative to analogues with circular FC and $K_{fc} < 0.922$ [10].

It is also possible to reduce the material intensity and laboriousness of producing magnetic circuits and to increase the EDS of planar rod EMS based on $n = 8$-faceted FC. When placing five (Figure 5, a) and seven ETS packets of three and four sizes, differing in width, in the equilateral octahedron, the filling factors FC $K'_{oi} = 0.9$ and $K''_{ci} = 0.93$ [9] are provided. Analogous $K^{(n)}_{ci}$ coefficients of circular FC by traditional "stepped" sections of the rods (Figure 1) are achieved, depending on the diameter, respectively 7-9 and 14-16 ETS dimensions [8].

An important difference between winding coils with polyhedral forming contours and cylindrical forming contours is the presence of sections of turns (Figure 2 - Figure 4) formed by straight lines intersecting at an obtuse angle $\alpha \geq 120°$.

Rounding of conductors is performed at corners α_κ. Between the rods and coils, as well as coils, vertical support-insulating elements are installed (Figure 5, b). Bending deformations (arising along the entire length of the turns of the

cylindrical coils) and residual mechanical stresses of the conductor fibers in the straight sections of the turns are eliminated. Zones of deformation and stresses are concentrated in the places of bending of the conductors on the axes of the vertices of the polyhedron. However, in these areas, insulation is strengthened and support elements are concentrated. To maximize the electrical strength and EDS, the piercing strips must be made with a cross-sectional shape that corresponds to the inner r_i and the outer r_o radius of rounding of the turns (Figure 5, b).

The full filling of the ETS with octahedral FC rods is possible in the construction of a combined magnetic circuit (Figure 6, 7). Such a magnetic core contains the middle parts of the rods and the yokes of rectangular sections and the lateral parts of the trapezoid cross-sections. Plates of ETS rods and yokes in the middle part of the blend are "bunched", and in the lateral parts are conjugated in a "joint".
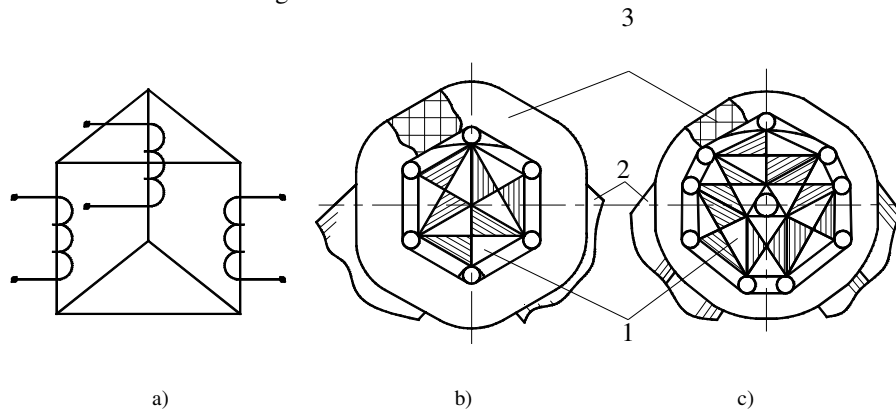

a) b) c)

Fig. 4. Structural (a) and constructive (b), (c) diagrams of the core zones of a three-phase axial spatial electromagnetic system with a single-circuit (b) and two-circuit (in) yokes:1- rod; 2- yoke; 3- winding.
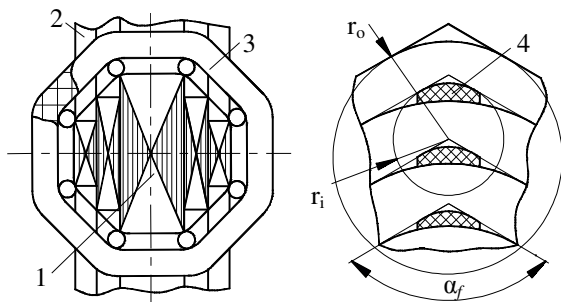

Fig. 5. Scheme of a fragment of a planar electromagnetic system with octagonal configurations of rods and winding coils (a) and features of the winding design with polyhedral forming contours: 1- rod; 2-yoke; 3-winding; 4-piercing rack.

ETS plates of the lateral parts of the magnetic circuit (Figure 6) can be performed by dividing the ETS band with a change in the feed step within the thickness of the ETS [8]. The production of packages of rods and yokes with trapezoidal sections is also possible by transverse cutting at an angle of the sides of the rod α_r of prismatic blanks of packages of rectangular and identical ETS layers (Figure 6).

In addition to laminating technology, in the manufacture of transformers and reactors, the technologies of winding the band (roll) of ETS are widely used. The formation of three-phase magnetic cores from a roll-over ETS leads to a significant complication of production due to the complex configuration of scan the twisted sections (Figure 8, a, b) [7, 8].
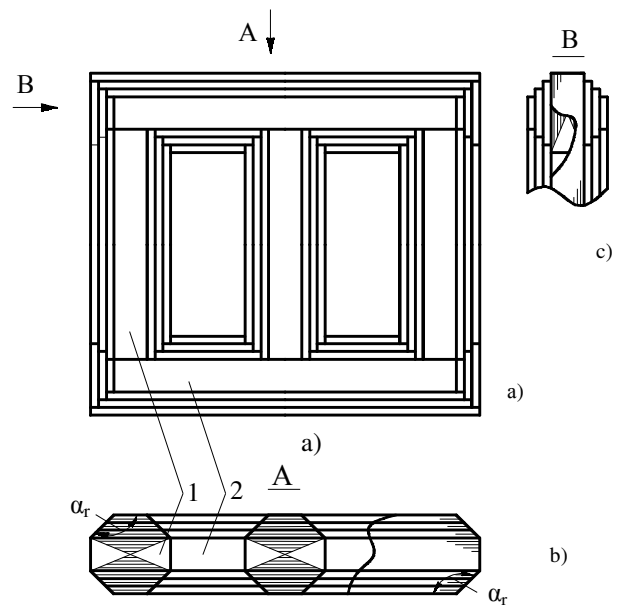

Fig. 6. Scheme (in projections a, b, c) of a 3-phased planar magnetic core with octagonal cross sections of rods: 1-rod; 2 yokes.
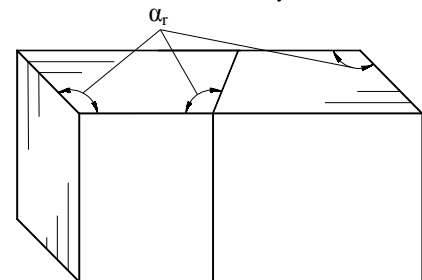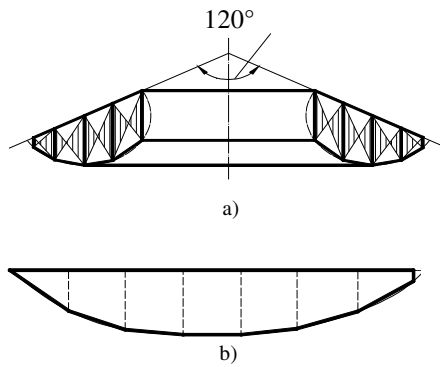

Fig. 7. Prismatic blank of magnetic circuit elements

Fig. 8. The scheme (a) and the scan (b) of the section of a twisted magnetic circuit with circular forming contours.

Hexagonal FC allow to reduce the overall dimensions and laboriousness of the EMC configuration (Figure 9, a, b) by 15 ... 20% relative to the analog of the sections (Figure 8, a) by changing and simplifying the configuration of the scan (Figure 8, b) to the view (Figure 9, c). When winding sections (Figure 9, a), the lateral surfaces of adjacent rods (winding windows) are formed, which increases the compactness [3, 10].

It is clarified [10] that the replacement of traditional rectangular and circular FC of a magnetic core by n ≥ 6-faceted leads to the decrease by 5…8 % of material consumption and active losses of transformers and reactors.
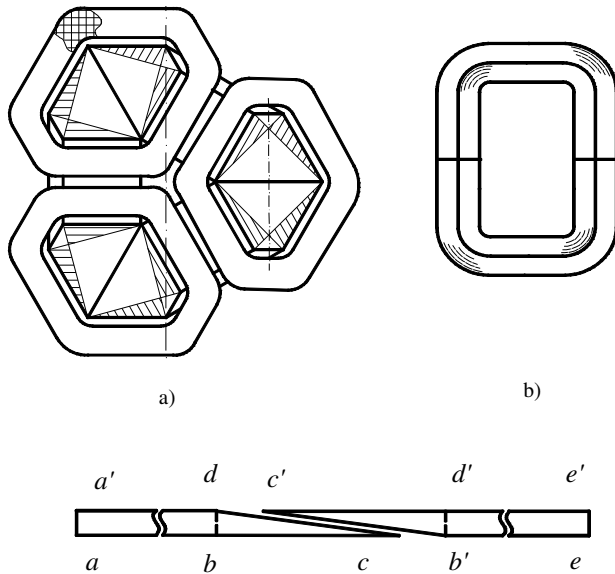

Fig. 9. The scheme (c) and the scan (d) of electrotechnical steel of two sections (e) of the type of an electromagnetic system with hexagonal forming contours.

V. CONCLUSION

In paper are considered such technical solutions of transformers and reactors improvement by structural conversion of the elements of active part as use of polyhedral FC rods and winding coils for the formation of planar and spatial EMSs, that creates the potential for energy conservation and enhancement of EDS of transformers and reactors of various capacities and applications.

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