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(71) Applicant: **Adamovych, Bilyi Leonid**
Lviv-Rudno city 79493 (UA)

(72) Inventor: **Adamovych, Bilyi Leonid**
Lviv-Rudno city 79493 (UA)

(74) Representative: **AOMB Polska Sp. z.o.o.**
ul. Rondo Ignacego Daszynskiego 1
00-843 Warsaw (PL)

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(54) **THREE-PHASE TRANSFORMER**

(57) **Application area:** The invention relates to the field of electrical engineering, in particular to the design of transformers and can be used in all industries whose production processes are associated with the production, operation and repair of transformers.

The essence of the invention: A three-phase transformer contains of the main primary and secondary windings, a spatial magnetic system composed of plates of electrical steel, the magnetic system is formed by six regular trihedral prisms, made up of analogous plates, and interconnected by a common rib, forming a hexagonal prism with a six-beam star in cross section, the adjacent edges of the star are the rods of the magnetic conductor, and the autonomous edges are the hexagonal yoke, the vertical density of the plates of the magnetic conductor is provided by central and lateral fastening, the turns of the main and additional windings divided in half are placed in phase on the rods with a spatial angle of 60°, the magnetic system is made with the ratio of the width of the rod and the yoke equal to two and the height of the prism to the width of the beam greater than five.

A three-phase transformer according to claim 1 characterised in that the main and additional windings are placed jointly on the rods with a spatial angle of 120°.

A three-phase transformer according to paragraph 1 characterised in that the spatial magnetic conductor is made of amorphous electrical steel with a thickness of 10 to 30 microns.

Technical effect consists in unifying the design of the spatial magnetic system, reducing its weight and size characteristics, combining in a transformer the functions of a higher harmonic filter, a balancing device and a volt-

age stabilizer.

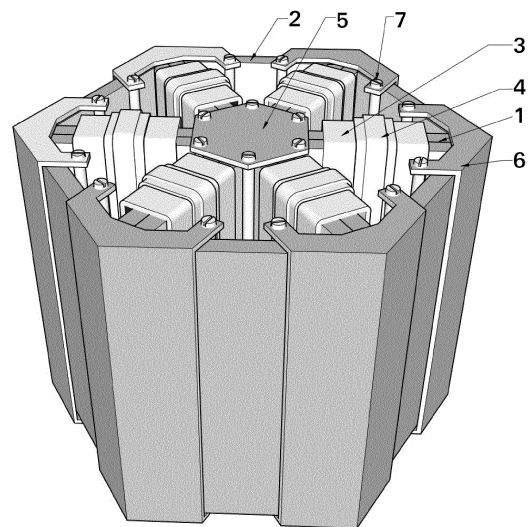


FIG. 1

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Description

[0001] The invention relates to the field of electrical engineering in particular to the design of transformers and can be used in all industries that need devices that can transform high-quality energy (without higher harmonics), independently eliminate voltage distortions in case of an asymmetric load, regulate voltage independently smoothly and over a wide range when changing load, and devices that have significantly higher reliability and a working resource.

[0002] Such properties of a transformer can only be provided by a spatial magnetic system that adequately reproduces or models the phenomenon of electromagnetism, the form and physics of which is to cover the current conductor by a magnetic conductor, while the metamorphoses disappear such as the need to replace the volumetric field with a plane-parallel one, the scattering of this field into the surrounding space and etc., but the manufacture of a spatial magnetic conductor requires a larger amount of steel.

[0003] A question of creating a spatial magnetic system with costs comparable to the costs of manufacturing E-shaped flat transformers has arisen taking into account that the design of modern transformers is carried out with a long-term and unrelenting trend towards the highest possible use of active materials, simplification of technological effectiveness, weight reduction and size reduction.

[0004] Three-phase spatial radial magnetic conductors of increased compactness are known, the rods and yokes of which are formed from two groups of chevron elements that have different length, and part of the yoke sections is made of elements having the shape of a parallelogram with angles of 60° and 120° (Patent of Ukraine for the invention UA 100077C2, Patent of Ukraine for utility model UA 99327). Such magnetic conductors have a number of disadvantages: the impossibility of installing separately manufactured windings on the magnetic conductor rods, since the rods have a geometry "in the form of a chevron of various length". The process of the winding on the finished magnetic conductor greatly complicates the technological process of the transformer manufacturing. The genesis of the structure of the magnetic conductors from a planar shape to a spatial one was carried out by the authors in one platitude by concentric placement of phases, which eliminated the magnetic asymmetry of the magnetic conductor, but did not affect the improvement of the conditions for the electromagnetic process, leaving the coverage of the magnetic field by current, which causes the presence of stray fields, power losses etc.

[0005] A spatially symmetrical magnetic conductor is known, which has an upper and lower wound yokes interconnected by rods, while the geometry of the cross section of the rods and yokes at the junctions is made with a square cross section (RF Patent RU No. 2380780 C1). Such magnetic conductors with spatial arrangement

of rods eliminate only the magnetic asymmetry of planar E-shaped cores, and the technical result in reducing losses in steel was achieved through the use of amorphous steel, which can also be achieved in a E-shaped magnetic conductor. Due to the low mechanical strength of amorphous steel (brittle like glass), special requirements are imposed on the design of such cores and the conditions for their production, since the magnetic conductor is a supporting structure that holds the entire active part. Amorphous steel does not allow excessive weight loading, and the inventors do not take into account this fact.

[0006] We also know a design of magnetic conductor with an inner part (rods) made of soft magnetic material, around which at least partially there is a screen, which has a laminated structure of at least one soft magnetic material. Between the inner part of the magnetic conductor and the screen there is a device for creating axial pressure on the inner part of the magnetic conductor, and the screen is divided into segments and its length in the axial direction is equal to or greater than the axial length of the coil frames located around the transformer magnetic conductor (Patent of Ukraine for the invention UA No. 88942 C2).

[0007] Above we indicated the reason for the appearance of the so-called stray fields, that is, magnetic fields, the force lines of which are linked to only one winding, and this reason lies in inadequate modelling of the electromagnetism phenomenon.

[0008] Instead of the spatial coverage of the current by the magnetic field in the transformer, the coils (current) cover the magnetic conductor (field). Violation of the laws and phenomena of nature gave rise to a number of negative consequences, including stray fields. Their physics is quite complex and there are still no unified methods for calculating them and ways to eliminate them. The screen proposed by the author closes on itself some part of the stray field and changes the place of transformer power losses, but does not eliminate them. In addition, stray fields determine the inductive resistances of the windings which they cover, and additional losses in copper, except of ohmic ones. The screen cannot close this part of the scattering flows onto itself. And it is impossible to predict "that the orientation of the laminated screen structure is directed parallel to the possible (?) direction of the scattering flux," since it is impossible to predict the configuration of the scattering phenomenon itself. Can there be an alternative to combating the consequences of stray fields, other than converting them into a working magnetic field by surrounding the windings with a volume-spatial magnetic system? Apparently it doesn't exist.

[0009] There is also known a spatial magnetic conductor for filter transformers with rods with yokes arranged in a circle, which form a multi-beam star in plan and which is made of two identical parts joined in rods in order to reduce magnetic asymmetry (SU No. 1714697 A1).

[0010] Firstly, the magnetic asymmetry disappears not from the joining of "two identical parts joined in rods", but

due to their spatial arrangement; secondly, large funds are spent on the manufacture of filter-transformers designed to eliminate higher harmonics in voltage and current curves. Costs and harmonics disappear in transformers with a spatial magnetic system that almost completely covers the windings. Such transformers transmit only the first harmonic at any saturation of the magnetic conductor, while the filters have a narrow efficiency range.

[0011] A three-phase transformer prototype is the closest to the proposed one according to the set of features and technical results (Patent of Ukraine for the invention UA No. 84746).

[0012] Three-phase transformer which contains low and high voltage windings in each phase and a folded magnetic system, characterised in that the magnetic system consists of a yoke and six rods arranged in the form of a six-beam star with spatial angles of 60 degrees between them and outside covered by the yoke, phase windings as part of the primary and secondary windings of one phase are located on three rods through one, the other three rods are free from windings and are shunt, on each of the six sections of the yoke there is an additional magnetizing winding, two for each phase, which are located in different sides of the corresponding phase of winding, the magnetic system is made with a ratio of its width and the width of the rods greater than one.

[0013] Three-phase transformer according to claim 1 characterised in that the magnetic system is made in the form of a cylinder, the cross section of which is a six-beam star of the rods, covered by an annular yoke.

[0014] Three-phase transformer according to claim 1 characterised in that the magnetic system is made in the form of a hexagonal prism, the cross section of which is a six-beam star of the rods, covered by a hexagonal yoke.

[0015] Signs of the prototype, which coincide with the design according to the invention are the following: magnetic system consists of a six-beam star of rods with spatial angles of 60°, covered by a six-sided yoke.

[0016] The prototype has a number of disadvantages, the main of which are the following:

1. As it is well known, cold-rolled electrical steel is characterized by anisotropy, that is, different magnetic properties along and across rolling. For economical use of steel and obtaining minimal losses in it, it is necessary to match the direction of rolling and the main magnetic flux. Such coincidence when stamping plates according to Fig. 6 - Fig. 11 or Fig. 17 - Fig. 22 takes place only in one or two rods, and in four or five rods the magnetic losses increase significantly.
2. Inefficient use of expensive electrical steel. The areas of the triangles surrounded by rods and yokes are much larger than the latter, therefore, in the process of plate stamping most of the steel goes to scrap.
3. The magnetic flux of the rod is closed by two yokes, that is, at the junction of the rod with the yokes the

flux is bifurcated in half due to the equality of the magnetic conductivities of both yokes. Therefore, the flow of the yokes is half the flow of the rod, and therefore the cross-sectional areas of the yokes and the rod must be appropriate. In case of serial production, the savings in steel will be noticeable due to a halving of the cross-sectional area of the yokes. 4. In the description of the prototype device it is explained that "the voltage regulation of the proposed transformer when operating under load is carried out with the help of additional windings placed on the yoke." It is further stated that "smooth adjustment of voltage balancing in the case of complex asymmetric operating modes is carried out by using additional windings placed on the outer yoke of the magnetic system." Thus, two physical processes due to different reasons are functionally connected and their control is entrusted to the same mechanism - additional windings. If we take into account that fluctuations of secondary voltages and their distortion occur, as a rule, simultaneously, it is almost impossible to carry out their simultaneous regulation. In addition, it is also impossible to automate the regulation of such a process, and therefore external intervention in the operation of the transformer is necessary.

[0017] The objective of the invention is to improve the production technology and reduce the weight and size characteristics of a spatial magnetic conductor in comparison with the prototype, the combination in the transformer of the functions of a higher harmonic filter, a balancing device and a voltage stabilizer.

[0018] The problem is solved due to the fact that a three-phase transformer contains of the main primary and secondary windings, a spatial magnetic system composed of plates of electrical steel, the magnetic system is formed by six regular trihedral prisms, made up of analogous plates, and interconnected by a common rib, forming a hexagonal prism with a six-beam star in cross section, the adjacent edges of the star are the rods of the magnetic conductor, and the autonomous edges are the hexagonal yoke, the vertical density of the plates of the magnetic conductor is provided by central and lateral fastening, the turns of the main and additional windings divided in half are placed in phase on the rods with a spatial angle of 60°, the magnetic system is made with the ratio of the width of the rod and the yoke equal to two and the height of the prism to the width of the beam greater than five.

[0019] A three-phase transformer according to claim 1 characterised in that the main and additional windings are placed jointly on the rods with a spatial angle of 120°.

[0020] Three-phase transformer according to claim 1 characterised in that the spatial magnetic conductor is made of amorphous electrical steel with a thickness of 10 to 30 microns.

[0021] The above mentioned set of essential features is sufficient to make the drawings of the claimed design

of a spatial magnetic system with windings placed on it according to the usual initial data for design in accordance with the claimed scope of legal protection, that is, the unification of the design of the transformer with minimization of waste when cutting sheets of electrical steel, with the possibility of reducing the weight and size characteristics of the magnetic conductor, the creation of a transformer with new properties.

[0022] The essence of the invention and the principle of operation are illustrated by drawings.

Fig. 1 shows a general view of the transformer.

Fig. 2 shows the geometry of a plate of a unified magnetic conductor.

Fig. 3 and Fig. 4 show the burdening of magnetic conductor plates in two successive layers.

Fig. 5 shows a regular trihedral prism.

Fig. 6 shows the marking of a sheet of electrical steel for laser cutting of magnetic conductor plates.

Fig. 7 shows a cross section of a magnetic conductor composed of six trihedral prisms.

Fig. 8 shows the side binding of the magnetic conductor.

Fig. 9 shows the central binding of the magnetic conductor.

Fig. 10 shows a winding turn covered by a spatial magnetic conductor (the yoke is removed).

Fig. 11 shows a winding turn that covers the rod of the magnetic conductor.

Fig. 12 shows a diagram of the relationships of the magnetic fluxes of the phases of the transformer.

Fig. 13 shows the electrical connection diagram of the main and additional windings of one phase of the transformer.

Fig. 14 shows the electrical connection diagram of the main and additional windings of a three-phase transformer.

[0023] The following designations are accepted on the figures of the drawings: 1 - rod, 2 - yoke, 3 - main windings, 4 - additional windings, 5 - central binding, 6 - side fastening, 7 - pin.

[0024] A three-phase transformer (Fig. 1) contains primary and secondary (main) windings 3 and additional windings 4, the transformation coefficient of which is greater than the main ones, a folded magnetic system (Fig. 1 pos. 1, 2). The spatial magnetic system is formed by six regular trihedral prisms (Fig. 5), made by burdening of plates (Fig. 2) into successive layers (Fig. 3, Fig. 4) and connected by a common edge. The adjacent edges of the prisms serve as rods 1, and the autonomous edges serve as yokes 2.

[0025] The magnetic conductor is made of plates of electrical steel, Fig. 2, with a thickness of 0.27 mm, 0.35 mm or it is made of amorphous steel strips with a thickness of 10-30 microns.

[0026] The vertical density of the plates of the magnetic conductor is carried out by the central 5 and side 6 bind-

ings, the horizontal parts of which are pulled together by pins 7.

[0027] There is a causal relationship between the set of distinctive features and the achieved technical result. Signs regarding the uniformity of the plates that make up the magnetic conductor, and the geometric ratio of the width of the rod and the width of the yoke equal to two are significant, because they directly affect a number of technical results.

[0028] Firstly, the design of the transformer, the magnetic conductor of which consists only of plates having the geometric shape of an equilateral trapezoid (Fig. 2), is a unified design.

[0029] Secondly, this ratio significantly affects the weight and size characteristics of the transformer, the weight of the yokes of which is half the weight of the rods.

[0030] Thirdly, a significant influence of this ratio is the optimization of laser cutting of electrical steel sheets into plates (Fig. 6) and minimization of waste (up to 5%) into scrap metal of expensive material.

[0031] The fourth technical result of this essential feature is the one hundred percent orientation of the cutting directions of the plates with the direction of rolling of cold-rolled steel, which significantly affects the reduction of losses and the improvement of the characteristics of the transformer.

[0032] The invention provides the presence in the claimed design of the transformer of a number of essential features that will lead to the emergence of new functions.

[0033] The more than five ratio of the height of the prism and the width of the beam of a six-beam star is the first such essential feature. This ratio provides maximum coverage of the phase windings by the spatial magnetic system. Let us turn to Fig. 11 and Fig. 10, which compare the pictures of the magnetic fields of the turn, covered by the spatial magnetic system (Fig. 10) and the turn, which covers the rod of a flat E-shaped magnetic conductor (Fig. 11). In the first case (Fig. 10), the geometry of the magnetic circuit evenly distributes the magnetic field over its entire height, which is adequate to the constant electric field tenseness, that is $\bar{E} = const$. The Second case (Fig. 11) illustrates the uneven distribution of the field along the turn, which is the result of a distortion of the phenomenon of electromagnetism - here current covers the field. Therefore, the density of the magnetic field of the rod is not uniform, it is intense between adjacent rods and its intensity drops to zero outside the magnetic conductor, that is, the electric field tenseness is variable $\bar{E} = var$.

[0034] Let's break the turns of Figure 10 and Fig. 11 into a number of identical segments $\Delta\bar{l}$ and calculate the work that the electromagnetic field does when transferring the charge along a given trajectory, that is, along the length of the turn \bar{l}_{tur} . From theoretical electrical engineering it is known that such work is called voltage and it is determined by the formula $U_{tur} = \oint \bar{E} d\bar{l}$.

[0035] Based on this formula, we determine the voltages of both turns. To do this, we replace the integral by the sum for n segments of the turn, and the derivative - by the increment. So we get

$$U_{\text{tur}} = \sum_1^n (\bar{E} \Delta \bar{l}) = \sum_1^n \bar{E} \sum_1^n \Delta \bar{l}$$

[0036] The sum of the increments of the segments of the turn in both cases is equal to the length of the turns

$$\sum_1^n \Delta \bar{l} = l_{\text{tur}} . \text{ Let us now find the sum of tenseness } \sum_1^n \bar{E}$$

[0037] For Fig. 10 this sum is equal to the sum of the identical tenseness of the segments, which is equivalent to the product of n by one tenseness, that is

$$\sum_1^n \bar{E} = E_1 + E_2 + \dots + E_n = nE_1$$

Physically, the product nE_1 means the presence of only one tenseness component of the same amplitude and frequency. Thus, the voltage of the turn (Fig. 10) $U_{\text{tur}} = nE_1 l_{\text{tur}}$ has only the first harmonic and no higher harmonics.

[0038] For Fig. 11, the total tenseness consists of the summands of the tenseness of the segments of the turn, different in amplitude and frequency, that is

$$\sum_1^n \bar{E} = E_1 + E_2 + \dots + E_n , \text{ besides } E_1 \neq E_2 \neq \dots \neq E_n , \text{ which is physically equivalent to the presence of higher harmonics in the voltage of the turn } U_{\text{tur}} = (E_1 + E_2 + \dots + E_n) \cdot l_{\text{tur}}$$

[0039] Therefore, the feature more than five regarding the ratio of the height of the prism and the width of the beam of a six-beam star is significant, since it fundamentally affects the technical result, which consists in the absence of higher harmonics in the voltages of the transformer, regardless of the degree of saturation of the steel. Thus, the technical result is to identify a new property of the transformer - to perform the functions of a filter of higher harmonics with simultaneously transmitting power.

[0040] The following causal relationship between the feature of the invention and the expected technical result is explained in Fig. 12, where the feature is a symmetrical six-beam star of rods with halves of the main and additional windings placed on them and surrounded by a hexagonal yoke. The consequence of this feature is a physical phenomenon expressed by the electromagnetic interconnection of each phase with two neighbouring phases: phase A is magnetically connected to phases B and C, phase B - to phases A and C, phase C - to phases A and B.

[0041] In case of an asymmetric load of the transformer, currents of various sizes flow in the windings of its phases, which cause corresponding voltage drops. Secondary voltages will have different values, this phenom-

enon is called "voltage distortion" and it negatively affects consumers.

[0042] In its turn, different winding currents induce different flows, which, due to the presence of magnetic relationships between the phases, are aligned, that is $\Phi_a = \Phi_b = \Phi_c$.

[0043] According to Maxwell's law, the voltage or EMF is determined by the change in the flow over time $U_j = e_j = -d\Phi_j/dt$, where $j = a, b, c$, therefore, the secondary voltages of the phases are aligned, that is $U_a = U_b = U_c$.

[0044] The technical result of this causal relationship is the identification of a new property of the claimed transformer, which consists in independent balancing of secondary voltages in the case of its unbalanced load, in other words, the transformer has assumed the functions of a balancing device.

[0045] The presence in each phase of the transformer, besides of the main 3, additional windings 4 allows smooth and in a wide range of self-regulation of secondary voltages when the load changes by connecting the main and additional windings in series according to the diagrams shown in Fig. 13 for one phase and for three phases in Fig. 14.

[0046] The essence of voltage self-regulation is as follows: a change in the load current causes a change in the magnetomotive force (MMF) of the additional or control winding connected in series with the main winding.

[0047] A change in the MMF will cause a change in the flux, which is adequate to a change in the EMF of the additional winding. With an increase in load, its EMF increases, with a decrease, it decreases. When the windings are connected in series, the EMF of the main and additional windings are added, that is, the output voltage increases. In the case of a decrease in load, the EMF of the additional winding decreases, which will lead to a decrease in the output voltage.

[0048] Common with RF patent No. 2422935 is the possibility of changing the voltage by a given transformation coefficient of additional windings.

[0049] The difference from the claimed patent lies in the elimination of the dependence of the design of the control transformer on the nature of the load, in the complete rejection of a separate control transformer, as well as from the devices for connecting the main and control transformers.

[0050] The presence of additional windings in each phase of the transformer is an essential feature because it determines the technical result, which consists in identifying a new function that the transformer can perform - the possibility of independent self-regulation of secondary voltages when the load changes without any external intervention. Such a function is adequate to the function of a voltage stabilizer. The patented transformers are produced in a dry version, that is, they do not need a forced cooling system (tank, oil, radiators, pumps, pipelines, etc.), due, firstly, to the good thermal conductivity of steel and heat removal by a hexagonal yoke and, secondly, due to the elimination by the transformer itself of the "volt-

age distortion", and, consequently, the overload of the windings with currents.

[0051] The obtained technical and economic indicators testify the creation of a transformer of a unified design with improved production technology, improved weight and size characteristics compared to the prototype, which combines the functions of a transformer with the functions of a higher harmonic filter, balancing device and voltage stabilizer.

[0052] The principle of operation of the transformer is known from literary sources, for example, Ivanov-Smolenskij A.V. Electric machines. Textbook for high schools in 2 volumes. M., 2004.

Claims

1. A three-phase transformer contains of the main primary and secondary windings, a spatial magnetic system composed of plates of electrical steel, the magnetic system is formed by six regular trihedral prisms, made up of analogous plates, and interconnected by a common rib, forming a hexagonal prism with a six-beam star in cross section, the adjacent edges of the star are the rods of the magnetic conductor, and the autonomous edges are the hexagonal yoke, the vertical density of the plates of the magnetic conductor is provided by central and lateral fastening, the turns of the main and additional windings divided in half are placed in phase on the rods with a spatial angle of 60° , the magnetic system is made with the ratio of the width of the rod and the yoke equal to two and the height of the prism to the width of the beam greater than five.
2. A three-phase transformer according to claim 1 **characterised in that** the main and additional windings are placed jointly on the rods with a spatial angle of 120° .
3. A three-phase transformer according to claim 1 **characterised in that** the spatial magnetic conductor is made of amorphous electrical steel with a thickness of 10 to 30 microns.

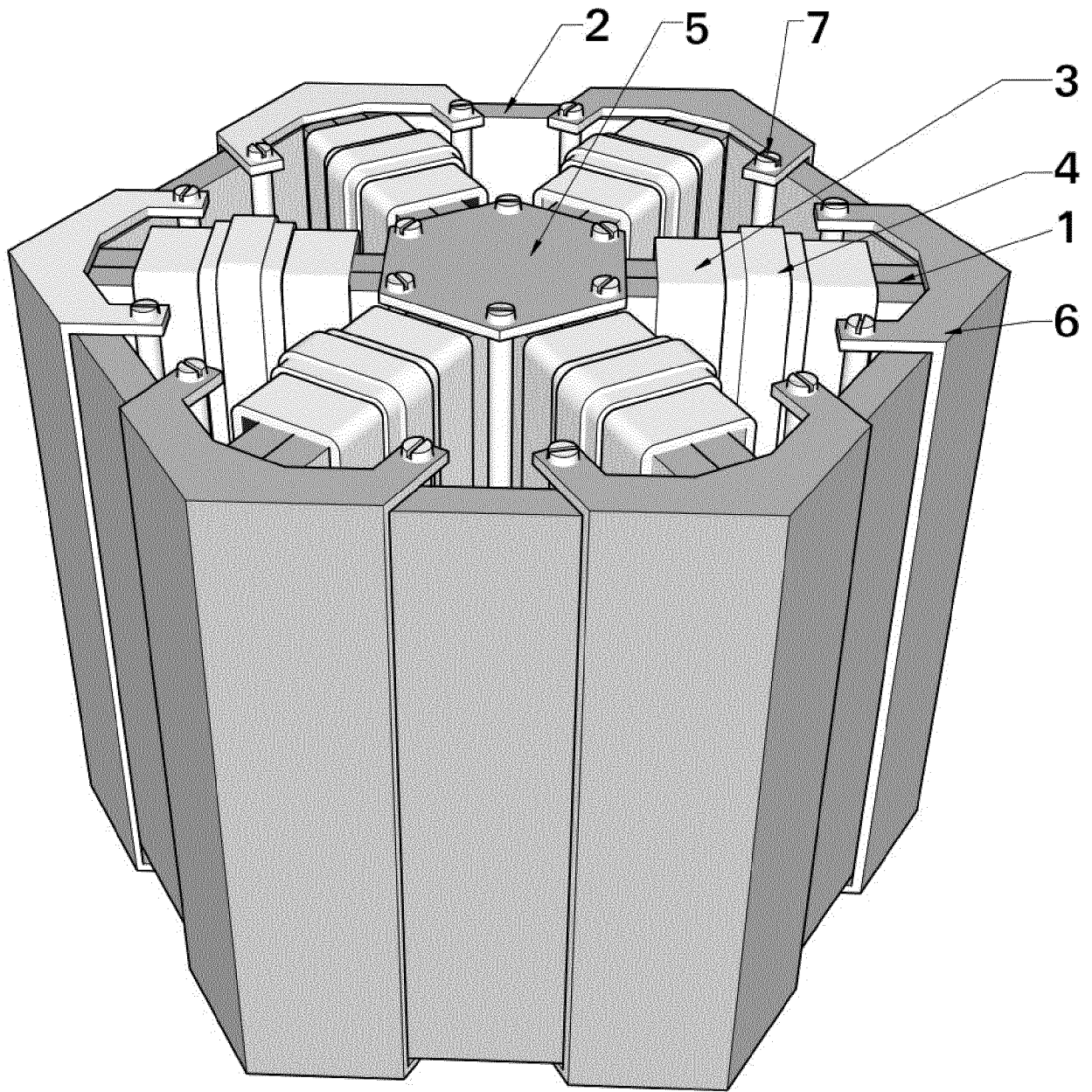


FIG. 1

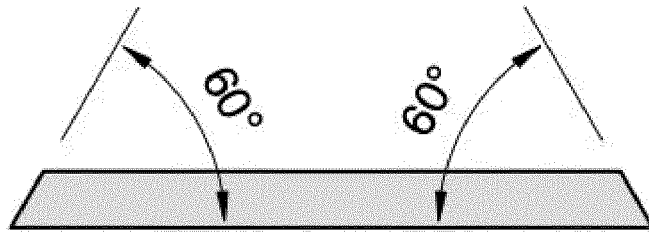


FIG. 2

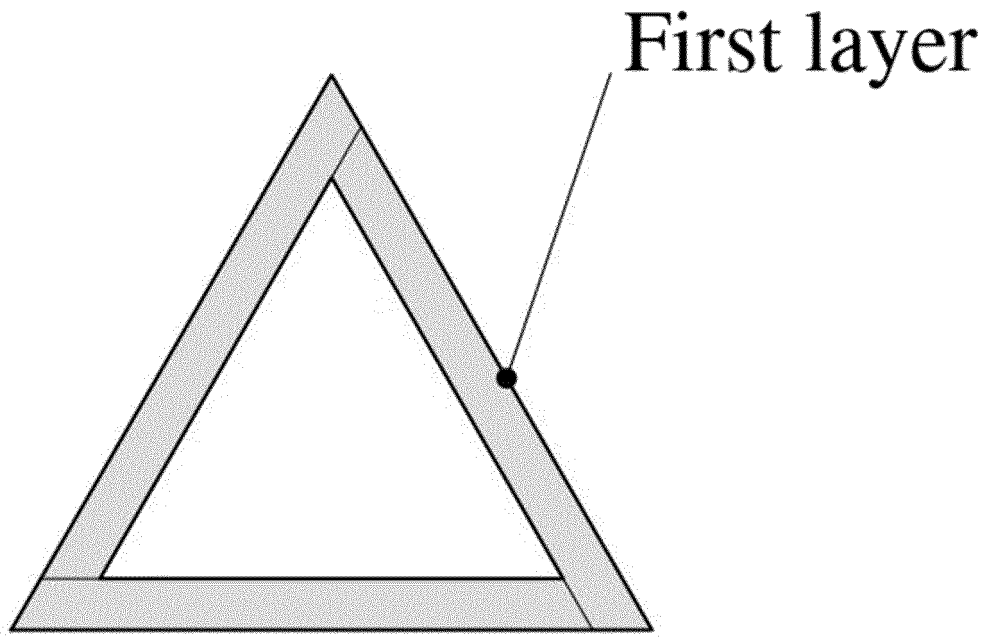


FIG. 3

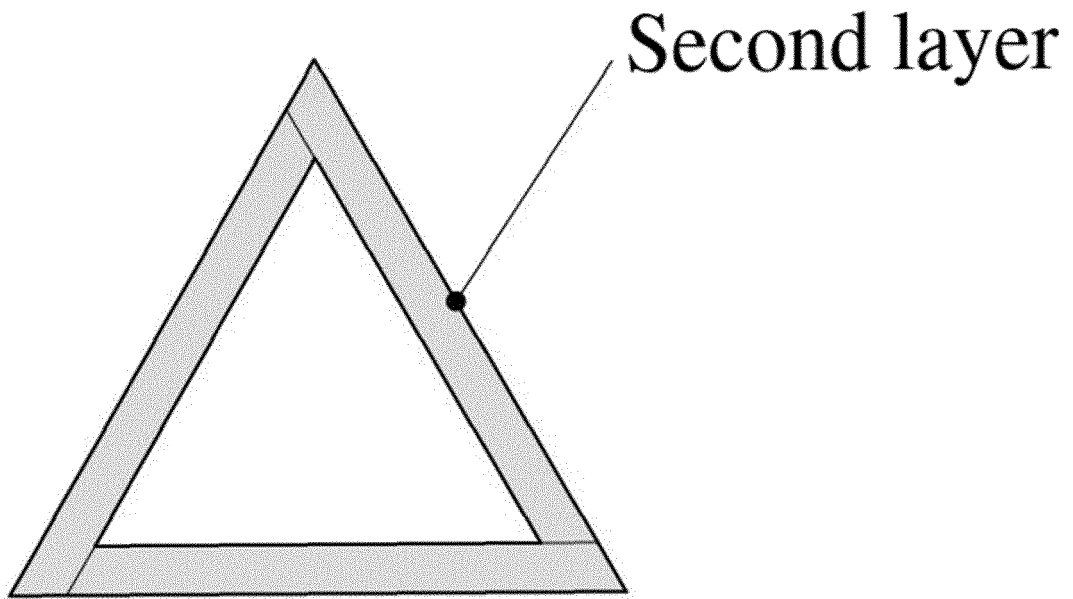


FIG. 4

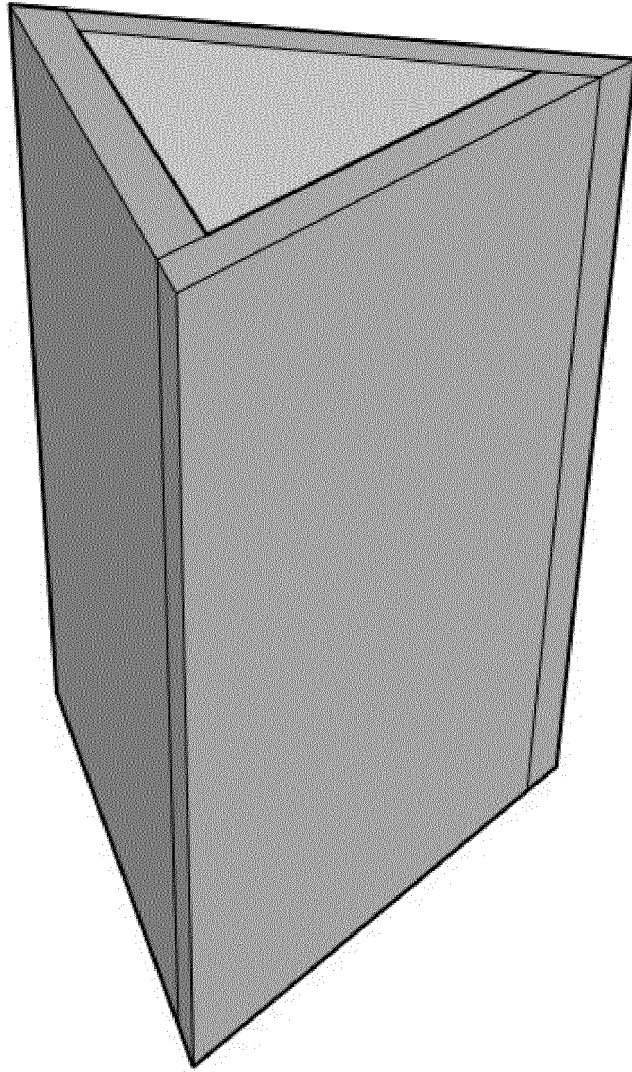


FIG. 5



FIG. 6

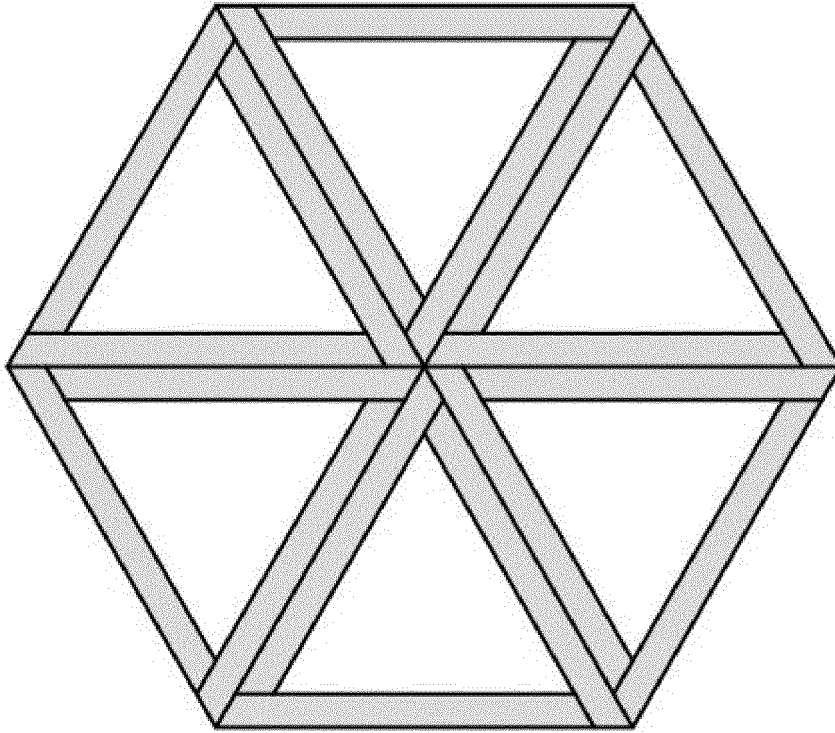


FIG. 7

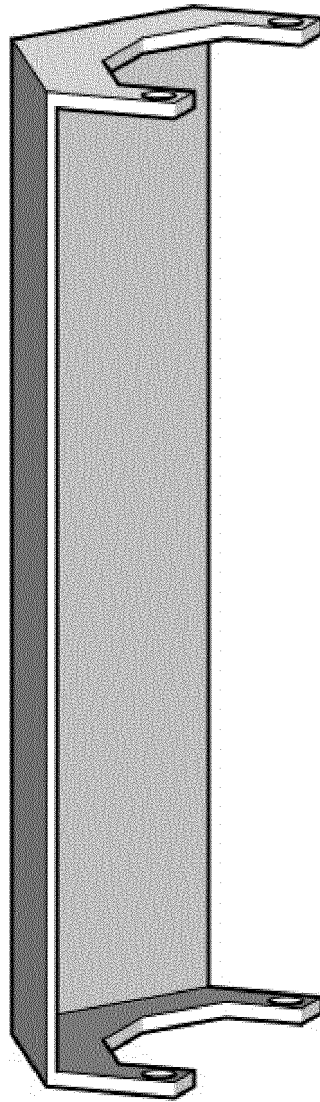


FIG. 8

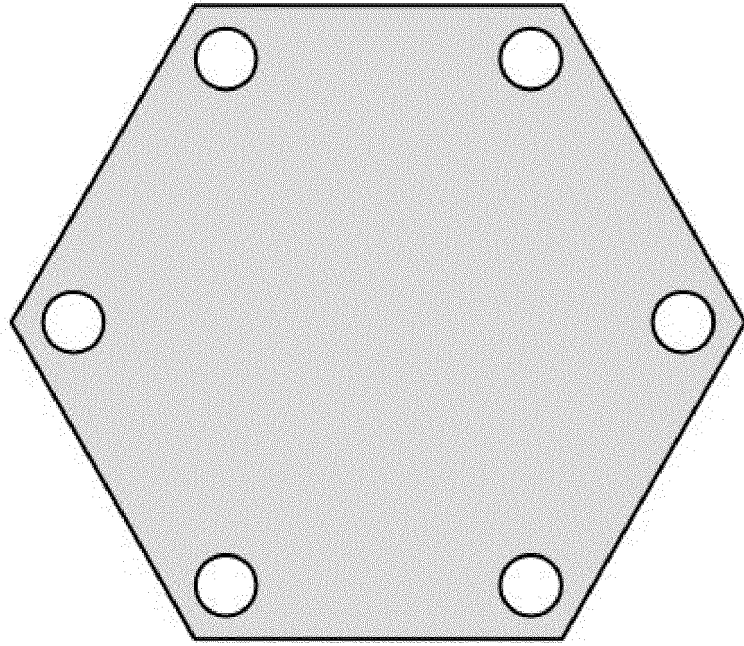


FIG. 9

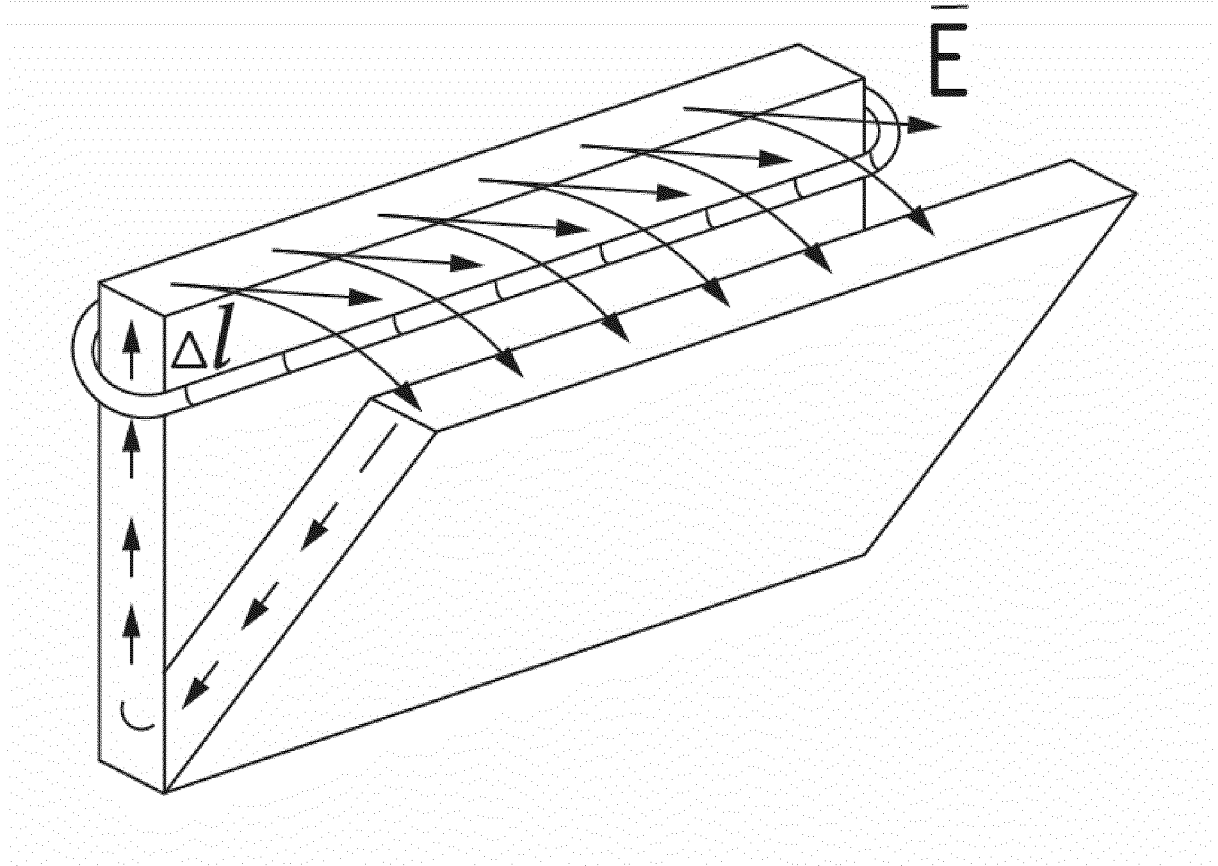


FIG. 10

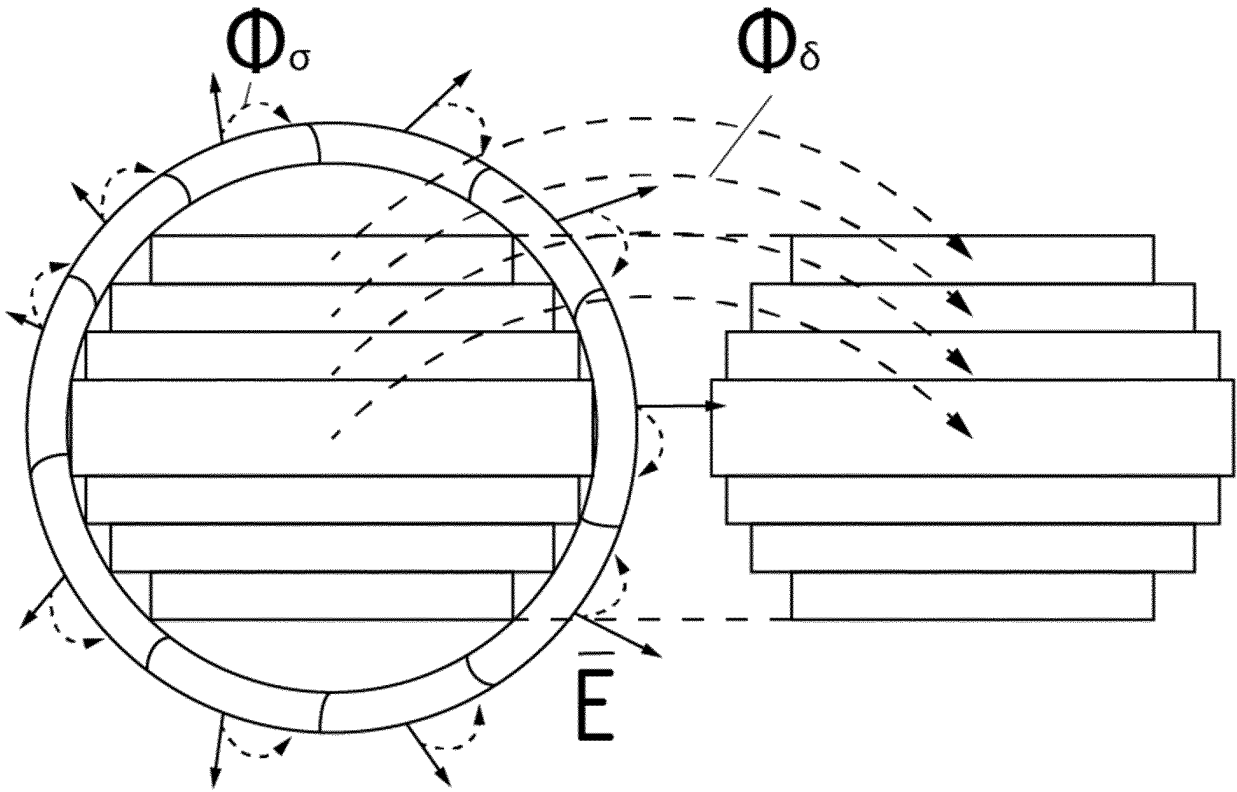


FIG. 11

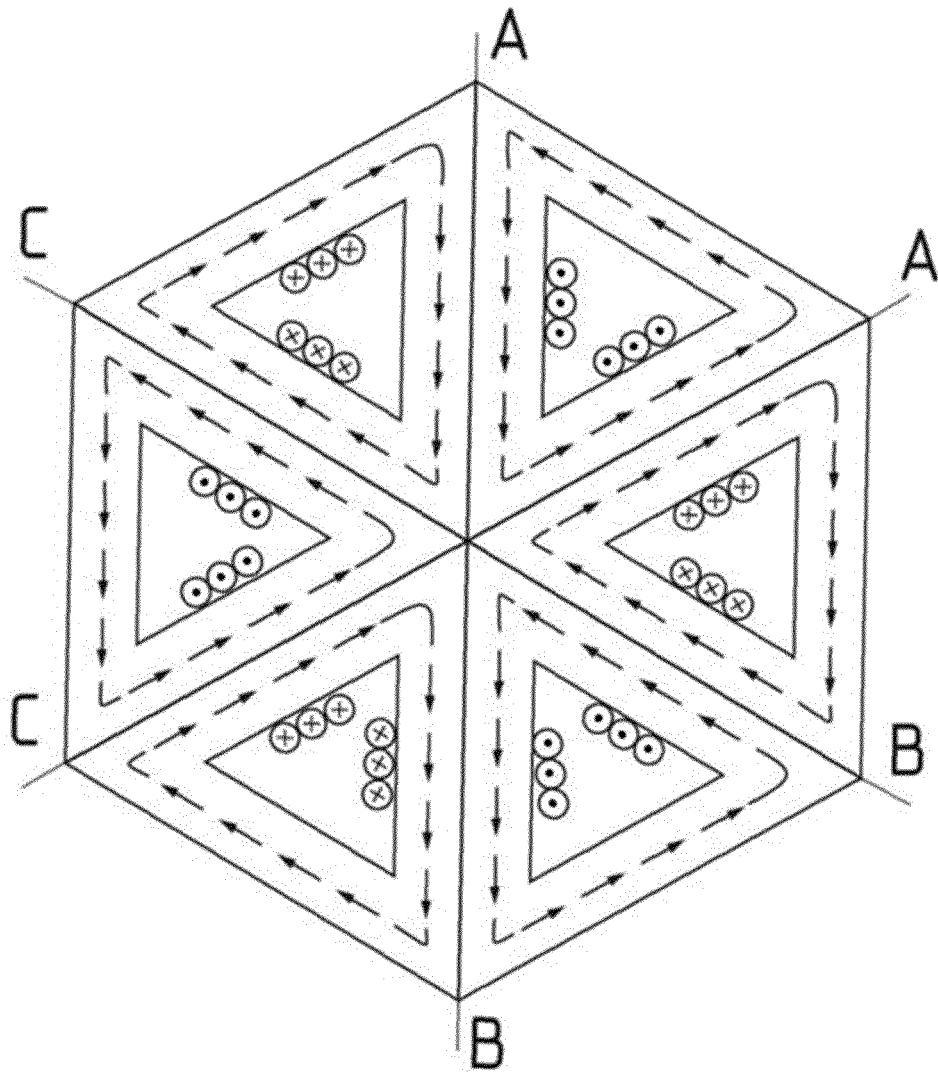


FIG. 12

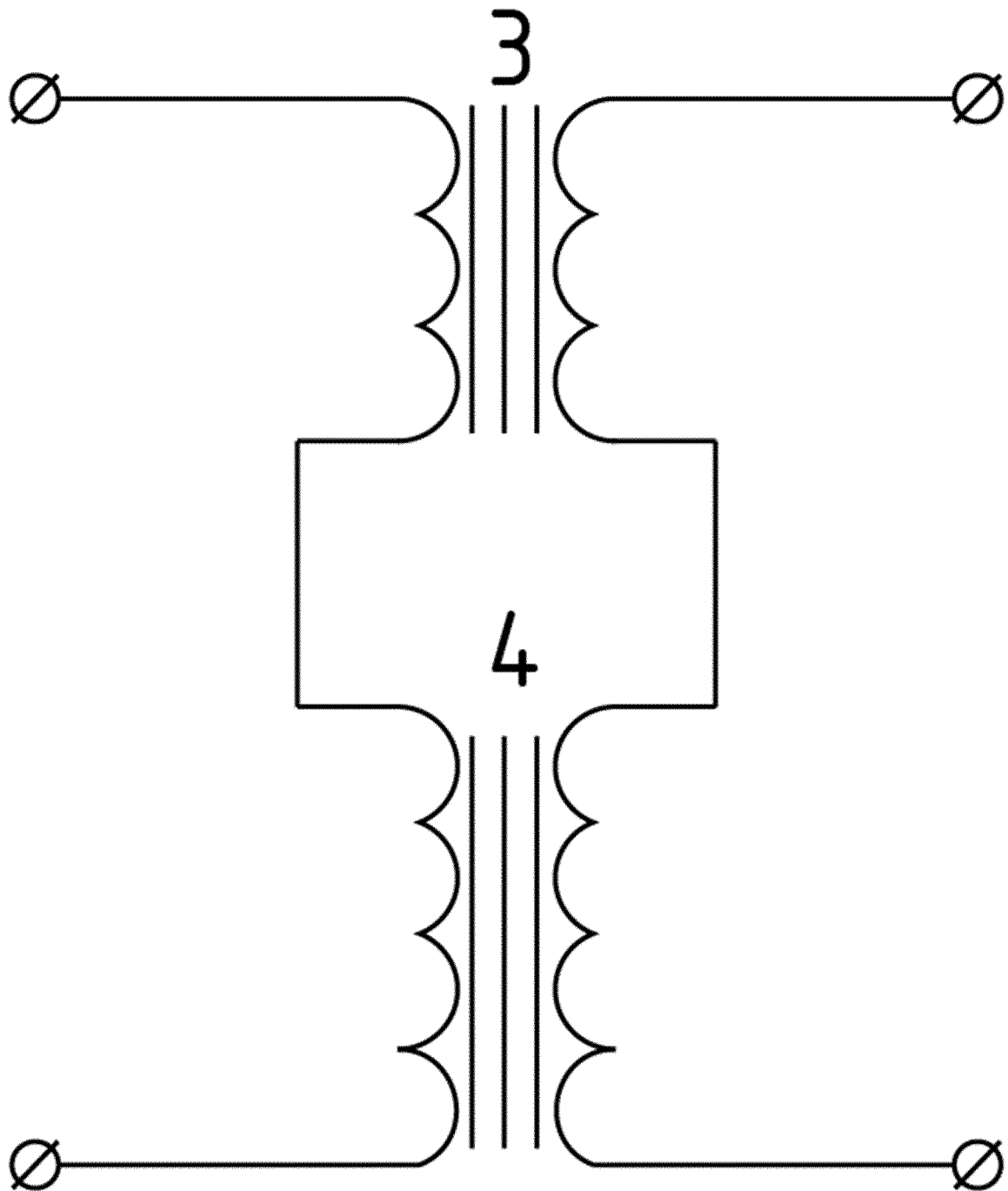


FIG. 13

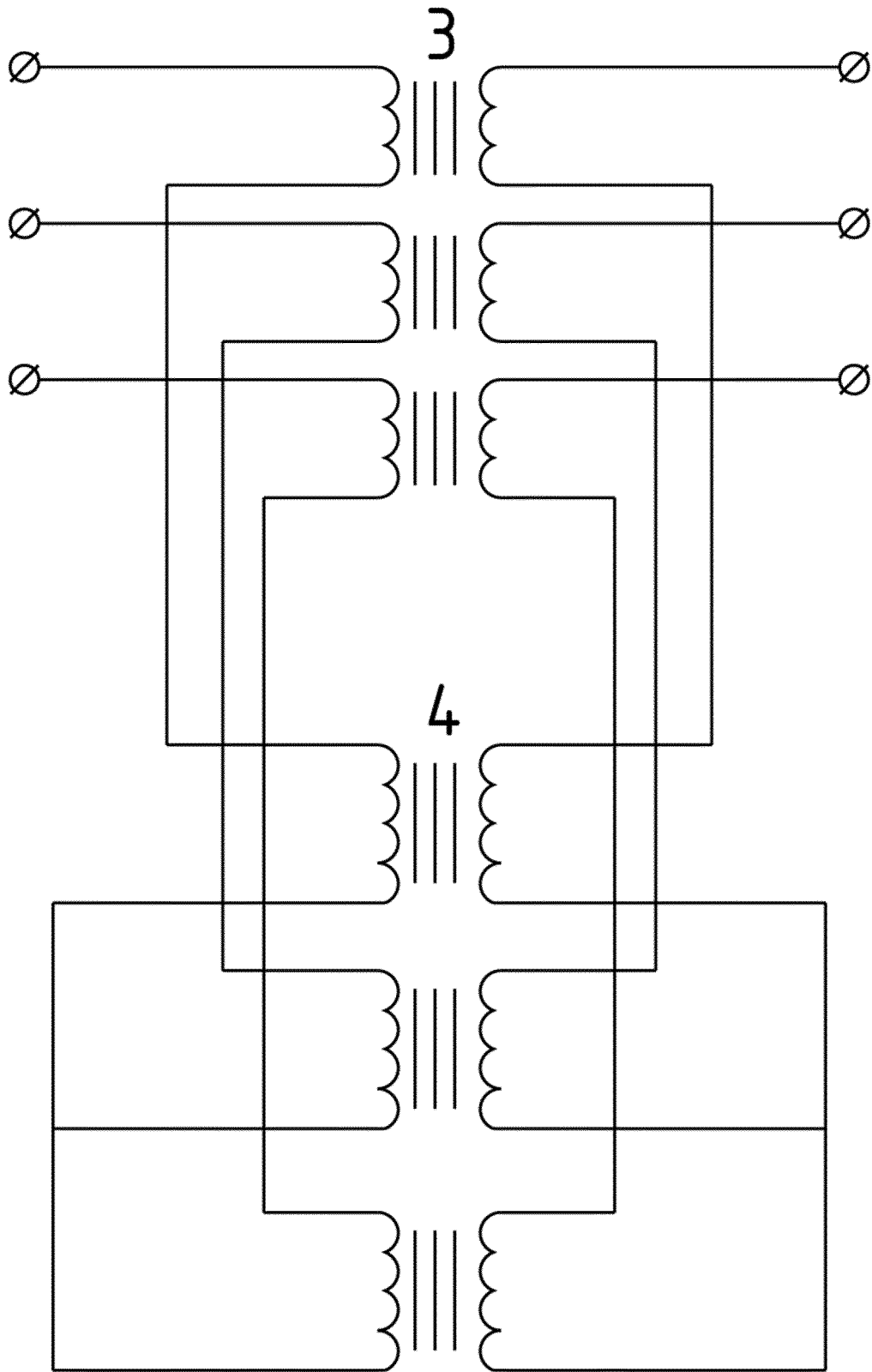


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/UA2021/000065

5	A. CLASSIFICATION OF SUBJECT MATTER H01F 27/24	
	According to International Patent Classification (IPC) or to both national classification and IPC	
10	B. FIELDS SEARCHED	
	Minimum documentation searched (classification system followed by classification symbols) H01F	
	Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched	
15	Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Espacenet, Google Patents	
20	C. DOCUMENTS CONSIDERED TO BE RELEVANT	
	Category*	Citation of document, with indication, where appropriate, of the relevant passages
		Relevant to claim No.
25	A	RU 2041515 C1 (KRIVONOSOV GENNADIY ALEKSANDROVICH [UA]) 09 August 1995 (1995-08-09) (the entire document)
		1-3
30	A	UA 119130 C2 (BILYI LEONID ADAMOVIYCH [UA]) 25 April 2019 (2019-04-25) (the entire document)
		1-3
	A	UA 79028 C2 (NATSIONALNY UNIVERSITET KORABLESTROENIYA IMENI ADMIRALA MAKAROVA [UA]) 10 May 2007 (2007-05-10) (the entire document)
		1-3
35	A	GB 994898 A (JOHN ANDERS GULOW [US]) 10 June 1965 (1965-06-10) (the entire document)
		1-3
	A	CN 111223646 A (YANG YUGANG [CN]) 02 June 2020 (2020-06-02) (the entire document)
		1-3
40	<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.	
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50	Date of the actual completion of the international search 31 December 2021 (31.12.2021)	Date of mailing of the international search report 14 January 2022 (14.01.2022)
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55	Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/UA2021/000065

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REFERENCES CITED IN THE DESCRIPTION

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