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(54) **Titre : MOTEUR A INDUCTION HYBRIDE A ROTOR A INDUCTION/AIMANTS PERMANENTS HYBRIDE A ALIGNEMENT AUTOMATIQUE**
(54) **Title: HYBRID INDUCTION MOTOR WITH SELF ALIGNING HYBRID INDUCTION/PERMANENT MAGNET ROTOR**

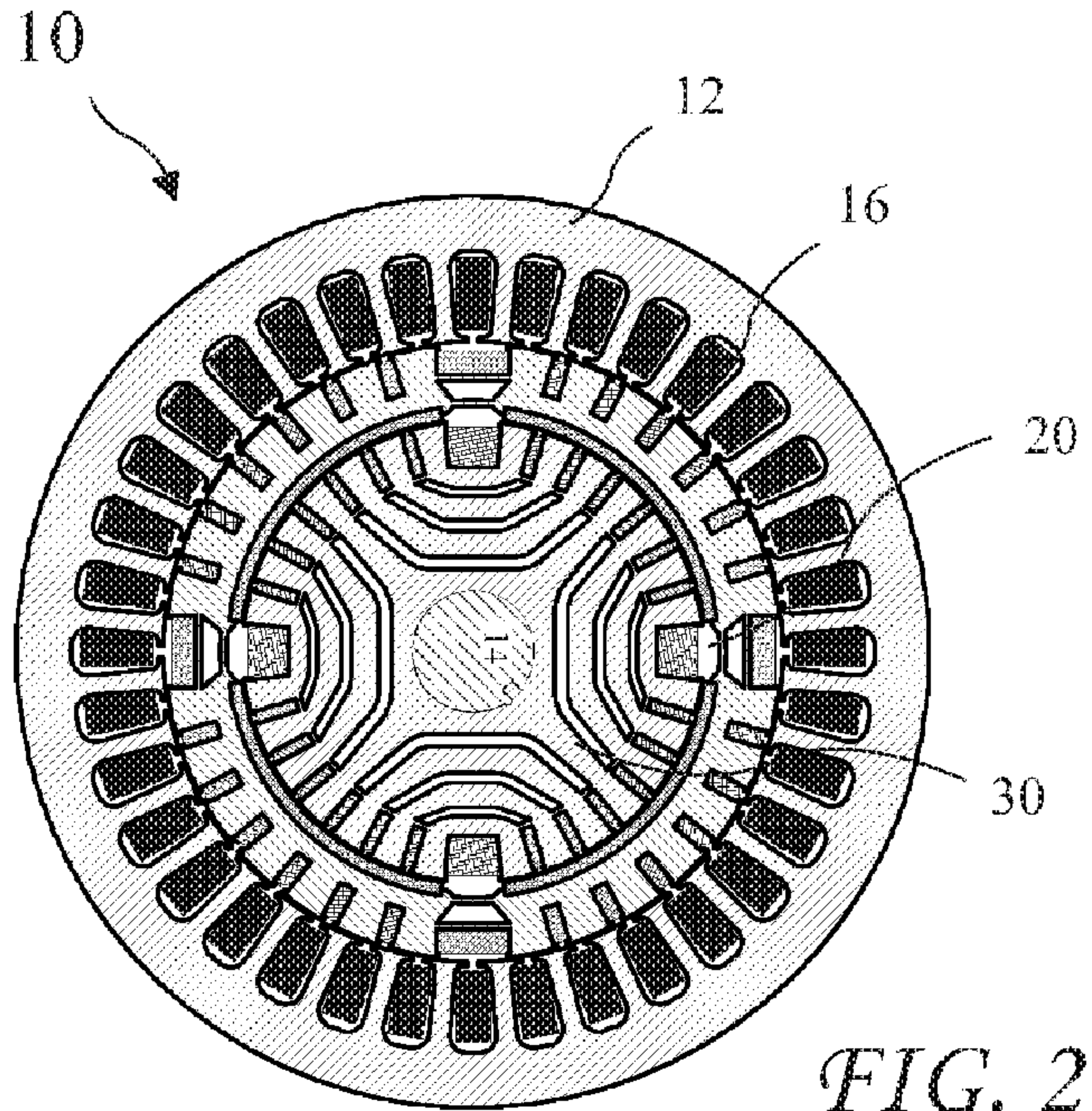

FIG. 2

(57) **Abrégé/Abstract:**
A hybrid induction motor 10 includes a fixed stator 16, an independently rotating outer rotor 20, and an inner rotor 30 fixed to a motor shaft 14. The outer rotor 20 is designed to have a low moment of inertia and includes angularly spaced apart first bars 26a,26b and permanent magnets 22 on an inner surface of the outer rotor 20. The inner rotor 30 includes angularly spaced apart second bars 32a and 32b and interior flux barriers 38 aligned with the second bars 32a and 32b. The outer rotor 20 is initially accelerated by cooperation of a rotating stator magnetic field with the first bars. As the outer rotor 20 accelerates towards synchronous RPM, a rotating magnetic field of the permanent magnets cooperate with the second bars of the inner rotor 30 to accelerate the inner rotor 30. At near synchronous speed the rotating stator magnetic field reaches through the outer rotor 20 and into the inner rotor 30 coupling the two rotors 20, 30 for efficient permanent magnet operation.

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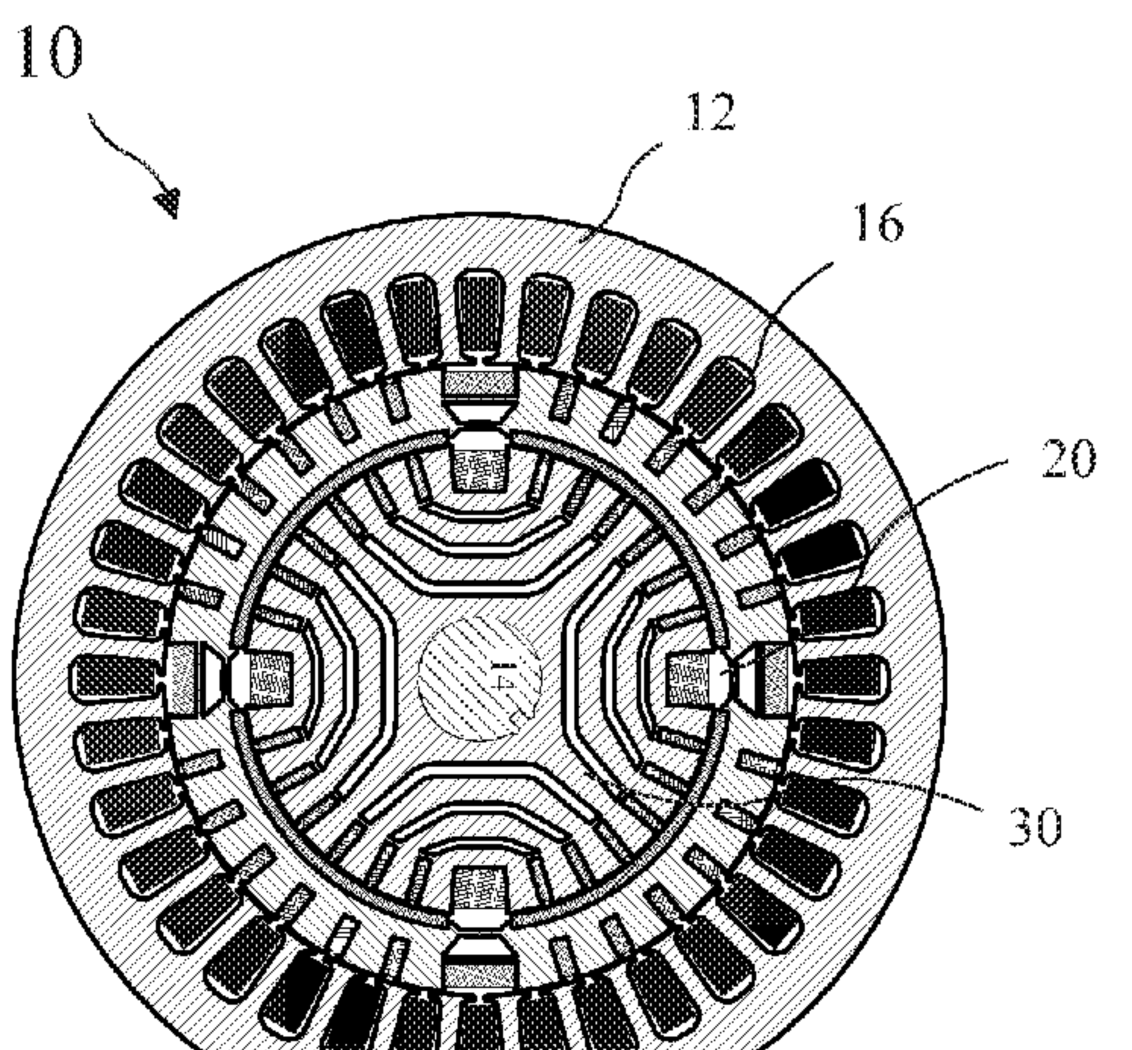

FIG. 2

(57) Abstract: A hybrid induction motor 10 includes a fixed stator 16, an independently rotating outer rotor 20, and an inner rotor 30 fixed to a motor shaft 14. The outer rotor 20 is designed to have a low moment of inertia and includes angularly spaced apart first bars 26a,26b and permanent magnets 22 on an inner surface of the outer rotor 20. The inner rotor 30 includes angularly spaced apart second bars 32a and 32b and interior flux barriers 38 aligned with the second bars 32a and 32b. The outer rotor 20 is initially accelerated by cooperation of a rotating stator magnetic field with the first bars. As the outer rotor 20 accelerates towards synchronous RPM, a rotating magnetic field of the permanent magnets cooperate with the second bars of the inner rotor 30 to accelerate the inner rotor 30. At near synchronous speed the rotating stator magnetic field reaches through the outer rotor 20 and into the inner rotor 30 coupling the two rotors 20, 30 for efficient permanent magnet operation.

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SPECIFICATION

HYBRID INDUCTION MOTOR WITH SELF ALIGNING HYBRID INDUCTION/PERMANENT MAGNET ROTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the priority of US Patent Application Serial No. 15/438,023 filed February 21, 2017, which application is incorporated in its entirety herein by reference.

Technical field

[0002] The present invention relates to electric motors and in particular to an induction motor having an independently rotating permanent magnet rotor variably coupled to an inductive rotor to reconfigure the motor from asynchronous induction operation at startup to synchronous operation after startup for efficient operation.

Background Art

[0003] A preferred form of electric motors are brushless AC induction motors. The rotors of induction motors include a cage (or squirrel cage resembling a “hamster wheel”) rotating inside a stator. The cage comprises axially running bars angularly spaced apart on the outer perimeter of the rotor. An AC current provided to the stator introduces a rotating stator magnetic field inside the rotor, and the rotating field inductively induces current in the bars. The current induced in the bars creates an induced magnetic field which cooperates with the stator magnetic field to produce torque and thus rotation of the rotor.

[0004] The introduction of current into the bars requires that the bars are not moving (or rotating) synchronously with the rotating stator magnetic field because electromagnetic induction requires relative motion (called slipping) between a magnetic field and a conductor in the field. As a result, the rotor must slip with respect to the rotating stator magnetic field to induce current in the bars to produce torque, and the induction motors are therefore called asynchronous motors.

[0005] Unfortunately, low power induction motors are not highly efficient at designed operating speed, and are even less efficient under reduced loads because the amount of power consumed by the stator remains constant at such reduced loads.

[0006] One approach to improving induction motor efficiency has been to add permanent magnets to the rotor. The motor initially starts in the same manner as a typical induction motor, but as the motor reached its operating speed, the stator magnetic field cooperates with the permanent magnets to enter synchronous operation. Unfortunately, the permanent magnets create transient breaking torque and undesirable anomalies until synchronization occurs because of the changing magnetic pole alignment between the stator and PM cage rotor. Further the permanent magnets are limited in size because if the permanent magnets are too large, they over power the stator flux producing a very poor or unsuccessful starting of motor. Such size limitation limits the benefit obtained from the addition of the permanent magnets.

[0007] US Patent Application Serial No. 14/151,333 filed January 09, 2014 filed by the present Applicant discloses an electric motor having an outer stator, an inner rotor including bars, fixed to a motor shaft, and a free spinning outer rotor including permanent magnets and bars, residing between the inner rotor and the stator. At startup, a rotating stator magnetic field accelerates the free spinning outer rotor, and after accelerating, the permanent magnets of the free spinning outer rotor accelerate and then lock with the inner rotor to achieve efficient permanent magnet operation.

[0008] The design of the ‘333 application is suitable for some motor designs, but in other designs, surface effects on the surface of the inner rotor reduce coupling of the inner rotor with the rotating magnetic fields.

Disclosure of the Invention

[0009] The present invention addresses the above and other needs by providing a hybrid induction motor includes a fixed stator, an independently rotating outer rotor, and an inner rotor fixed to a motor shaft. The outer rotor is designed to have a low moment of inertia and includes angularly spaced apart first bars and permanent magnets on an inner surface of the outer rotor. The inner rotor includes angularly spaced apart second bars and interior flux barriers aligned with the second bars. The outer rotor is initially accelerated by cooperation of a rotating stator magnetic field with the first bars. As the outer rotor accelerates towards synchronous RPM, a rotating magnetic field of the permanent magnets cooperate with the second bars of the inner rotor to accelerate the inner rotor. At near synchronous speed the rotating stator magnetic field reaches through the outer rotor and into the inner rotor coupling the two rotors for efficient permanent magnet operation.

[0010] In accordance with one aspect of the invention, there is provided a hybrid induction motor which includes a fixed stator, an independently rotating Hybrid Permanent Magnet/squirrel Cage (HPMSC) outer rotor, and a Squirrel Cage (SC) inner rotor fixed to a motor shaft. The HPMSC outer rotor has a multiplicity of angularly spaced apart first bars proximal to an outer surface of the HPMSC outer rotor, and a plurality of permanent magnets on an inner surface of the HPMSC outer rotor. The SC inner rotor has a multiplicity of angularly spaced apart second bars proximal to an outer surface of the SC inner rotor, and magnetic flux barriers aligned with the second bars in rotor laminates. The flux barriers establish lines of stator magnetic flux though the HPMSC outer rotor and the SC inner rotor at synchronous speed to couple the HPMSC outer rotor and the SC inner rotor.

[0011] The HPMSC outer rotor is initially accelerated by cooperation of the rotating stator magnetic field with the first bars. Once the HPMSC outer rotor is rotating, the permanent magnets create a rotating magnetic field in the SC inner rotor cooperating with the second bars to accelerate the SC inner rotor. As the HPMSC outer rotor accelerates towards synchronous RPM, the stator magnetic field reaches through the HPMSC outer rotor and cooperates with the permanent magnets, and into the SC inner rotor coupling the HPMSC and SC inner rotors, to transition to synchronous operation.

[0012] In accordance with yet another aspect of the invention, there is provided a motor having stronger permanent magnets than known Line Start Permanent Magnet (LSPM). Known LSPM motors are limited by braking and pulsating torques caused by the permanent magnets. The first bars and magnets of the HPMSC outer rotor are light weight and the HPMSC rotor outer is decoupled from the motor shaft and load at startup, allowing stronger permanent magnets than the known LSPM motors. The stronger permanent magnets provide improved efficiency.

[0013] In accordance with yet another aspect of the invention, there is provided a motor having outer bars of an HPMSC outer rotor aligned with inner bars of an SC inner rotor. At synchronous speed magnetic field lines of the rotating stator magnetic field pass between the aligned bars and into the SC inner rotor to couple the HPMSC outer rotor and the SC inner rotor.

[0014] In accordance with still another aspect of the invention, there is provided a motor having a number of larger squirrel cage bars mixed with smaller squirrel cage bars of the HPMSC outer rotor. The larger bars improve the structural strength of the HPMSC outer rotor.

[0015] In accordance with another aspect of the invention, there is provided a method according to the present invention. The method includes providing electrical current to a stator, generating a rotating stator magnetic field, the rotating stator magnetic field inductively cooperating with a squirrel cage of an HPMSC outer rotor, the rotating stator magnetic field accelerating the HPMSC outer rotor, permanent magnets of the HPMSC outer rotor generating a rotating permanent magnet magnetic field, the rotating permanent magnet magnetic field inductively cooperating with a squirrel cage of an SC inner rotor, the rotating stator magnetic field accelerating the SC outer rotor, the HPMSC outer rotor and SC inner rotor approaching synchronous speed, and the HPMSC outer rotor and SC inner rotor magnetically coupling at synchronous speed.

[0016] In accordance with yet another aspect of the invention, there is provided a hybrid induction motor according to the present invention including a Hybrid Permanent Magnet Hysteresis (HPMH) outer rotor. An eddy current ring (or hysteresis) inductive starting element replaces the squirrel cage of the HPMSC outer rotor to provide initial starting torque. Once the HPMH outer rotor reaches synchronous speed, the inductive starting element has no effect on motor operation. The eddy current ring may be any electrically conductive material would be potential material for starting element and is commonly hard chrome or cobalt steel but may be any non ferrous material. A preferably material for the HPMH outer rotor ring of the present invention is copper which is efficient because of its high electrical conductivity. Silver is slightly better performing than copper having better electrical conductivity and aluminum is lower performing than copper having less electrical conductivity. Potentially, new nano technology and a new class of highly conductive material could offer better performance than copper.

Brief Description of the Drawing

[0017] The above and other aspects, features and advantages of the present invention will be more apparent from the following more particular description thereof, presented in conjunction with the following drawings wherein:

[0018] FIG. 1A shows an end view of an electric motor having an independently rotating Hybrid Permanent Magnet/squirrel Cage (HPMSC) outer rotor and a Squirrel Cage (SC) inner rotor fixedly coupled to a motor shaft, according to the present invention.

[0019] FIG. 1B shows a side view of the electric motor having an independently rotating HPMSC outer rotor and a Squirrel Cage (SC) inner rotor fixedly coupled to a motor shaft, according to the present invention.

[0020] FIG. 2 shows a cross-sectional view of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 2-2 of FIG. 1B, according to the present invention.

[0021] FIG. 3 shows a cross-sectional view of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 3-3 of FIG. 1A, according to the present invention.

[0022] FIG. 4 shows a cross-sectional view of a housing and fixed stator portion of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 2-2 of FIG. 1B, according to the present invention.

[0023] FIG. 5 shows a cross-sectional view of the housing and the fixed stator portion of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 5-5 of FIG. 4, according to the present invention.

[0024] FIG. 6 shows a cross-sectional view of the independently rotating HPMSC outer rotor of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 2-2 of FIG. 1B, according to the present invention.

[0025] FIG. 7 shows a cross-sectional view of the independently rotating HPMSC outer rotor of the electric motor having the independently rotating HPMSC outer rotor and the

SC inner rotor fixedly coupled to a motor shaft taken along line 7-7 of FIG. 6, according to the present invention.

[0026] FIG. 8 shows a cross-sectional view of an SC inner rotor of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 2-2 of FIG. 1B, according to the present invention.

[0027] FIG. 9 shows a cross-sectional view of the SC inner rotor of the electric motor having the independently rotating HPMSC outer rotor and the SC inner rotor fixedly coupled to a motor shaft taken along line 9-9 of FIG. 8, according to the present invention.

[0028] FIG. 10 shows a cross-sectional view of a sixth embodiment of a motor having a hybrid inductive/permanent magnet outer rotor according to the present invention.

[0029] FIG. 10A shows a cross-sectional view of a stator of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor according to the present invention.

[0030] FIG. 10B shows a cross-sectional view of the hybrid inductive/permanent magnet outer rotor of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor according to the present invention.

[0031] FIG. 10C shows a cross-sectional view of an inner inductive rotor of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor according to the present invention.

[0032] FIG. 11A shows magnetic field lines of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at startup according to the present invention.

[0033] FIG. 11B shows magnetic field lines of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at synchronous speed according to the present invention.

[0034] FIG. 12A shows magnetic field lines of a two pole embodiment of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at synchronous speed, excluding the stator, according to the present invention.

[0035] FIG. 12B shows magnetic field lines of a four pole embodiment of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at synchronous speed, excluding the stator, according to the present invention.

[0036] FIG. 12C shows magnetic field lines of a six pole embodiment of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at synchronous speed, excluding the stator, according to the present invention.

[0037] FIG. 12D shows magnetic field lines of an eight pole embodiment of the sixth embodiment of the motor having a hybrid inductive/permanent magnet outer rotor at synchronous speed, excluding the stator, according to the present invention.

[0038] FIG. 13 shows a method according to the present invention.

[0039] FIG. 14 shows a time line for rotations according to the present invention.

[0040] FIG. 15 shows a cross-sectional view of an embodiment of the present invention including a Hybrid Permanent Magnet Hysteresis (HPMH) outer rotor.

[0041] FIG. 16A is a cross-sectional side view of the embodiment of the present invention including an HPMH outer rotor.

[0042] FIG. 16B is an exploded cross-sectional side view of the embodiment of the present invention including an HPMH outer rotor.

[0043] FIG. 17 is a cross-sectional side view of the HPMH outer rotor according to the present invention.

[0044] FIG. 18 is a cross-sectional side view of a second SC inner rotor according to the present invention.

[0045] Corresponding reference characters indicate corresponding components throughout the several views of the drawings.

Best Mode for Carrying out the Invention

[0046] The following description is of the best mode presently contemplated for carrying out the invention. This description is not to be taken in a limiting sense, but is made merely for the purpose of describing one or more preferred embodiments of the invention. The scope of the invention should be determined with reference to the claims.

[0047] The term “not mechanically coupled” is used herein to describe a first structure connection to second structure through bearings, and no other mechanical/material connection exists between the first and second structure. The structures may however be magnetically coupled which is not considered a mechanical coupled in the present patent application.

[0048] An end view of an electric motor 10 having an independently rotating Hybrid Permanent Magnet/squirrel Cage (HPMSC) outer rotor 20 and a Squirrel Cage (SC) inner rotor 30 fixedly coupled to a motor shaft 14, according to the present invention is shown in FIG. 1A, and a side view of the electric motor 10 is shown in FIG. 1B. A cross-sectional view of the electric motor 10 taken along line 2-2 of FIG. 1B, is shown in FIG. 2 and a cross-sectional view of the electric motor 10 taken along line 3-3 of FIG. 1A is shown in FIG. 3. The electric motor 10 includes a housing 12, a stator portion 16 fixedly coupled to the housing 12, the independently rotating HPMSC outer rotor 20 riding on bearings 29 (see FIG. 7), and the SC inner rotor 30 fixed to the motor shaft 14. The HPMSC outer rotor 20 is mounted to the motor shaft 14 by bearings and is not mechanically coupled to rotate with the motor shaft 14.

[0049] A cross-sectional view of the housing 12 and fixed stator portion 16 of the electric motor 10 taken along line 2-2 of FIG. 1B, is shown in FIG. 4 and a cross-sectional view of the housing 12 and the fixed stator portion 16 taken along line 5-5 of FIG. 4, is shown in FIG. 5. Fixed stator windings 18 reside in a stator core 19. The stator windings 18 create a rotating stator magnetic field when provided with an Alternating Current (AC) signal. The housing 12 includes bearings 13 for carrying the shaft 14.

[0050] A cross-sectional view of the independently rotating HPMSC outer rotor 20 taken along line 2-2 of FIG. 1B, is shown in FIG. 6 and a cross-sectional view of the independently rotating HPMSC outer rotor 20 taken along line 7-7 of FIG. 6, is shown in FIG. 7. The HPMSC outer rotor 20 includes angularly spaced apart permanent magnets 22 on an interior of the HPMSC outer rotor 20 and angularly spaced apart first bars 26a and 26b residing proximal to an outer surface of the HPMSC outer rotor 20 embedded in a core (or laminate) 23. The HPMSC outer rotor 20 may include any even number of permanent magnets 22, for example, two, four, six, eight, etc. permanent magnets 22 (see FIGS. 12A-12D). Non-ferrous voids 24 in the rotor core 23 are present between the permanent magnets 22. The voids 24 are air gaps or non ferrous material to provide flux barriers, if a ferrous material was present between the magnets 22, magnetic flux would curl back into the magnets 22, shorting much of the magnetic flux lines back into the magnets 22. The core 23 is preferably a laminated core and thin laminates 23a of the core 23 forming the core 23 may result in flux leakage. The thickness of the laminates 23a is preferably optimized to minimize the leakage while maintaining mechanical integrity of the rotor core laminates 23. The bars 26a and 26b are preferably evenly angularly spaced apart. The magnets 22 are preferably neodymium magnets bonded to an inside surface of the rotor core 23.

[0051] The HPMSC outer rotor 20 may include only minor bars 26a but preferably also includes larger major bars 26b providing structural strength. The major bars 26b preferably reside angularly(i.e., may be spaced out radially) between the permanent magnets 22 and the number of major bars 26b preferably us the same as the number of magnets 22. The voids 24 preferably reside under the major bars 26b. The bars 26a and 26b are preferably made of a light weight material, for example, aluminum. The magnets 22 are also preferably made of a light weight material, and are preferably rare earth magnets allowing lighter weight for a given magnet strength. The light weight of the bars 26a and 26, and the magnets 22, reduce the moment of inertia of the HPMSC outer rotor 20 allowing the HPMSC outer rotor 20 to overcome braking and pulsating torques caused by the permanent magnets 22, thus allowing stronger permanent magnets 22 and greater efficiency than a LSPM motor. A balance between bars 26a and 26b resistance and rotor core 23 saturation may be optimized and the shape, number and dimensions of the bars 26a and 26b may have great effect on performance, for example, motor startup.

[0052] Rotor end caps 28 are attached to opposite ends of the HPMSC outer rotor 20 and include bearings 29 allowing the HPMSC outer rotor 20 to rotate freely on the motor shaft 14. The bearings 29 are preferably low friction bearings (for example, ball bearings or roller bearings), but may simple be bushings (for example, bronze bushings, oilite bushings, or Kevlar® bushings). The HPMSC outer rotor 20 is not mechanically coupled to rotate with the SC inner rotor 30 or the motor shaft 14 at any time.

[0053] A cross-sectional view of the SC inner rotor 30 of the electric motor 10 taken along line 2-2 of FIG. 1B, is shown in FIG. 8 and a cross-sectional view of the SC inner rotor 30 of the electric motor 10 taken along line 9-9 of FIG. 8, is shown in FIG. 9. The SC inner rotor 30 is fixed to the motor shaft 14 and cooperates with the HPMSC outer rotor 20 to magnetically couple the HPMSC outer rotor 20 to the motor shaft 14 at synchronous speed. Second minor bars 32a and major bars 32b reside in a second rotor core (or laminate) 36. The bars 32a and 32b are not necessarily, but are preferably evenly angularly spaced apart. The major bars 32b add structural strength to the SC inner rotor 30 and help direct lines of magnetic flux 50 (see FIG. 11B).

[0054] A detailed cross-sectional view of the motor 10 is shown in FIG. 10, a cross-sectional view of a stator 16 of the motor 10 is shown in FIG. 10A, a cross-sectional view of the HPMSC outer rotor 20 of the motor 10 is shown in FIG. 10B, and a cross-sectional view of a SC inner rotor 30 of the motor 10 is shown in FIG. 10C. The stator 16 includes stator windings 18 in a laminate 19 creating a rotating stator magnetic field.

[0055] The HPMSC outer rotor 20 is rotationally coupled to the motor shaft through bearings 29 (see FIG. 7) and includes the minor squirrel cage bars 26a and the major squirrel cage bars 26b, the bars 26a and 26b are embedded in the laminate 23. The permanent magnets 24 reside on an inner surface of the HPMSC outer rotor 20 facing the SC inner rotor 30.

[0056] The SC inner rotor 30 includes the minor bars 32a and the major bars 32b. The flux barriers 38 follow a concave path through the laminate 36 and outer ends of the flux barriers 38 are generally aligned with the minor bars 32a. Both the minor bars 32a and the major bars 32b are slightly recessed into the laminate 36.

[0057] Magnetic field lines 42a between the stator windings 18 and the bars 26a and 26b at startup and magnetic field lines 42b between the permanent magnets 22 and the bars 32a and 32b of the motor 10 just after at startup are shown in FIG. 11A. The magnetic field lines 42a result from slippage of the bars 26a and 26b with respect to the rotating stator magnetic field. The magnetic field lines 42a are immediately present at startup because the HPMSC outer rotor 20 is stationary at startup, and slippage is present between the stationary HPMSC outer rotor 20 and the rotating stator magnetic field. The slippage results in current generation in the bars 26 through magnetic induction, and the current produces torque on the HPMSC outer rotor 20 to accelerate the HPMSC outer rotor 20.

[0058] Nearly immediately after startup, as the HPMSC outer rotor 20 begins to rotate, slippage is developed between the permanent magnets 22 of the HPMSC outer rotor 20 and the bars 32a and 32b of the SC inner rotor 30, producing the magnetic field lines 42b. It is an important feature of the motor 10 that the magnetic field lines 42b are not present immediately at startup, because such magnetic field lines rotationally couple the HPMSC outer rotor 20 to the SC inner rotor, creating resistance to acceleration of the HPMSC outer rotor 20. Such resistance may prevent the HPMSC outer rotor 20 from overcoming the braking and pulsating torques caused by the permanent magnets in know LSPM motors, and limit the strength of the permanent magnets 22, thus limiting the efficiency of the motor 10. The motor 10 is thus self regulating, only coupling the HPMSC outer rotor 20 to the SC inner rotor 30 and motor shaft 14, after the HPMSC outer rotor 20 has overcome the braking and pulsating torques.

[0059] Magnetic field lines 50 between the stator windings 18 and the permanent magnets 22, and further penetrating the SC inner rotor 30 of the motor 10 at synchronous speed, are shown in FIG. 11B. At synchronous speed, there is no slippage between the rotating stator magnetic field and the bars 26a, 26b, 32a, and 32b, and therefore no electrical cooperation between the rotating stator magnetic field and the bars 26a, 26b, 32a, and 32b. The rotating stator magnetic field now cooperates fully with the permanent magnets 22, and is guided though the SC inner rotor by the flux barriers 38.

[0060] Magnetic field lines of a two pole embodiment of the motor 10, excluding the stator 16, are shown in FIG. 12A, magnetic field lines of a four pole embodiment of the motor 10, excluding the stator 16, are shown in FIG. 12B, magnetic field lines of a six pole embodiment of the motor 10, excluding the stator 16, are shown in FIG. 12C, and magnetic field lines of an eight pole embodiment of the motor 10, excluding the stator 16, are shown in FIG. 12D.

[0061] A method according to the present invention is shown in FIG. 13. The method includes providing electrical current to a stator at step 100, generating a rotating stator magnetic field at step 102, the rotating stator magnetic field inductively cooperating with a squirrel cage of an HPMSC outer rotor at step 104, the rotating stator magnetic field accelerating the HPMSC outer rotor at step 106, permanent magnets of the HPMSC outer rotor generating a rotating permanent magnet magnetic field at step 108, the permanent magnet magnetic field combining with the rotating stator magnetic field to form a joint rotating magnetic field at step 110, the joint rotating magnetic field inductively cooperating with a squirrel cage of an SC inner rotor at step 112, the joint rotating magnetic field accelerating the SC inner rotor at step 114, the SC inner rotor approaching synchronous speed at step 116, and the HPMSC outer rotor and SC inner rotor magnetically coupling at synchronous speed at step 118. An important feature of the method being that the HPMSC outer rotor is not coupled to the SC inner rotor until the HPMSC outer rotor is rotating, and can thus overcome the braking and pulsating torques which limit permanent magnet strength in LSPM motors.

[0062] A hybrid electric motor having an HPMSC outer rotor and an SC inner rotor is described. The HPMSC outer rotor includes first electrically conductive squirrel cage bars embedded in a first rotor core and a number of the permanent magnets on an inner surface of the second rotor core, the HPMSC outer rotor residing between the stator and SC inner rotor and coaxial with the motor shaft, and is not mechanically coupled to rotate with the motor shaft during any operation. The SC inner rotor is fixed to the motor shaft residing coaxial with the motor shaft and having a second rotor core, and a second electrically conductive squirrel cage bars embedded in the second rotor core, and flux barriers guiding the rotating stator filed through the SC inner rotor at synchronous speed. Those skilled in the art will recognize other embodiments with different numbers of magnets, bars, and flux barriers not described here, but relying on the principles disclosed here, and those embodiments are intended to come within the scope of the present invention.

[0063] A time line for rotations of the stator magnetic field, the HPMSC outer rotor magnetic field, and the SC inner rotor magnetic field are shown in FIG. 14.

[0064] A cross-sectional view of a second hybrid induction motor 10' of the present invention including a Hybrid Permanent Magnet Hysteresis (HPMH) outer rotor 20' is shown in FIG. 15. The inductive starting element is an eddy current (or hysteresis) ring 60 (see FIG. 16) which replaces the squirrel cage 26a and 26b of the HPMSC outer rotor 20 (see FIG. 6) to provide initial starting torque. The major squirrel cage bars 32b of the SC inner rotor are not required and not shown in the hybrid induction motor 10'. The hybrid induction motor 10' is otherwise similar to the hybrid induction motor 10.

[0065] A cross-sectional side view of the hybrid induction motor 10' including an HPMH outer rotor is shown in FIG. 16A and an exploded cross-sectional side view of the hybrid induction motor 10' including an HPMH outer rotor is shown in FIG. 16B.

[0066] A cross-sectional side view of the HPMH outer rotor according to the present invention showing the eddy current ring 60 is shown in FIG. 17. Once the HPMH outer rotor 20' reaches synchronous speed, the eddy current ring 60 has no effect on motor operation. The eddy current ring 60 may be any electrically conductive material would be potential material for starting element and is commonly hard chrome or cobalt steel but may be any non ferrous material. A preferably material for the HPMH outer rotor ring of the present invention is copper which is efficient because of its high electrical conductivity. Silver is slightly better performing than copper having better electrical conductivity and aluminum is lower performing than copper having less electrical conductivity. Potentially, new nano technology and a new class of highly conductive material could offer better performance than copper.

[0067] A cross-sectional side view of the second SC inner rotor 30' is shown in FIG. 18. The SC inner rotor 30' does not show the major squirrel cage bars 32b which may be present, but are not necessary. The SC inner rotor 30' is otherwise similar to the SC inner rotor 30.

Industrial Applicability

[0068] The present invention finds industrial applicability in the field of electric motors.

Scope of the Invention.

[0069] While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention set forth in the claims.

I CLAIM:

1. A hybrid squirrel cage/permanent magnet motor comprising:

a motor housing;

a stator fixed to the motor housing and producing a rotating stator magnetic field;

a motor shaft rotatably connected to the motor housing and extending from at least one end of the motor housing for attachment to a load;

an inner rotor rotationally fixed to the motor shaft residing coaxial with the motor shaft, the inner rotor including:

a second rotor core;

second electrically conductive squirrel cage bars embedded in the second rotor core; and

flux barriers inside the second rotor core, the flux barriers guiding the rotating stator magnetic field through the second rotor core during synchronous operation;

an outer rotor residing between the stator and inner rotor and coaxial with the motor shaft and not rotationally mechanically coupled to the motor shaft to rotate with the motor shaft and including:

a first rotor core;

inductive elements configured to cooperate with a rotating stator magnetic field to provide torque at startup; and

permanent magnets residing on an interior surface of the first rotor core.

2. The motor of Claim 1, wherein the flux barriers are voids in the second rotor core.

3. The motor of Claim 2, wherein the flux barriers are concave paths connecting interior ends of the second electrically conductive squirrel cage bars.

4. The motor of Claim 3, wherein the inductive elements comprise a multiplicity of angularly spaced apart squirrel cage bars embedded in an exterior surface of the first rotor core.

5. The motor of Claim 4, wherein the first electrically conductive squirrel cage bars comprise a multiplicity of angularly spaced apart first minor squirrel cage bars separated into equal number groups angularly separated by first major squirrel cage bars, the number of groups and the number of first major squirrel cage bars equal to the number of poles of the motor.

6. The motor of Claim 5, wherein the second electrically conductive squirrel cage bars are embedded angularly spaced apart in a second exterior surface of the second rotor core.

7. The motor of Claim 2, wherein:

the inductive elements comprise a multiplicity of angularly spaced apart squirrel cage bars embedded in an exterior surface of the first rotor core; and small gaps are present between the first electrically conductive squirrel cage bars and a surface of the outer rotor.

8. The motor of Claim 7, wherein the small gaps are non-ferrous gaps.

9. The motor of Claim 7, wherein the small gaps are voids.

10. The motor of Claim 2, wherein the inductive elements comprise an eddy current ring surrounding the outer rotor.

11. The motor of Claim 10, wherein the current ring is a copper ring.

12. A hybrid squirrel cage/permanent magnet motor comprising:

a motor housing;

a stator fixed to the motor housing and producing a rotating stator magnetic field;

a motor shaft rotatably connected to the motor housing and extending from at least one end of the motor housing for attachment to a load;

an inner rotor rotationally fixed to the motor shaft residing coaxial with the motor shaft and comprising:

a second rotor core

second electrically conductive squirrel cage bars embedded angularly spaced apart in a second exterior surface of the second rotor core; and voids creating flux barriers inside the second rotor core, the flux barriers comprising concave paths connecting interior ends of the second electrically conductive squirrel cage bars and guiding the rotating stator magnetic field through the second rotor core during synchronous operation; and

an outer rotor residing between the stator and inner rotor and coaxial with the motor shaft and not mechanically coupled to the motor shaft, the inner rotor, and the stator, and comprising:

a first rotor core;

first electrically conductive squirrel cage bars embedded in the first rotor core; and

permanent magnets on an interior surface of the first rotor core.

13. A hybrid squirrel cage/permanent magnet motor comprising:

a motor housing;

a stator fixed to the motor housing and producing a rotating stator magnetic field;

a motor shaft rotatably connected to the motor housing and extending from at least one end of the motor housing for attachment to a load;

an inner rotor rotationally fixed to the motor shaft residing coaxial with the motor shaft and comprising:

a second rotor core;

a multiplicity of angularly spaced apart second minor squirrel cage bars embedded in the second rotor core and separated into equal number groups angularly separated by second major squirrel cage bars embedded in the second rotor core, the number of groups and the number of second major squirrel cage bars equal to the number of phases of the motor; and

flux barriers inside the second rotor core, the flux barriers comprising concave paths connecting interior ends of the second minor electrically conductive squirrel cage bars and guiding the rotating stator magnetic field through the second rotor core during synchronous operation; and

an outer rotor residing between the stator and inner rotor and coaxial with the motor shaft and not mechanically coupled to the motor shaft, the inner rotor, and the stator, the outer rotor comprising:

a first rotor core;

a multiplicity of angularly spaced apart first minor squirrel cage bars embedded in the first rotor core and separated into equal number groups angularly separated by first major squirrel cage bars embedded in the first rotor core, the number of groups and the number of first major squirrel cage bars equal to the number of phases of the motor; and

permanent magnets on an interior surface of the first rotor core.

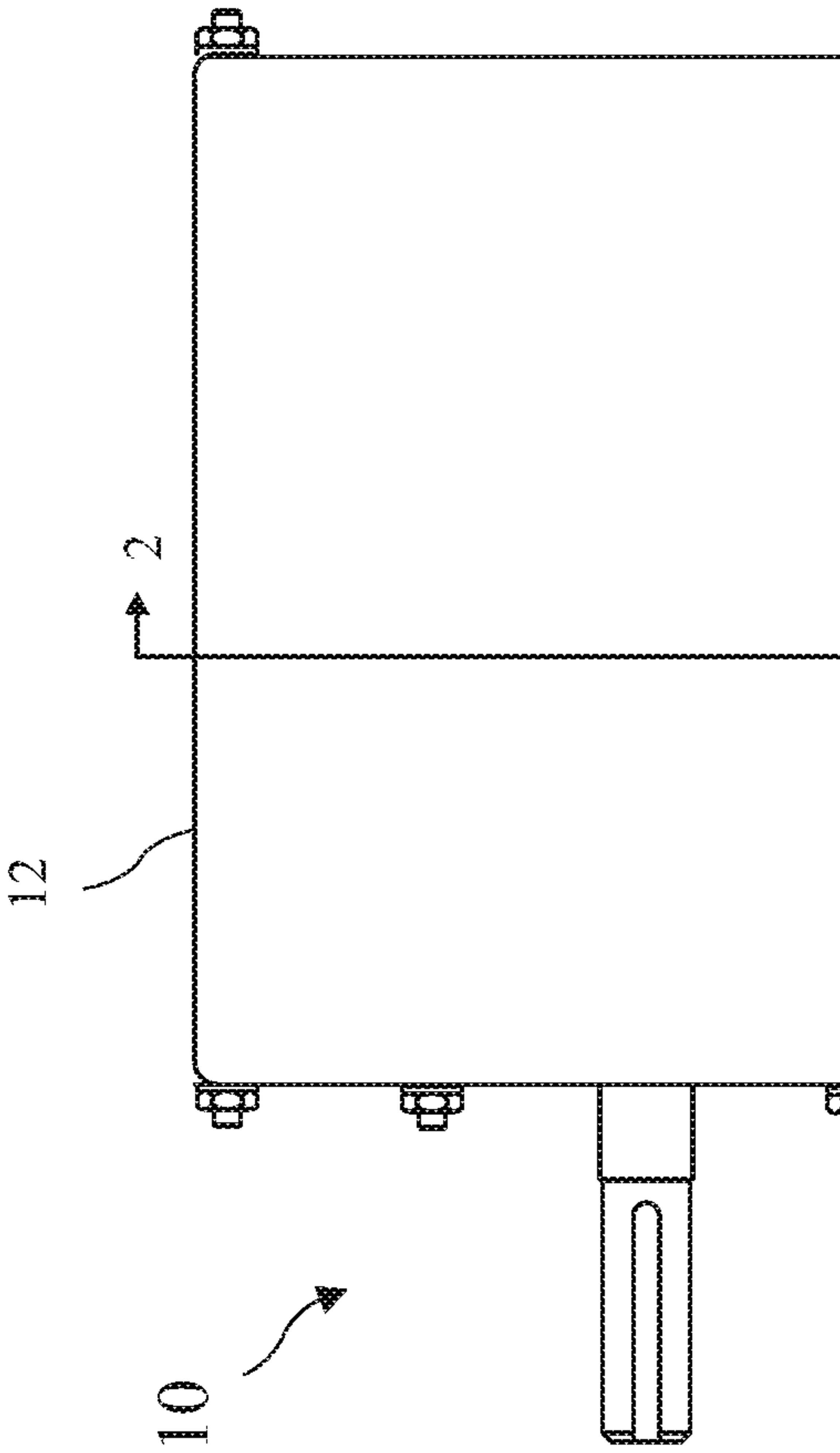

FIG. 1B

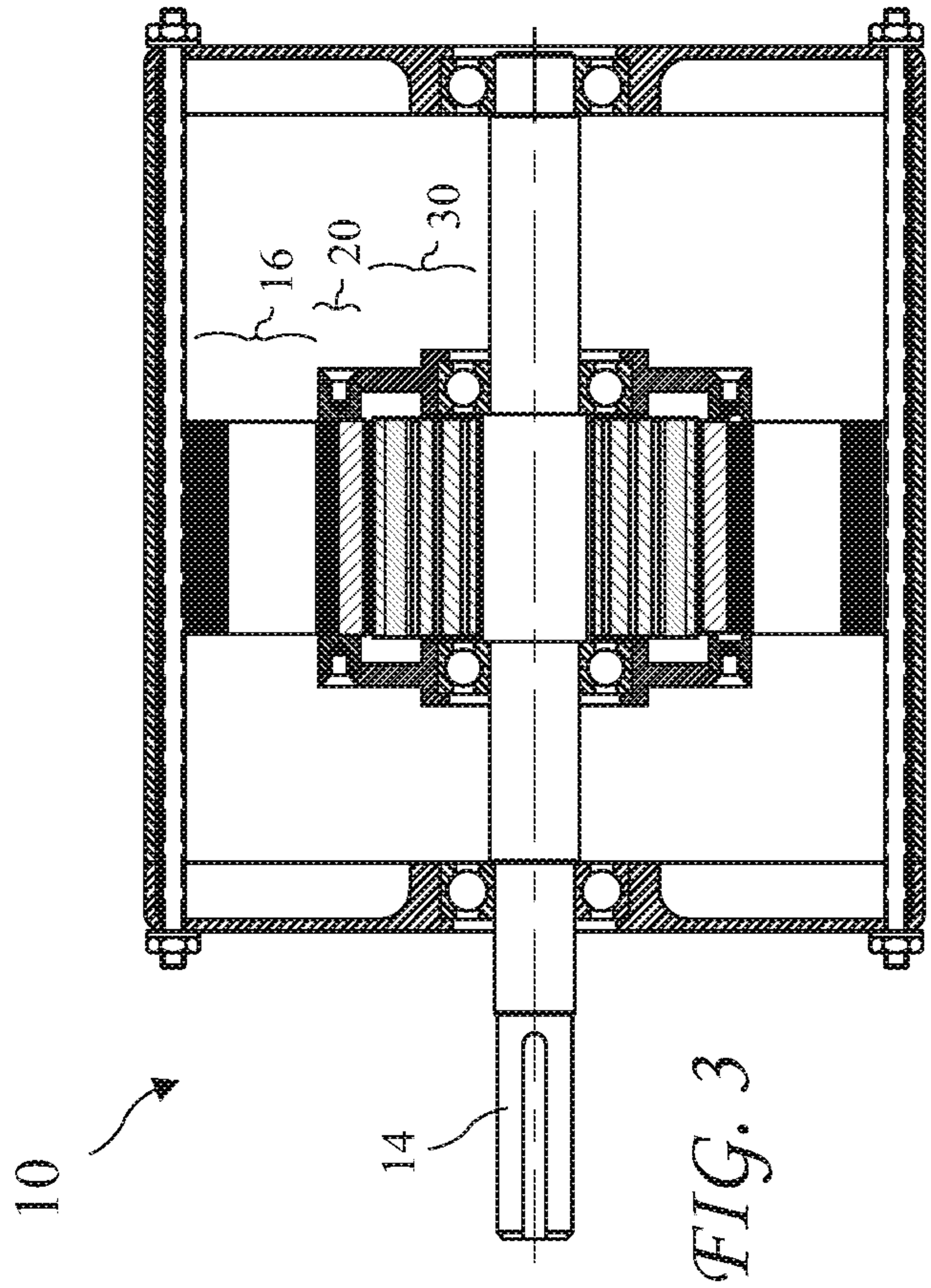

FIG. 3

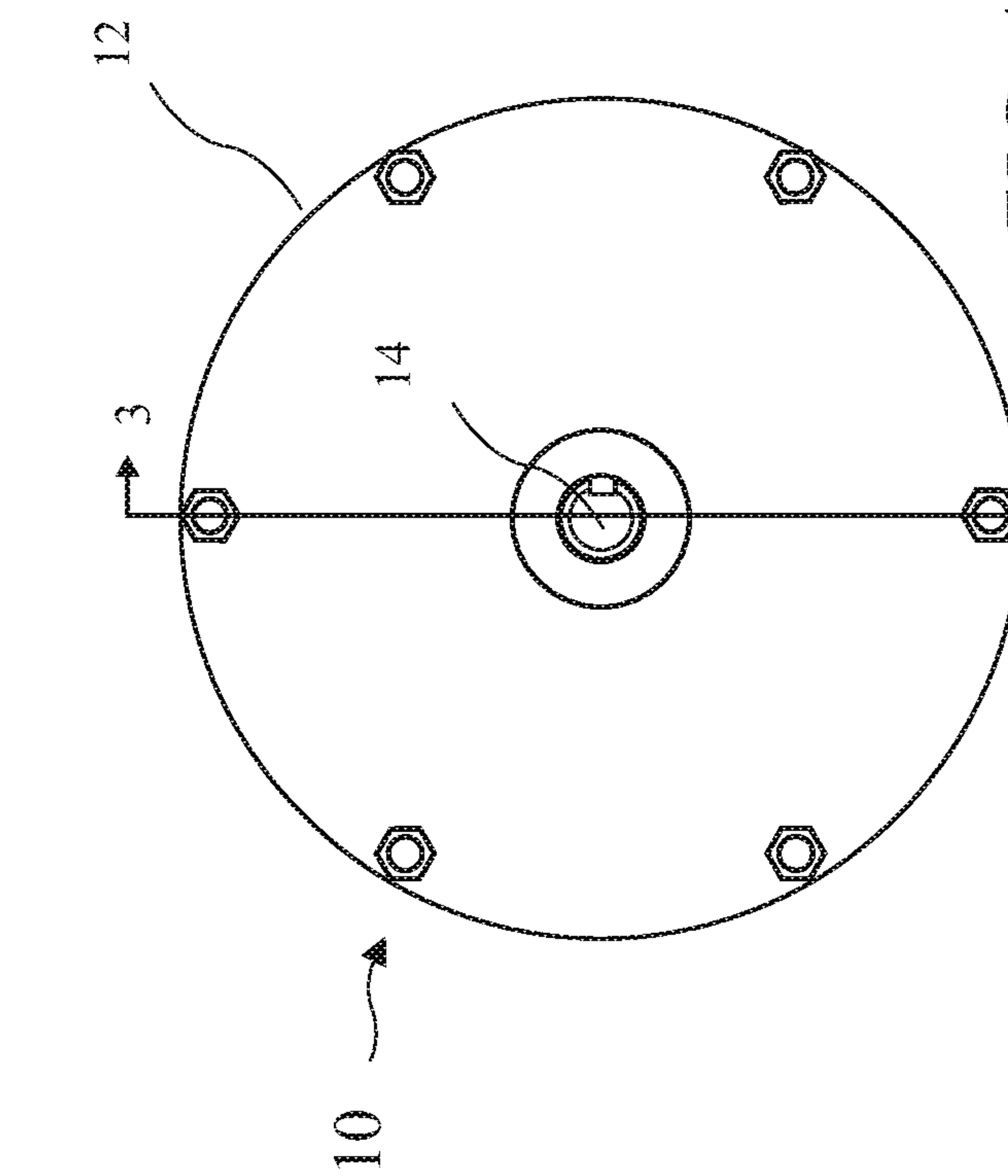

FIG. 1A

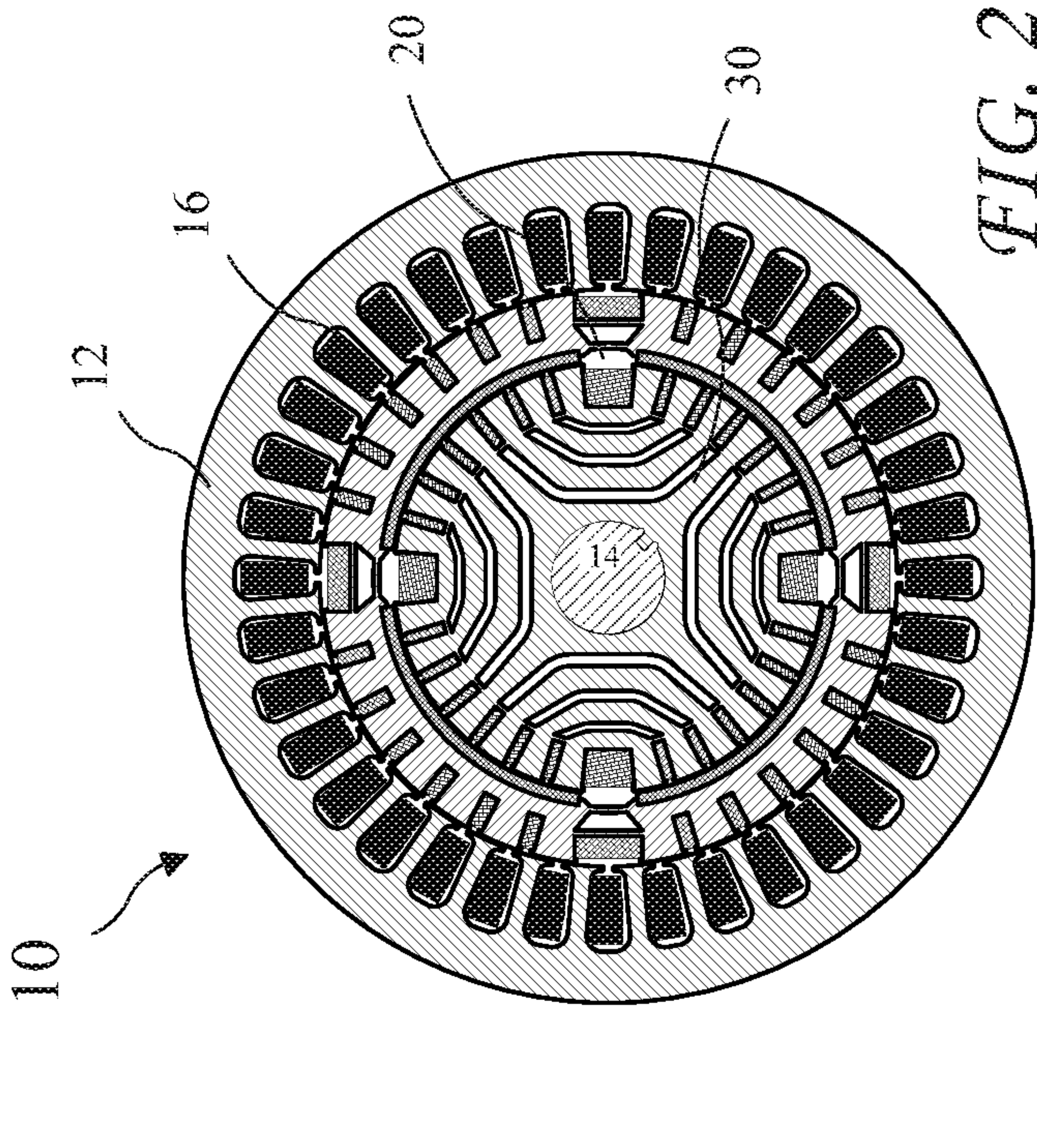

FIG. 2

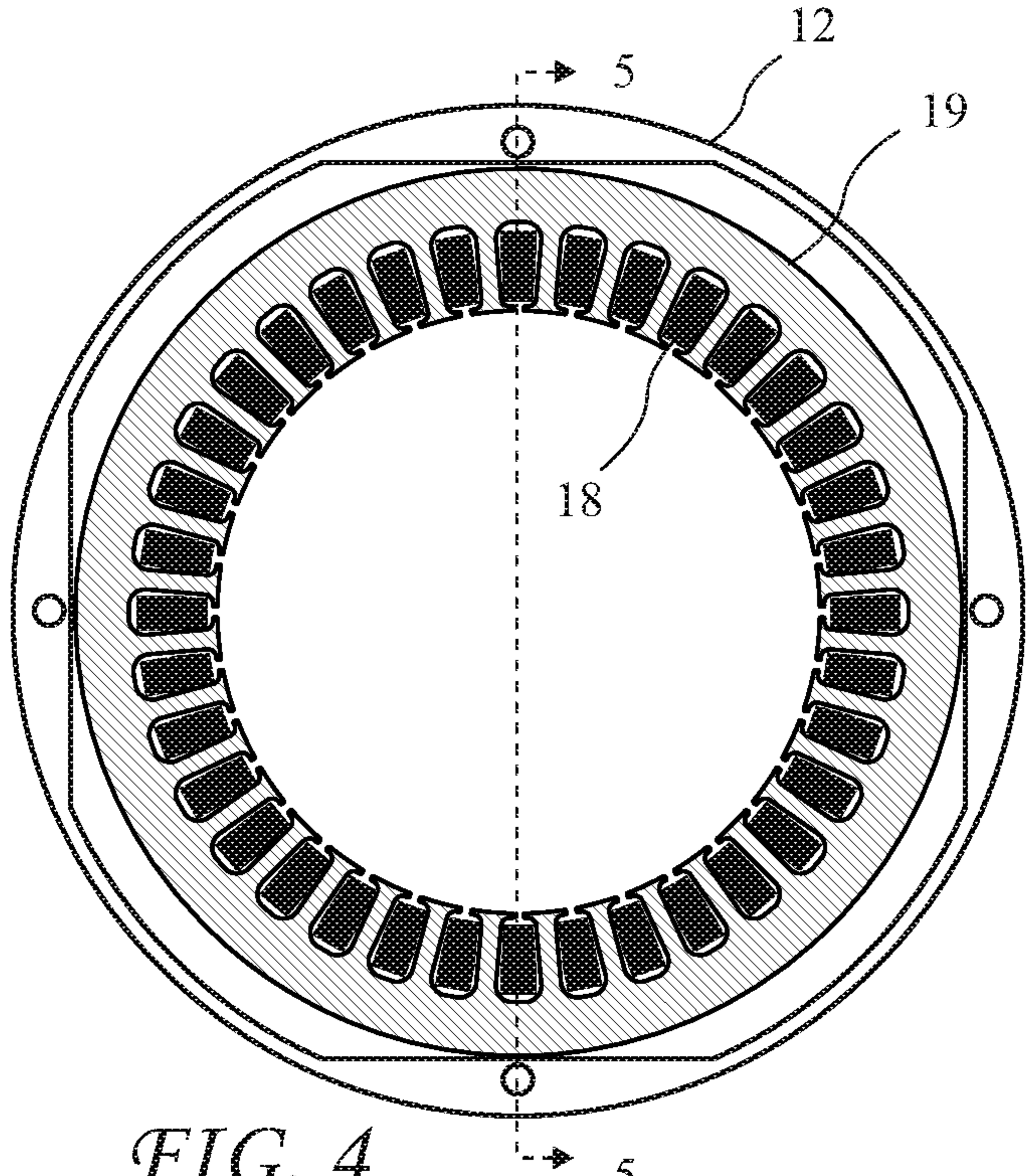

FIG. 4

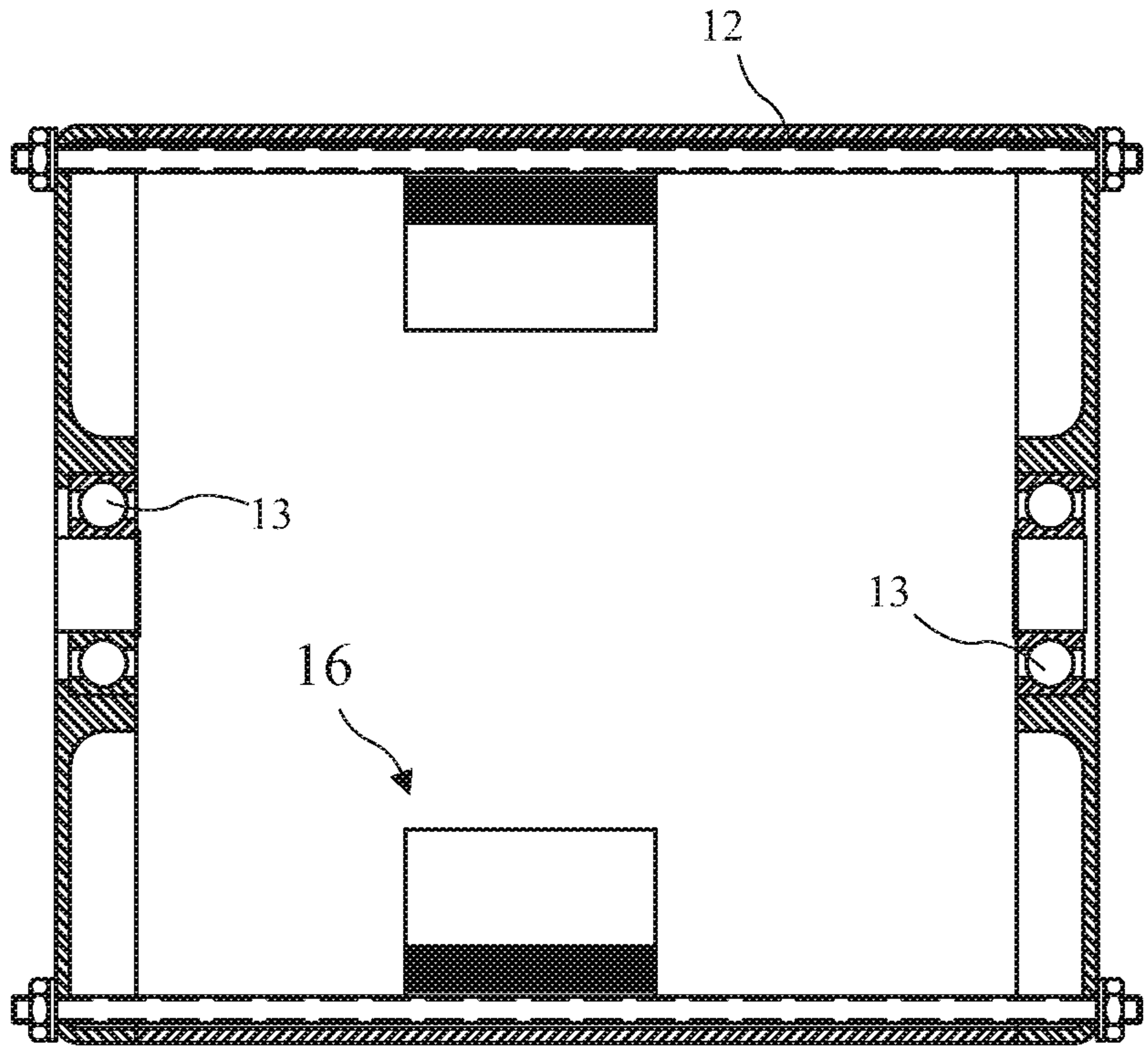

FIG. 5

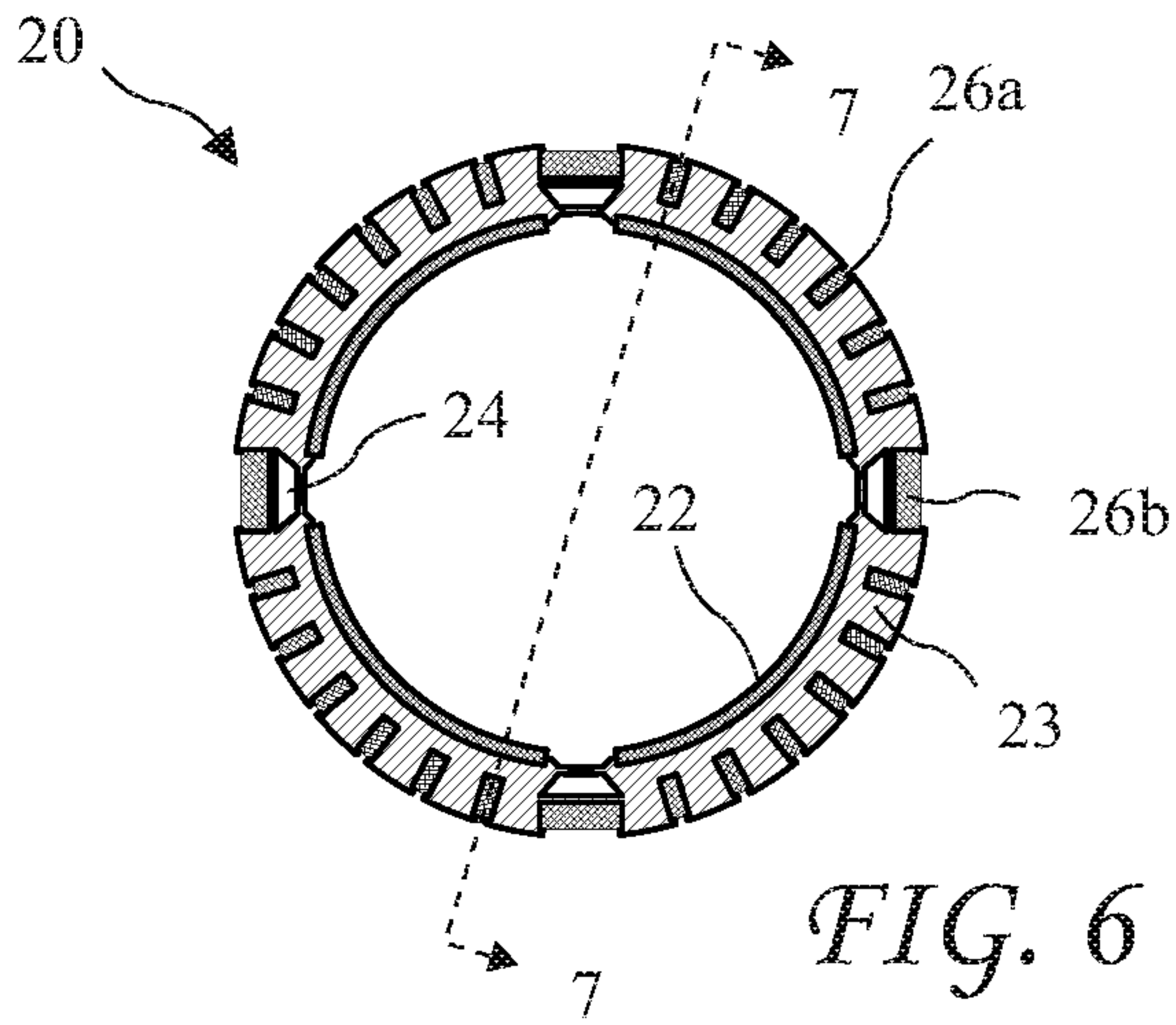

FIG. 6

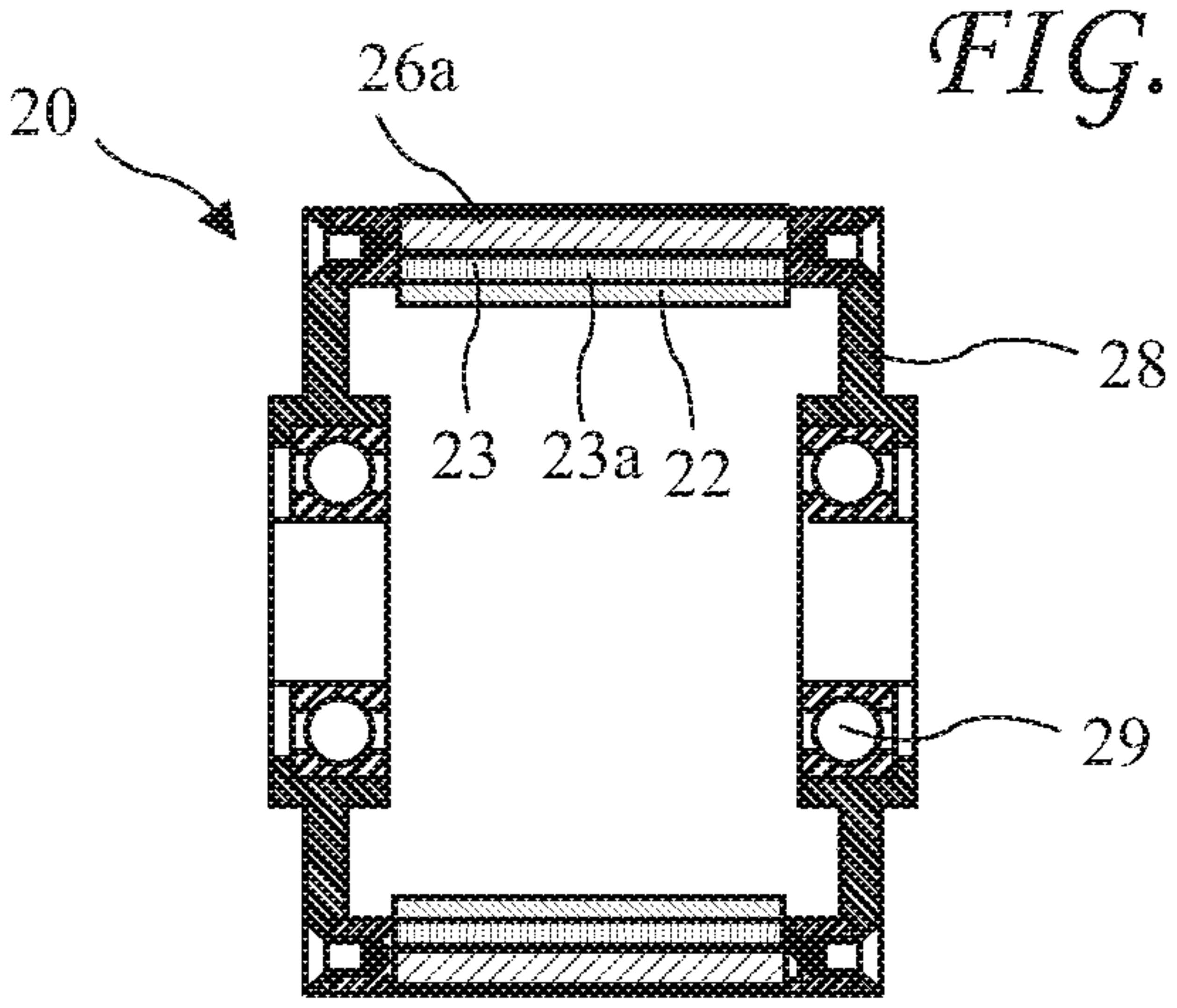

FIG. 7

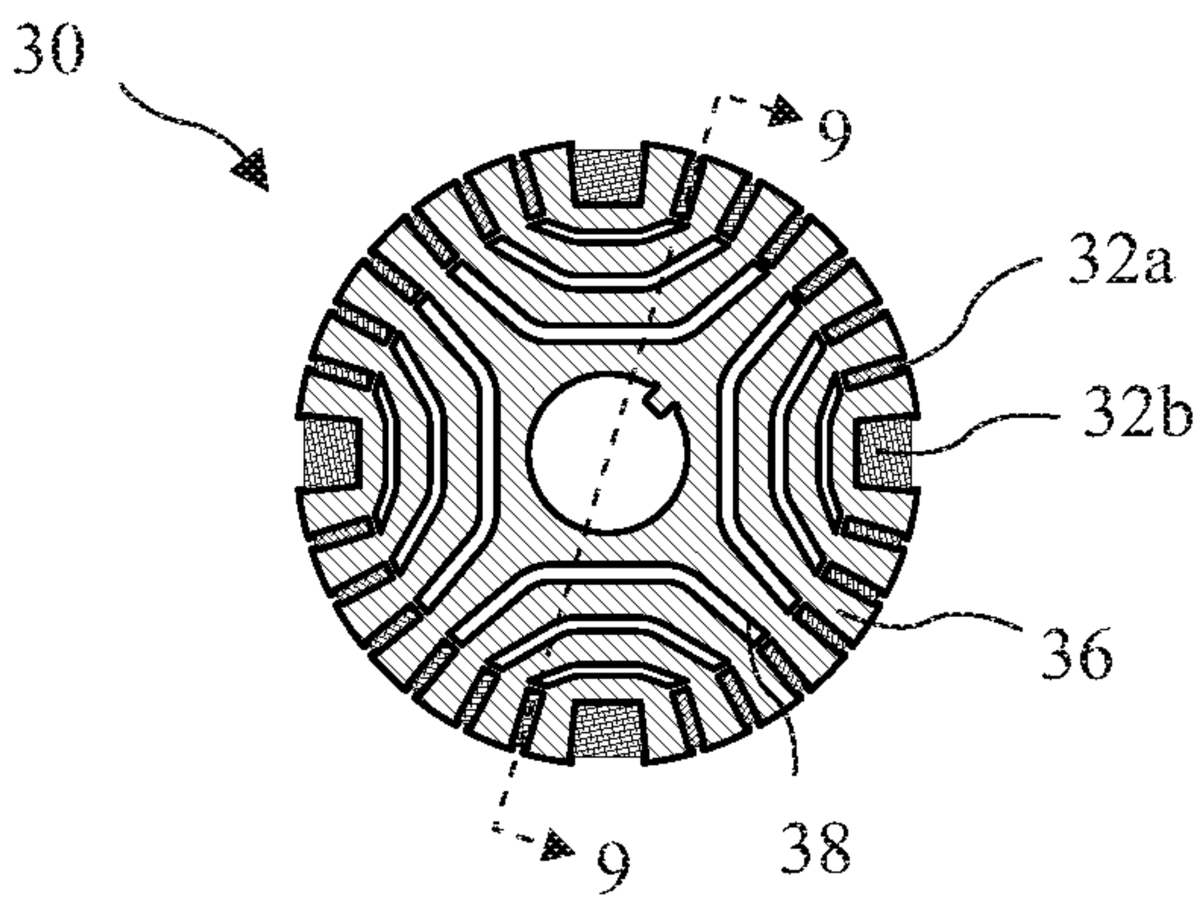

FIG. 8

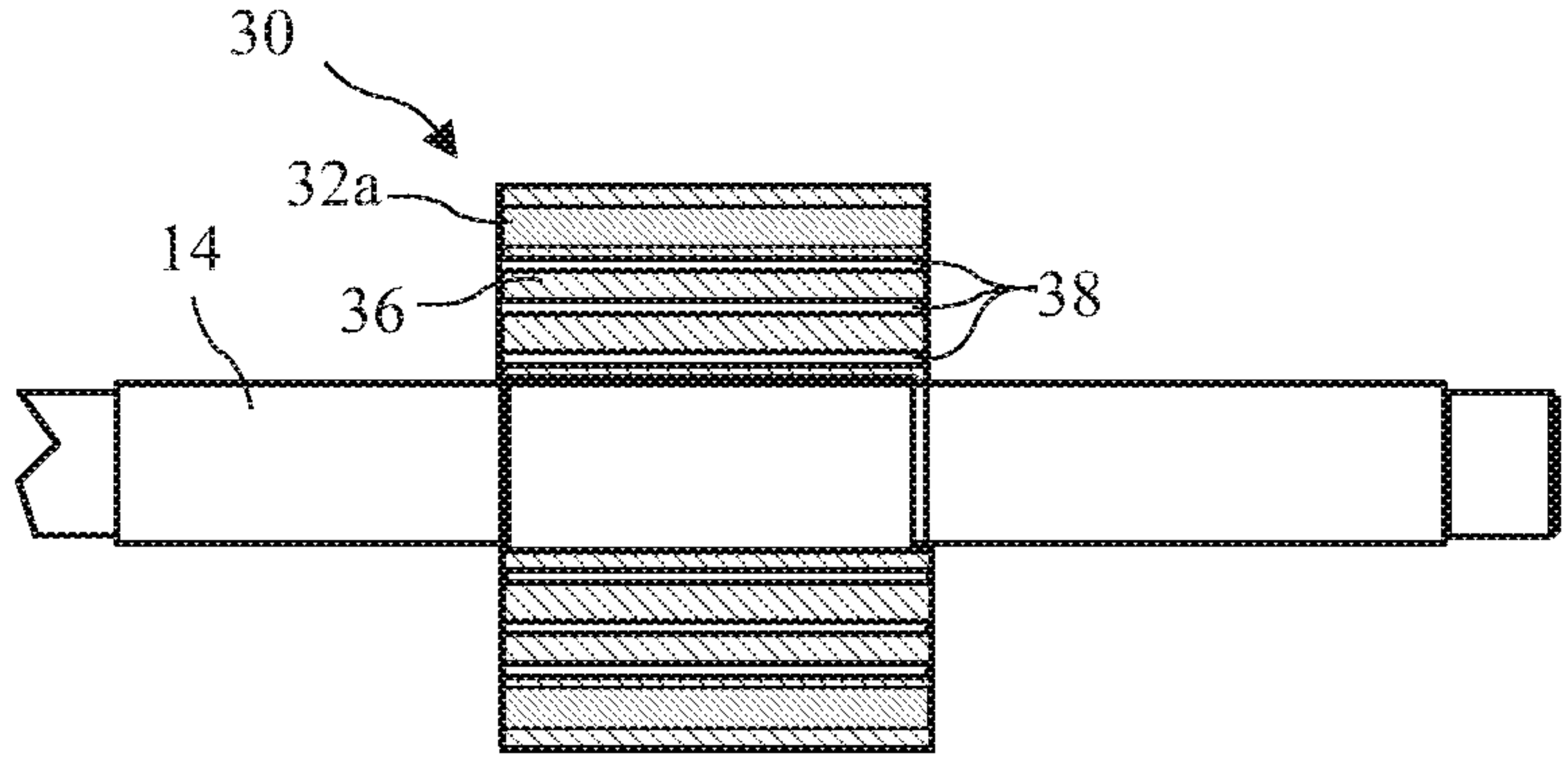

FIG. 9

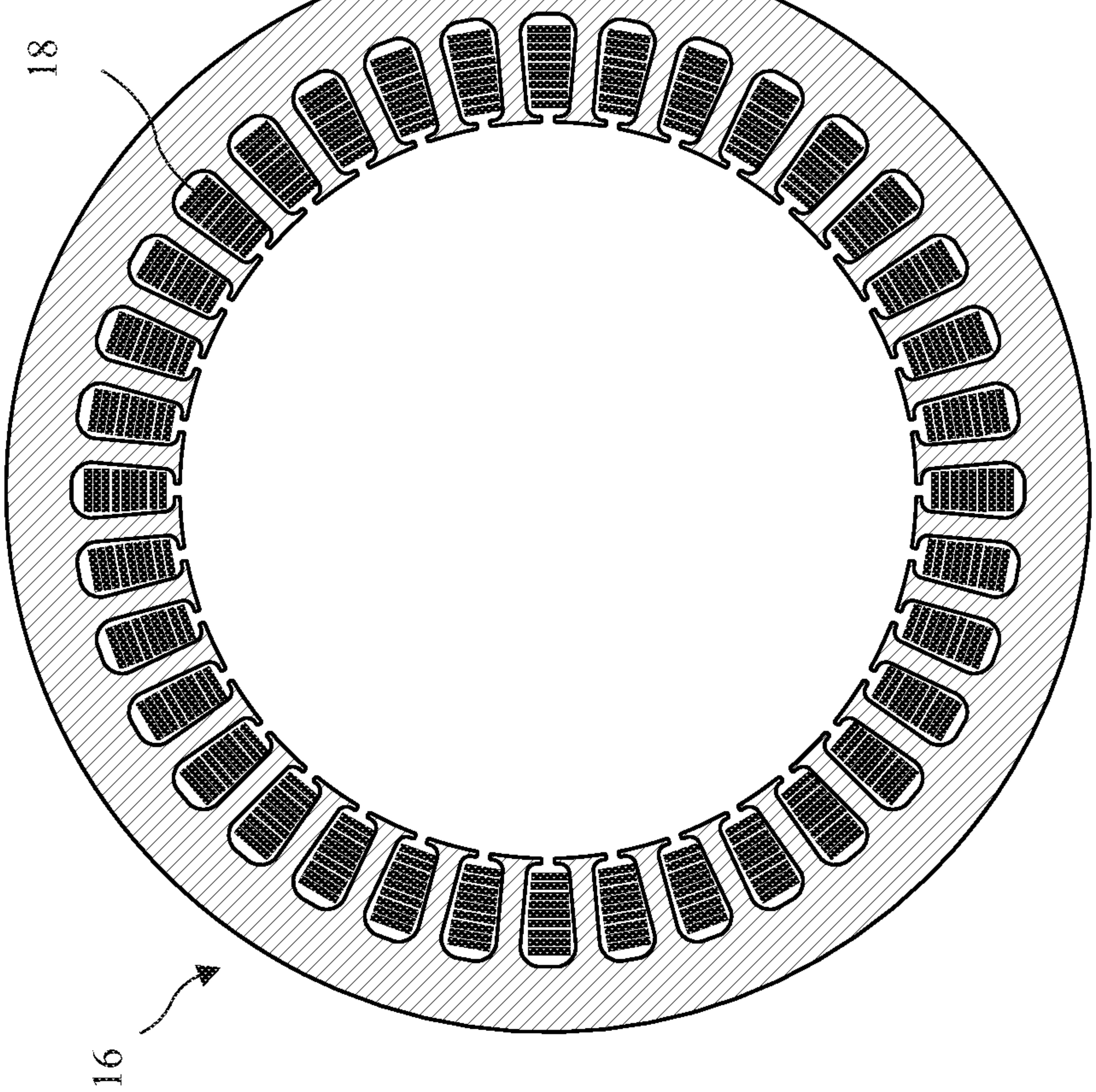

FIG. 10A

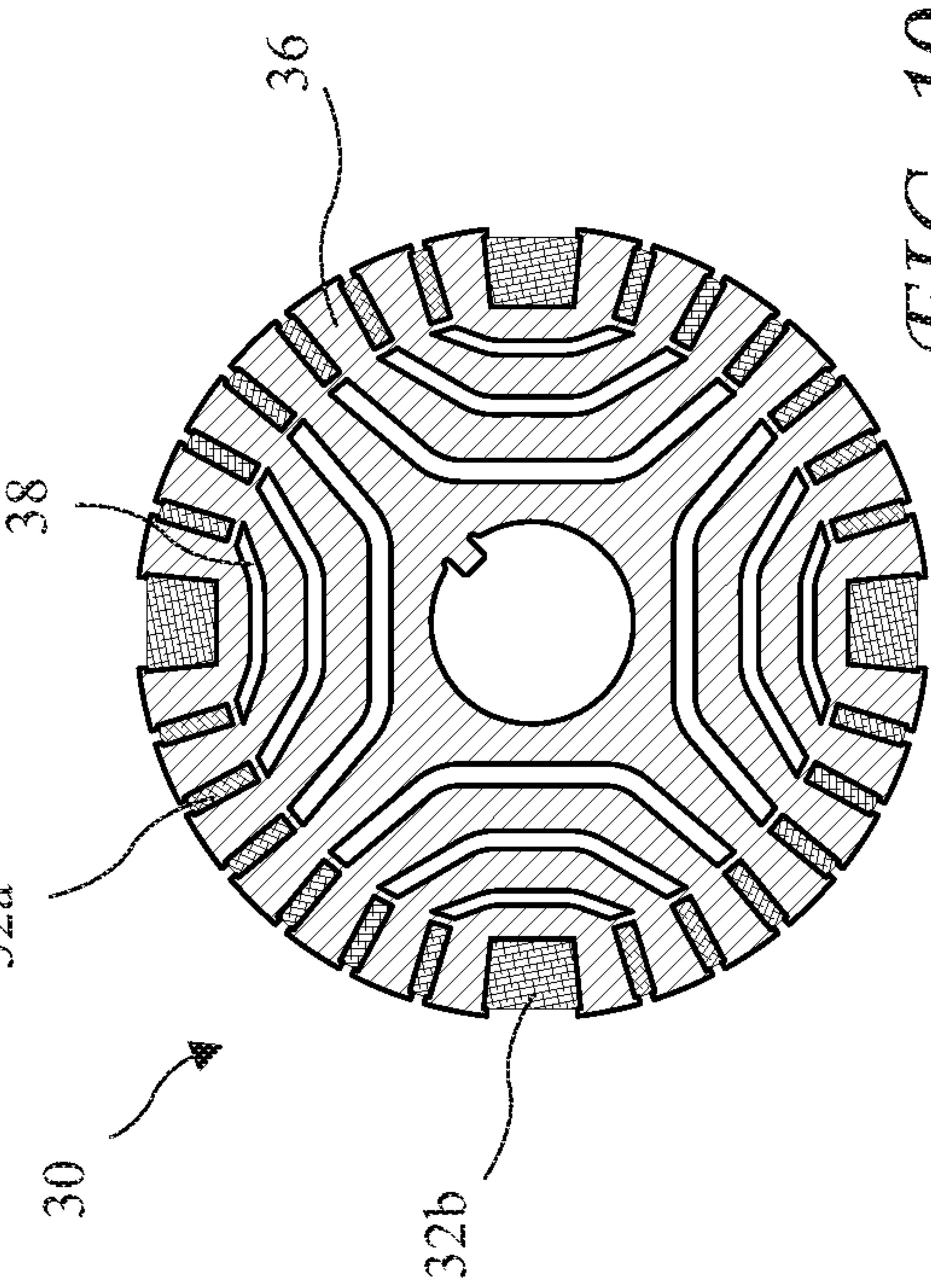

FIG. 10C

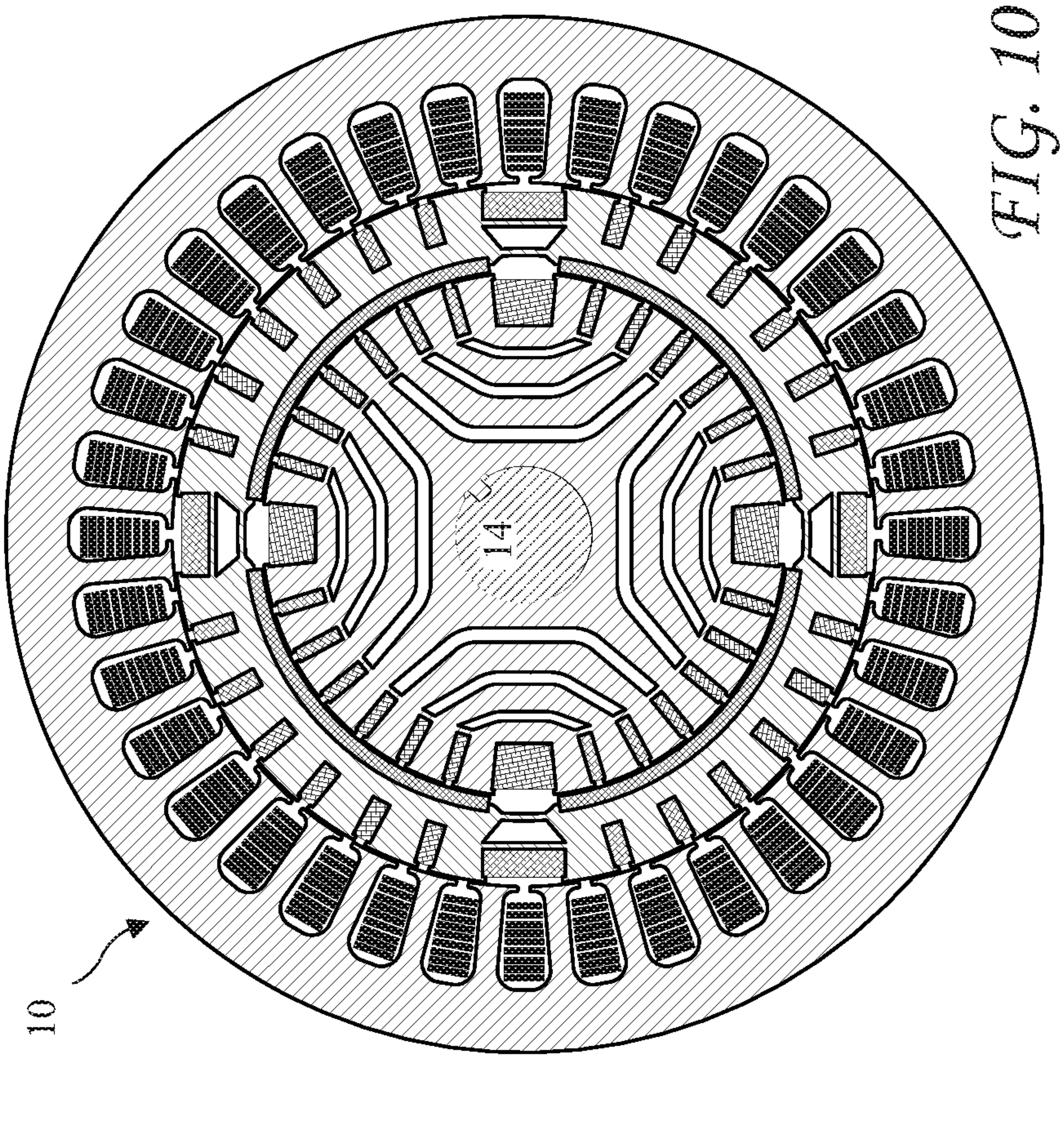

FIG. 10

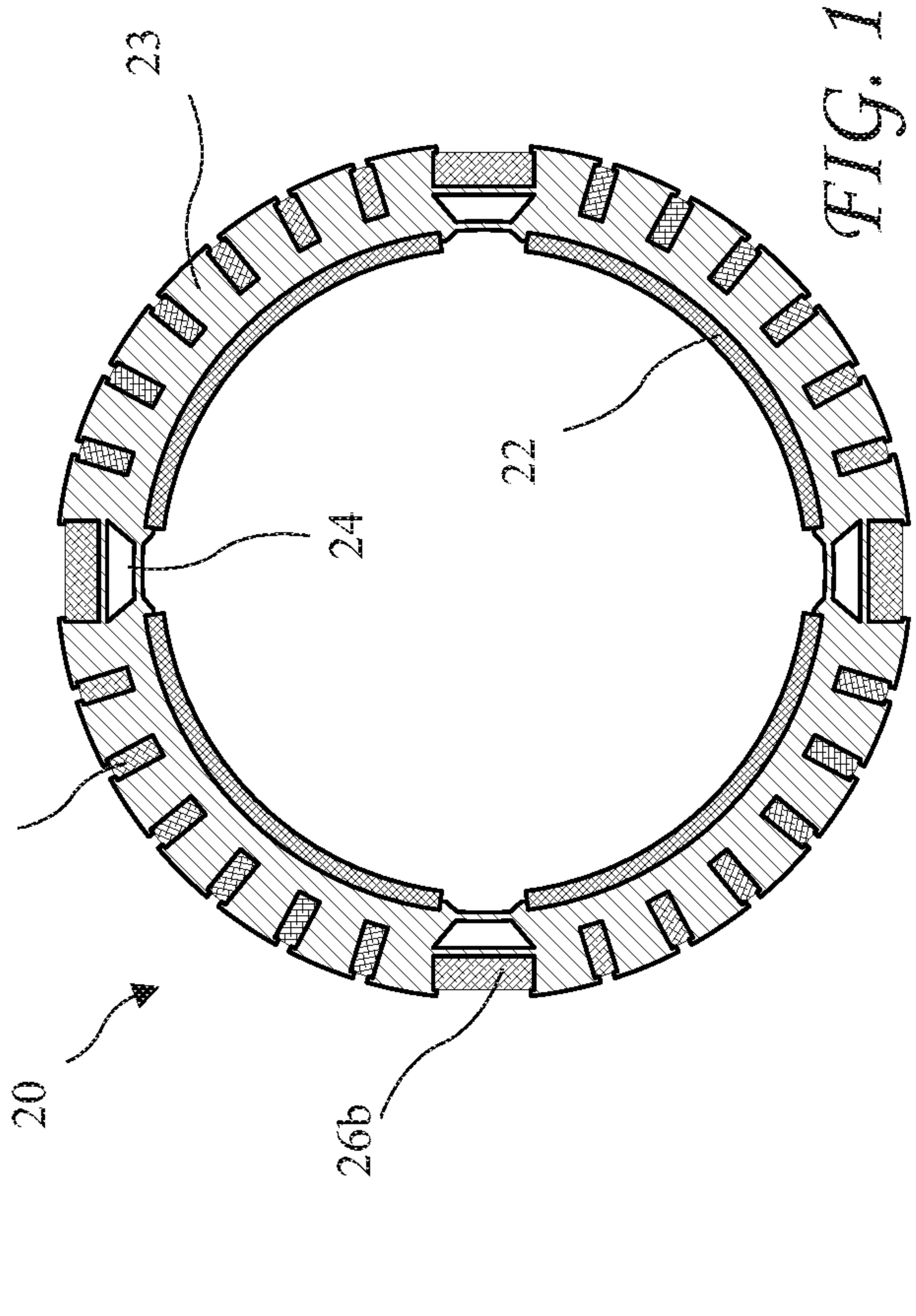

FIG. 10B

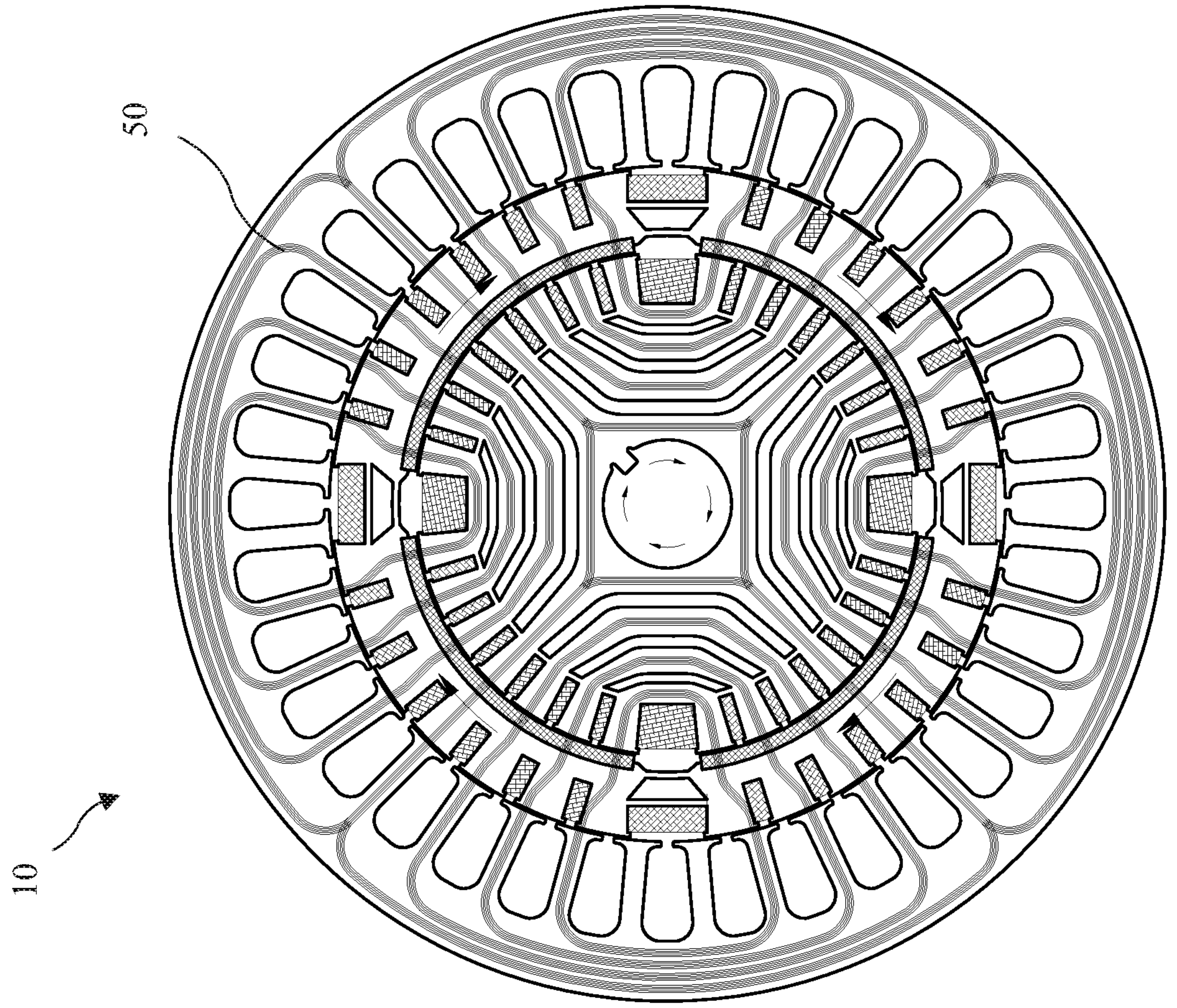

FIG. 11B

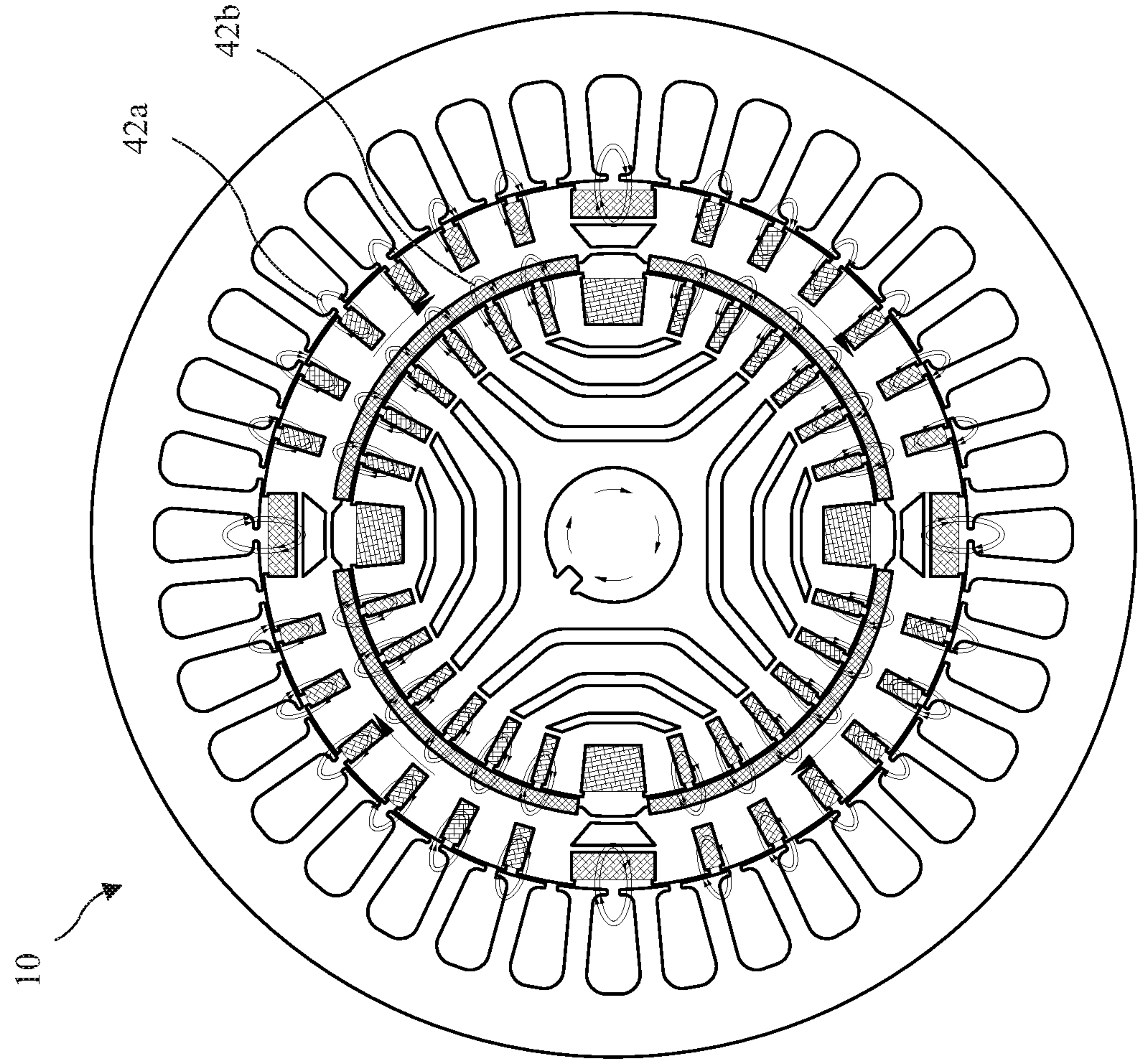

FIG. 11A

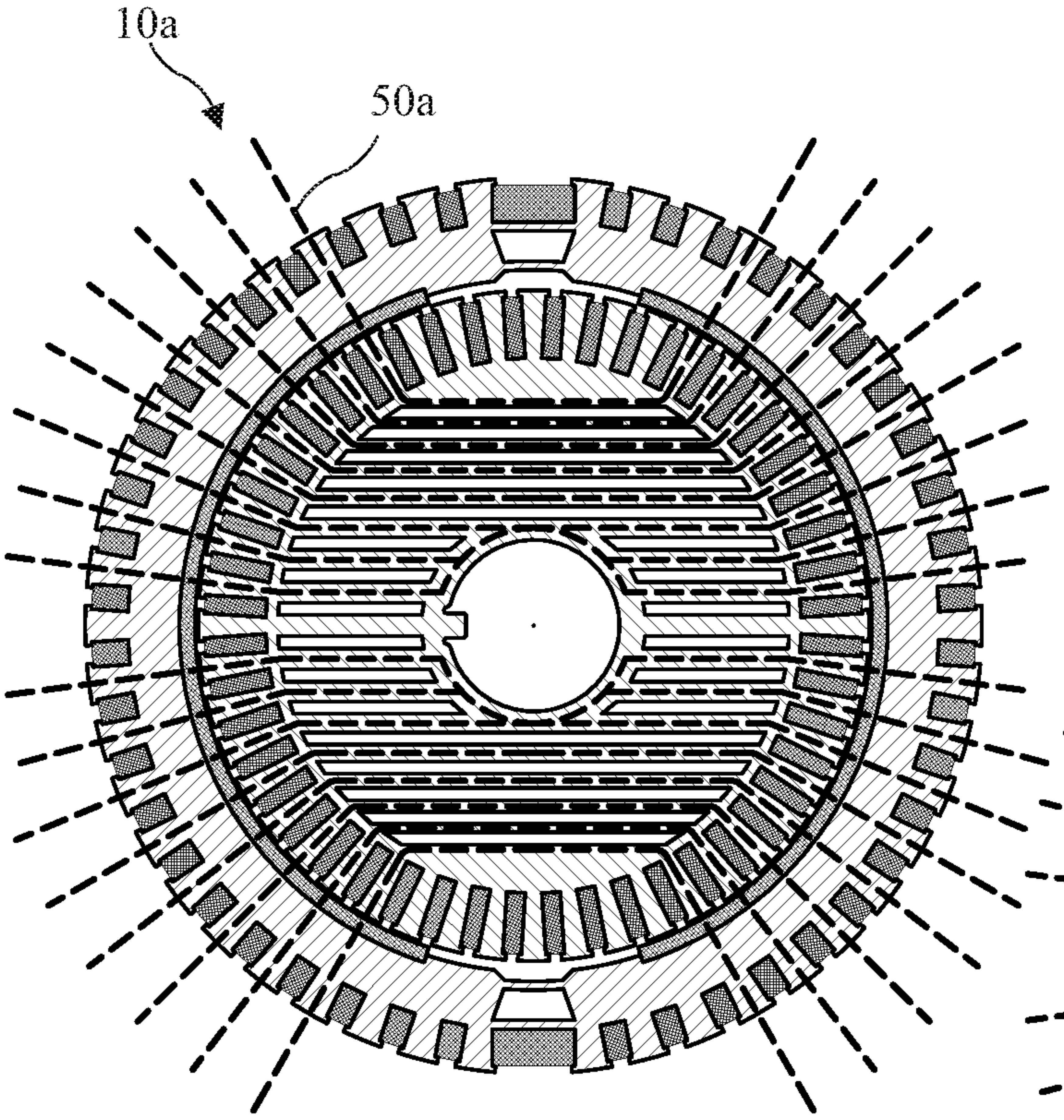

FIG. 12A

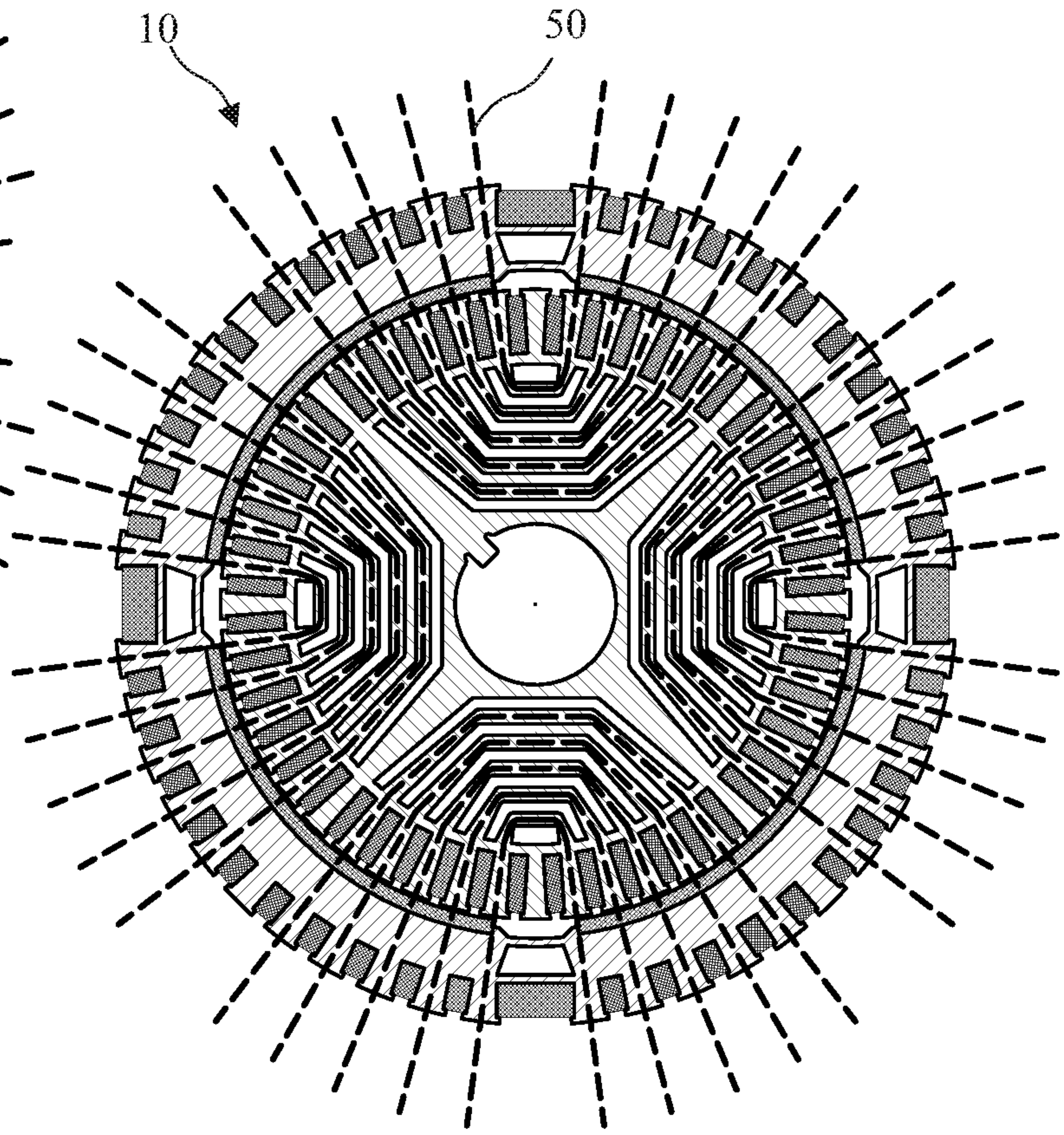

FIG. 12B

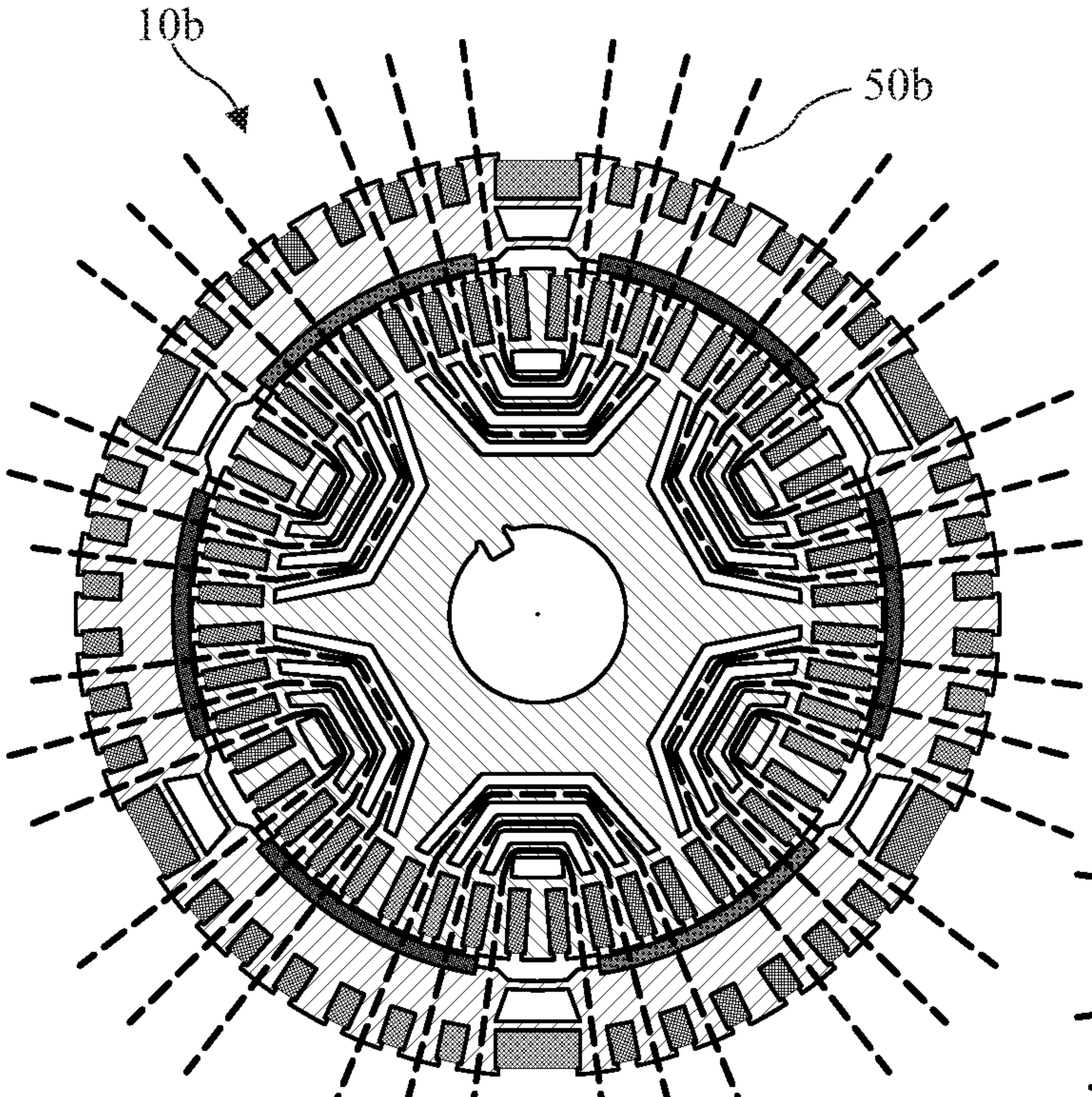

FIG. 12C

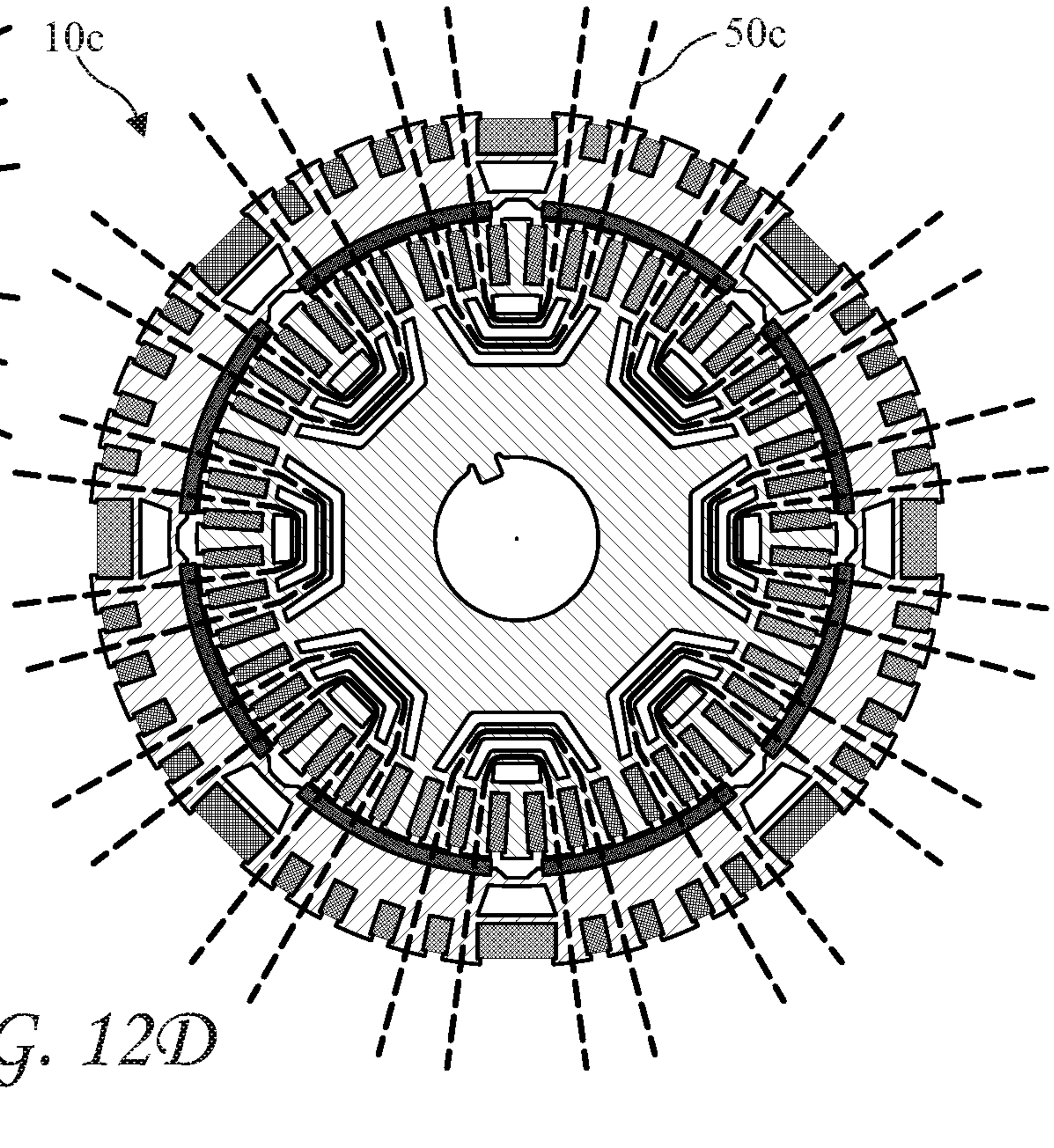

FIG. 12D

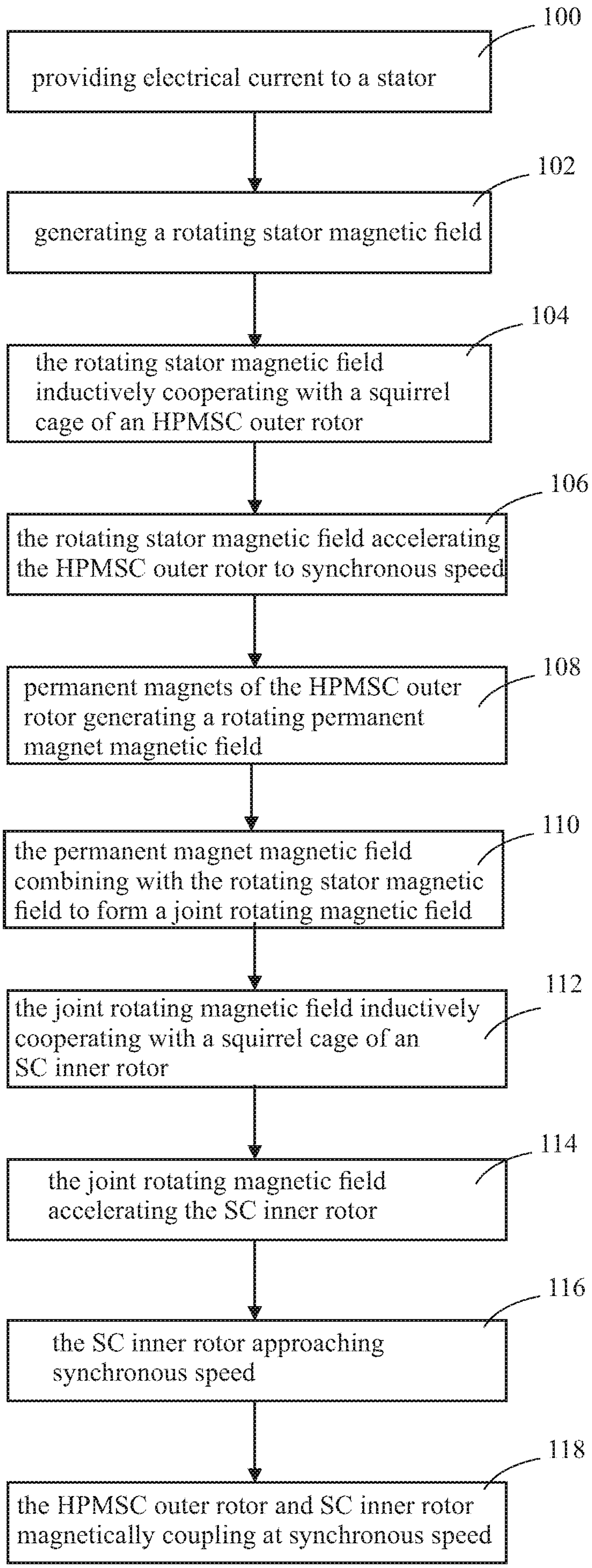
providing electrical current to a stator
100
generating a rotating stator magnetic field
102
the rotating stator magnetic field inductively cooperating with a squirrel cage of an HPMSC outer rotor
104
the rotating stator magnetic field accelerating the HPMSC outer rotor to synchronous speed
106
permanent magnets of the HPMSC outer rotor generating a rotating permanent magnet magnetic field
108
the permanent magnet magnetic field combining with the rotating stator magnetic field to form a joint rotating magnetic field
110
the joint rotating magnetic field inductively cooperating with a squirrel cage of an SC inner rotor
112
the joint rotating magnetic field accelerating the SC inner rotor
114
the SC inner rotor approaching synchronous speed
116
the HPMSC outer rotor and SC inner rotor magnetically coupling at synchronous speed
118

FIG. 13

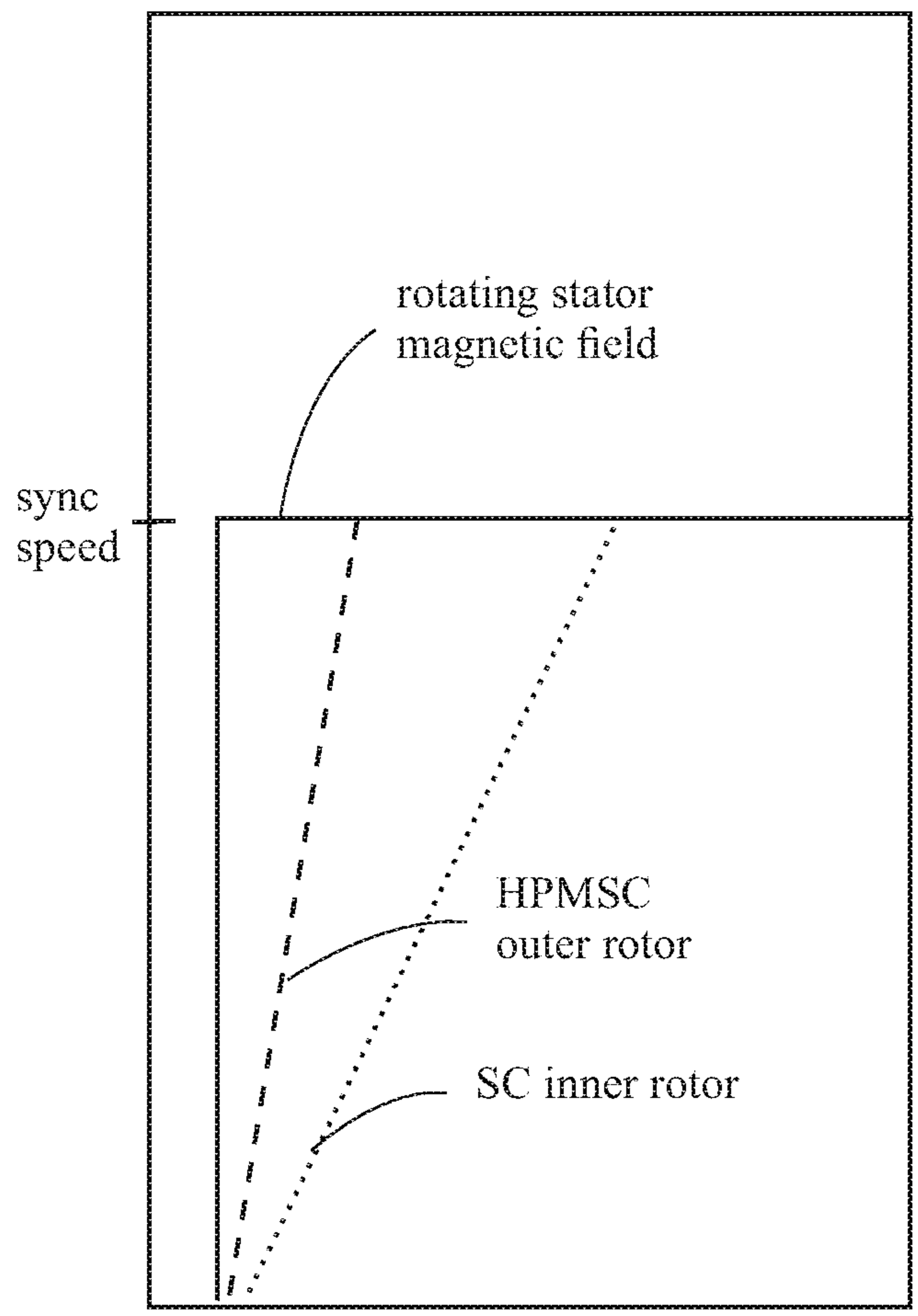
rotating stator magnetic field
sync speed
HPMSC outer rotor
SC inner rotor

FIG. 14

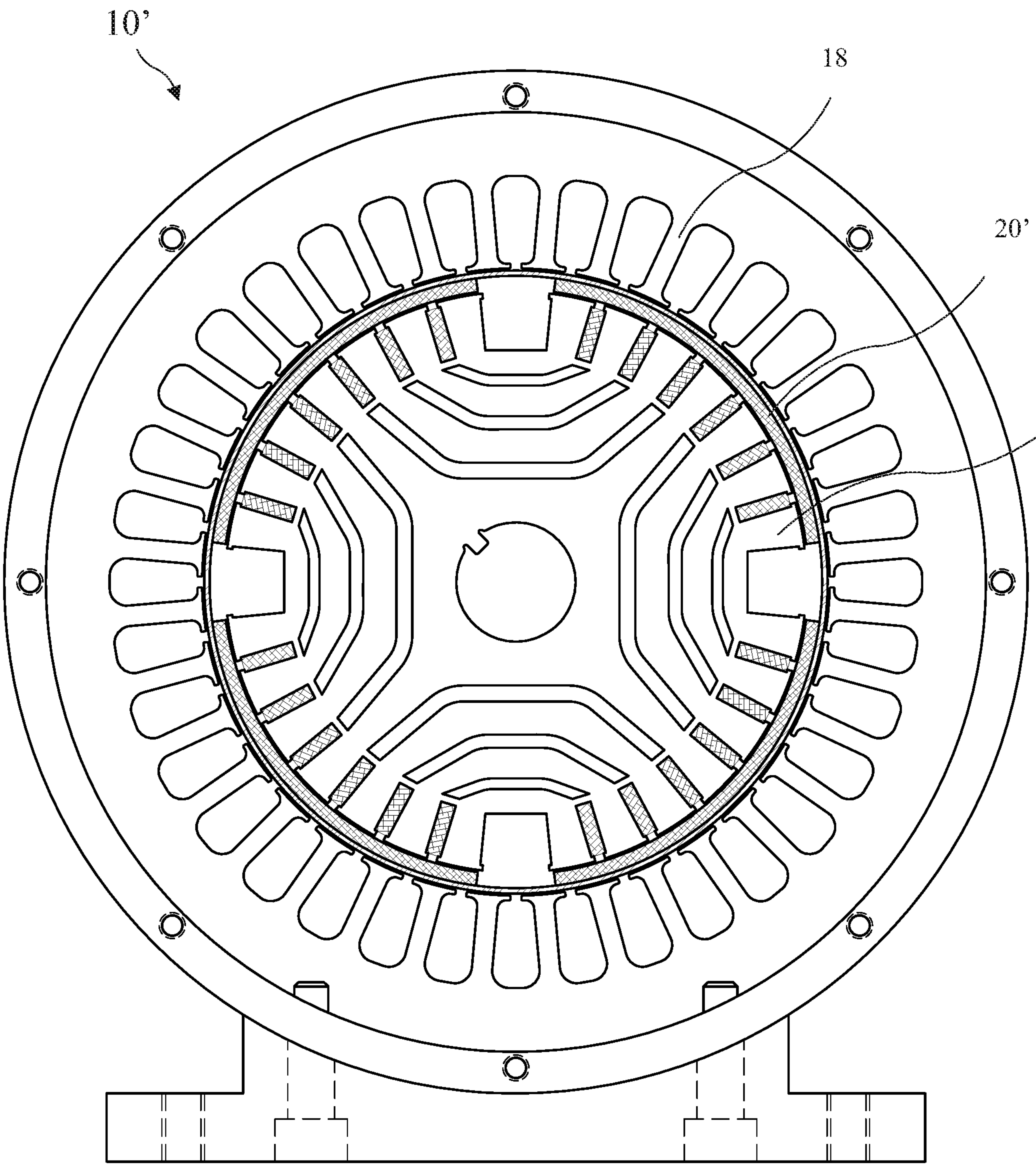

FIG. 15

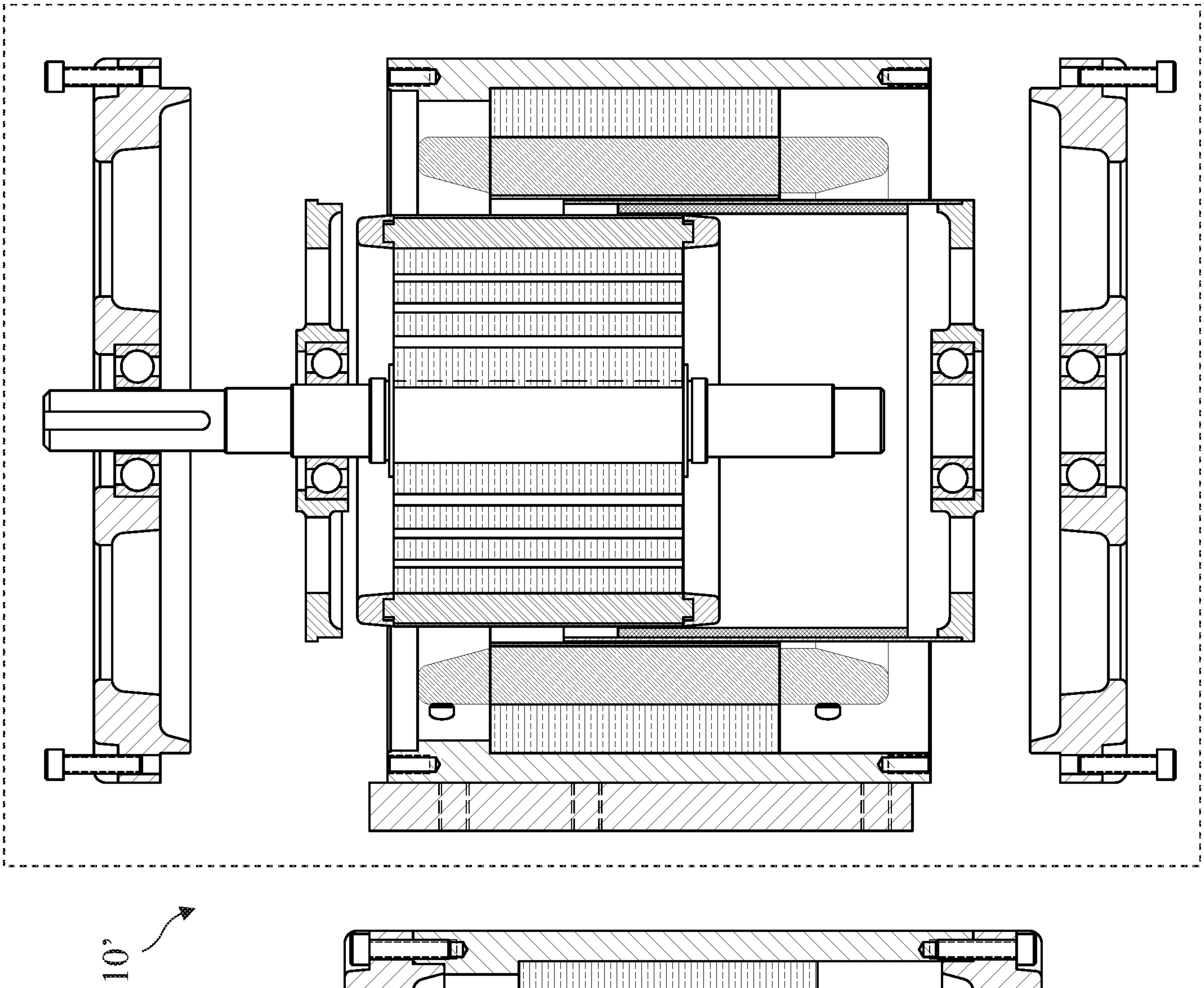

FIG. 16B

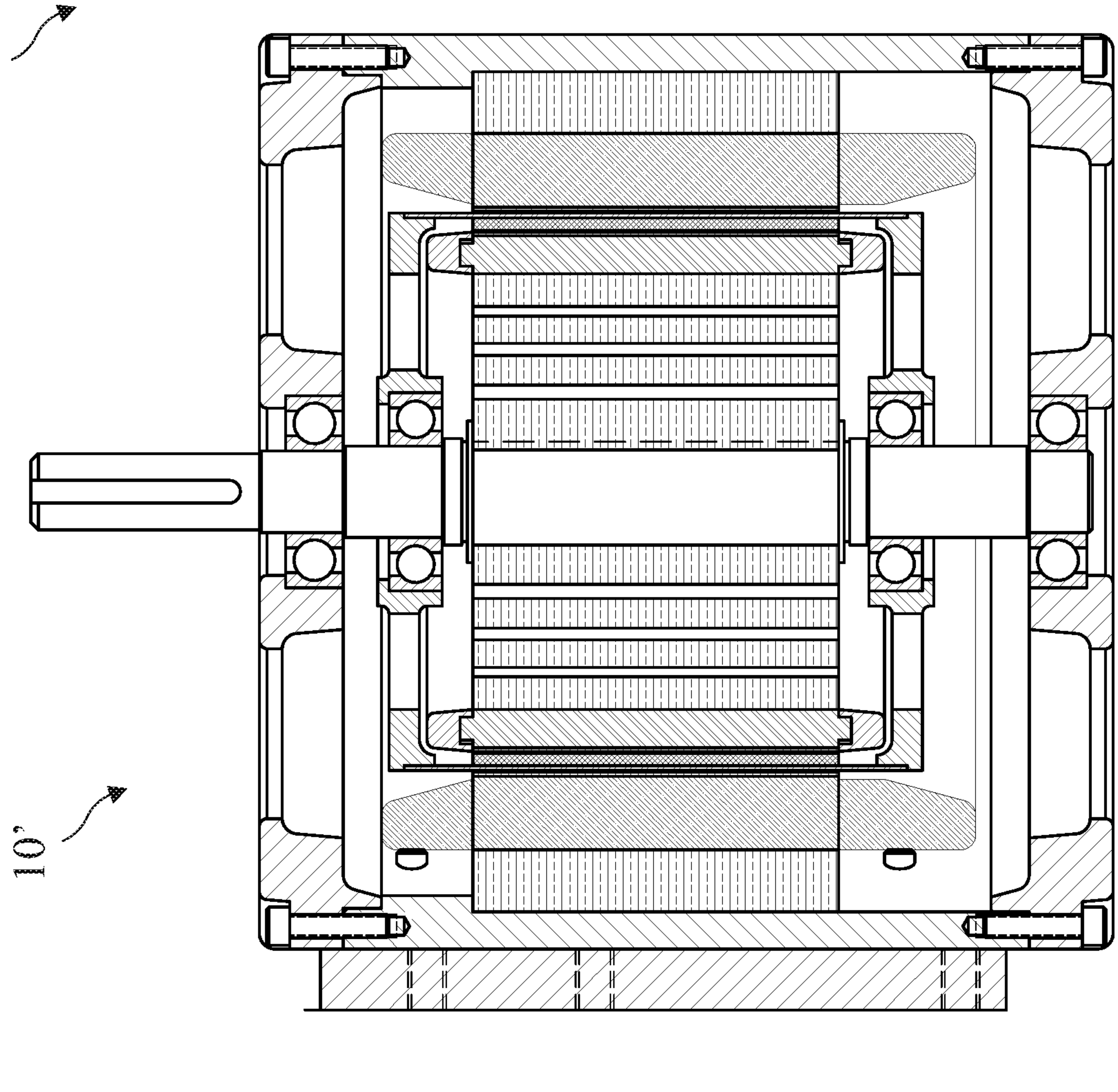

FIG. 16A

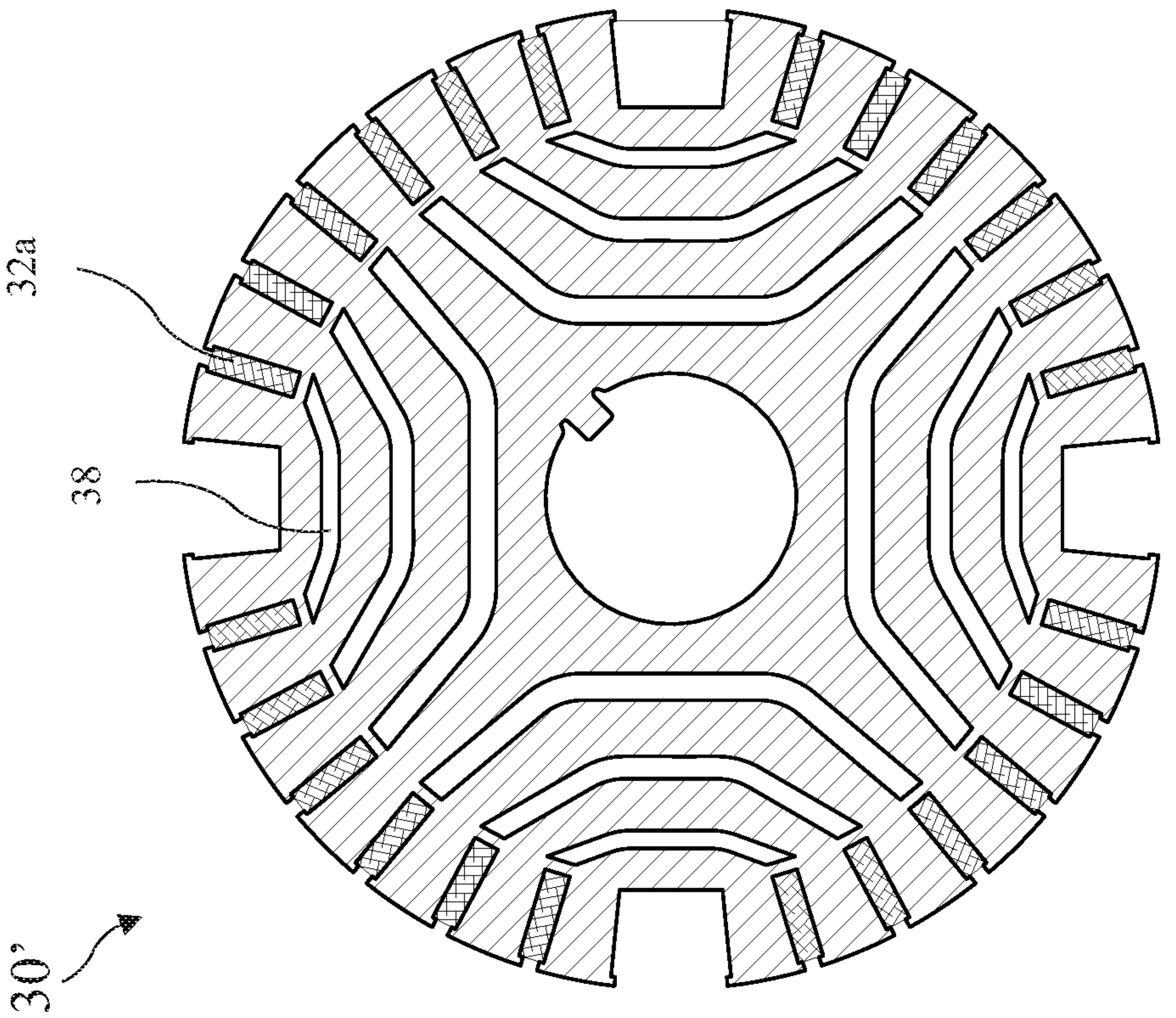

FIG. 18

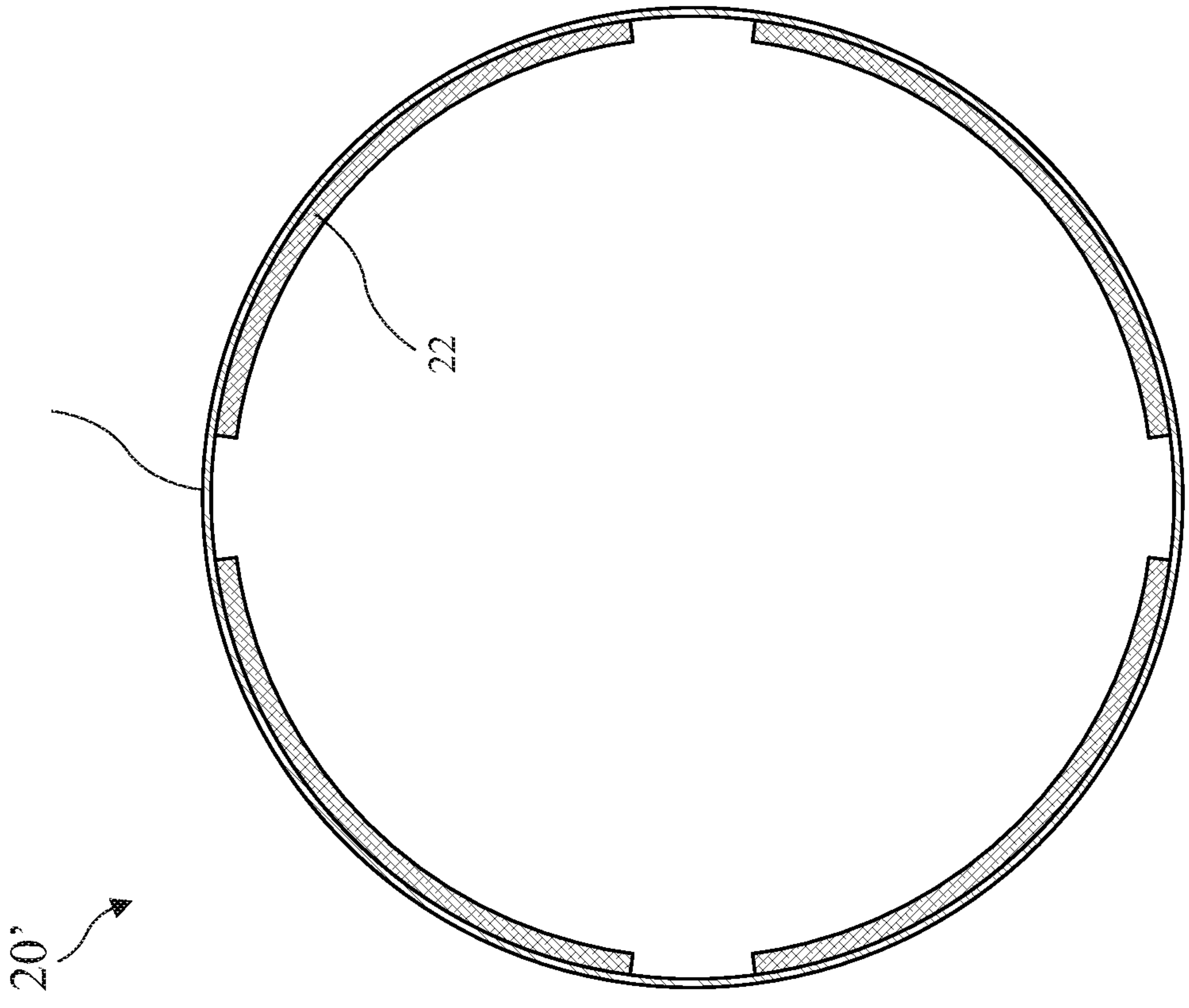

FIG. 17

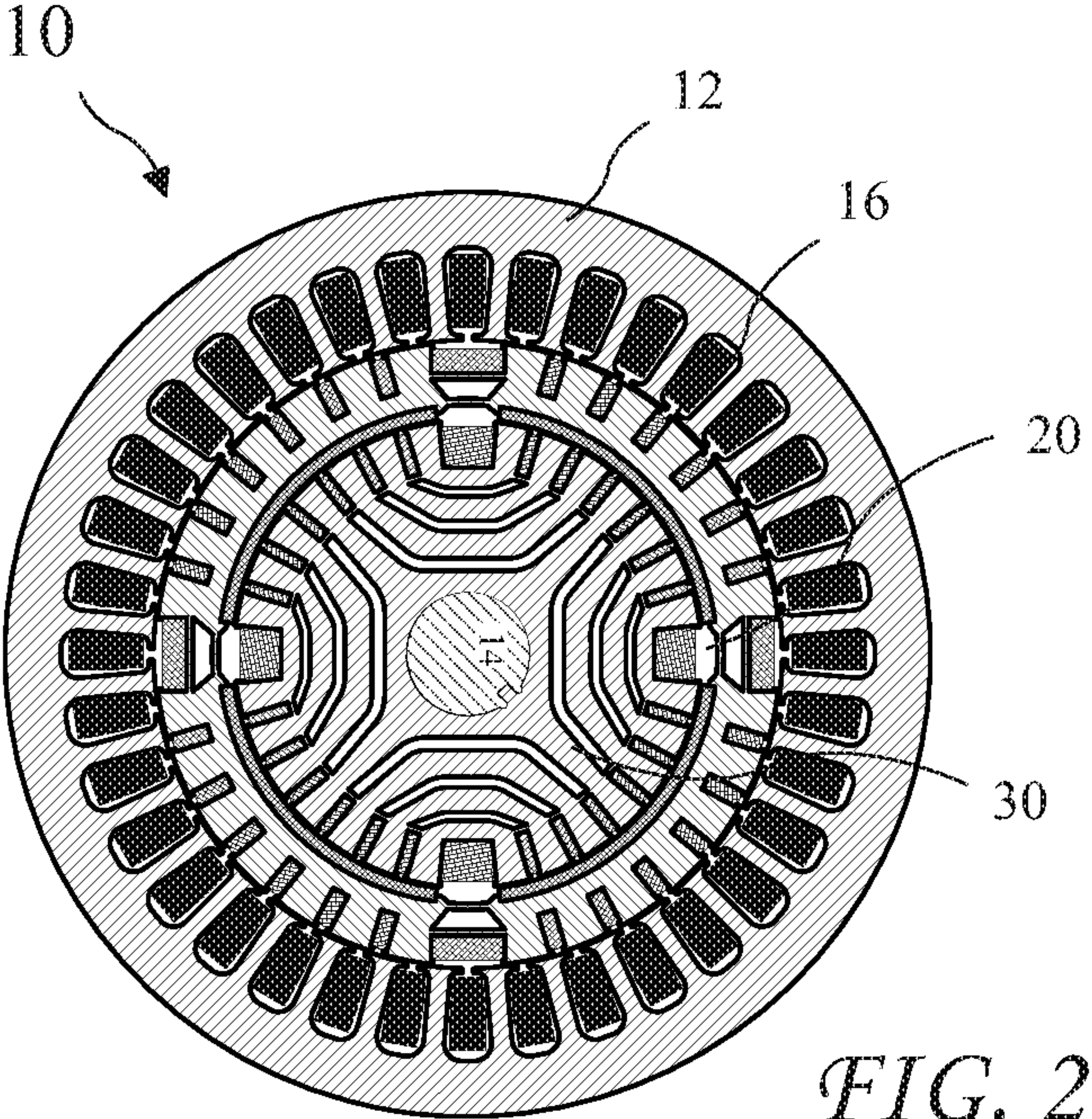

FIG. 2