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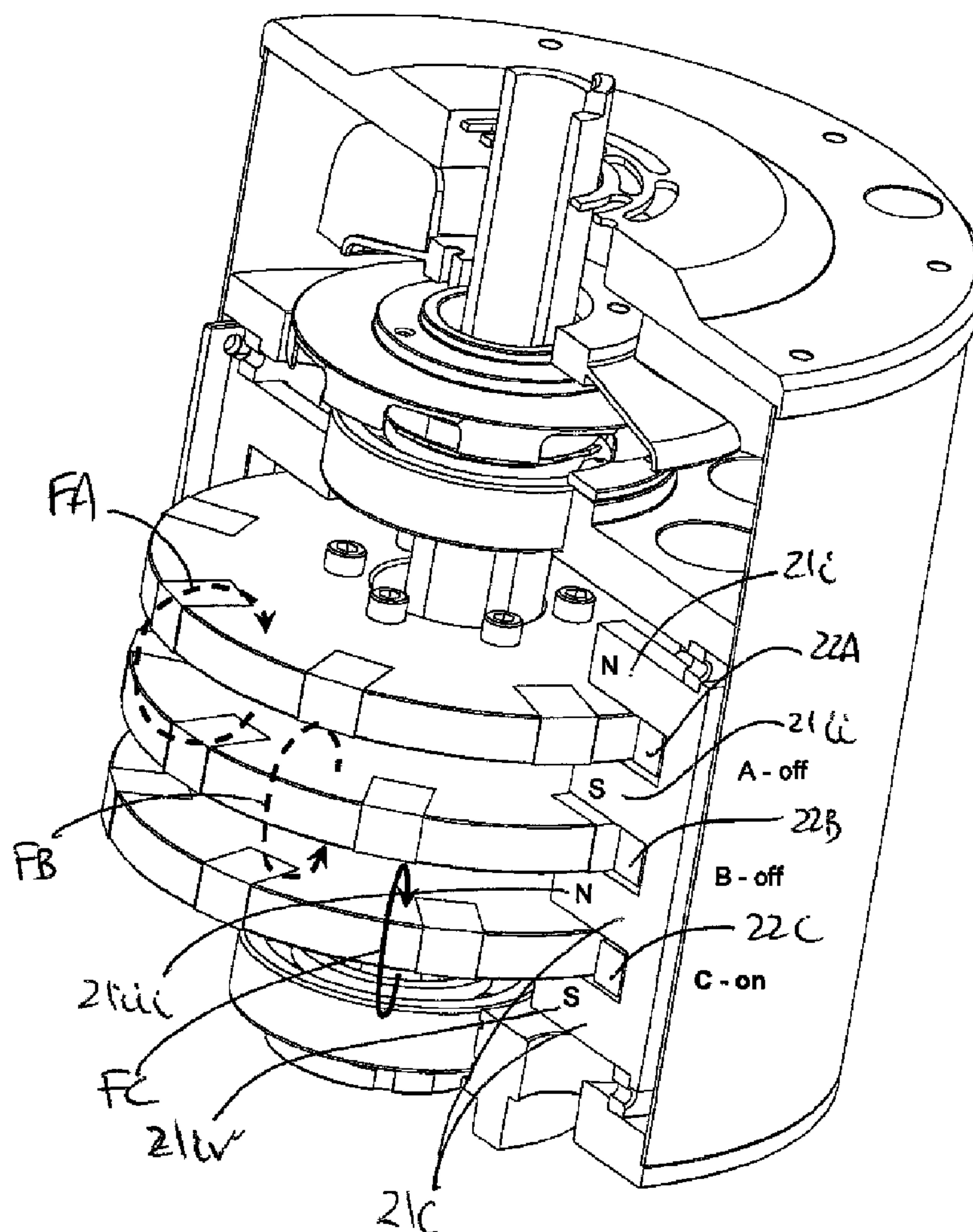
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(54) Titre : MOTEUR A RELUCTANCE COMMUTE PAR FLUX AXIAL

(54) Title: AXIAL FLUX SWITCHED RELUCTANCE MOTOR



1 **“AXIAL FLUX SWITCHED RELUCTANCE MOTOR”**

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3 FIELD OF THE INVENTION

4 The present invention relates to axial flux switched reluctance motors
5 and more particularly to motors using a plurality of rotor discs, circumferentially-
6 wound coils and circumferentially-spaced stators arranged axially to straddle each
7 of the rotor discs.

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9 BACKGROUND OF THE INVENTION

10 Conventional cylindrical switch reluctance (SR) motors (SRM) typically
11 utilize rotors with poles extending along the rotor and corresponding stators
12 extending axially along the rotor. The circumferential flux path of such motors is
13 along a significant angular portion of the motor: in a 6 pole rotor being $\frac{1}{2}$ of the
14 circumference of the motor and in a 12 pole motor, being $\frac{1}{4}$ of the away around
15 contributing to iron losses. Copper windings of the coils are intricate, being wound
16 about discrete poles and having ineffective coil-end connectors to the next pole
17 contributing to copper losses. Further, cylindrical switched reluctance motors are
18 plagued by noise as radial flexure of the machine housing. Some noise issues are
19 resolved using axial flux motors such as that set for in US 5,177,392 assigned to
20 Westinghouse Electrical Corp.

21 Axial flux motors conventionally utilize one or more axially stacked and
22 radially extending rotor disks. Each rotor disc utilizes circumferentially placed poles.

1 Typically a plurality of "U"-shaped stators, each having two poles is arranged
2 tangentially along the periphery of each rotor and radially positioned to magnetically
3 influence a corresponding pair of rotor disk poles. This arrangement is common to a
4 variety of axial flux motor designs including permanent magnet rotor designs such
5 as those in the that family of patents to CORE Innovation, LLC such as that set forth
6 in WO 2004/073365 and those currently assigned to Turbo Genset Company
7 Limited such as US 5,021,698 and wound rotor designs such as that described by
8 Westinghouse Electric Corp in US patent 5,177,392.

9 In existing commercial art axial flux SRM designs, an upper U-shaped
10 stator is arranged above the disc and a corresponding lower U-shaped stator is
11 arranged below the disc. An air gap is formed between the poles of each stator
12 pole and the disc. An air gap flux path between the two poles of the upper stator
13 passes about the stator coil from one pole, through the disc, and through the other
14 pole. Similarly, an air gap flux path between the two poles of the lower stator
15 passes from one pole, through the disc, and to the other pole. It is known that air
16 gap spacing can vary between the upper and lower U-shaped stators resulting in
17 differential attractive forces and causing an axial loading on the rotor.

18 In all of these designs, the flux path includes a circumferential
19 component in either the stator or rotor or both.

20 Further, the winding of each rotor and stator are conventional and
21 therefor complex, being a series of windings about discrete poles and having
22 ineffective coil-end connectors to the next pole and so on.

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SUMMARY OF THE INVENTION

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An axial flux switched reluctance motor is set forth herein having significantly lower iron and copper losses than conventional SR motors. The flux path is markedly shorter requiring less iron in the electrical steel used, the polarity of the poles is fixed resulting in less eddy and hysteresis loss and the coil design requires significantly less copper.

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In one embodiment of the present invention an axial flux switched reluctance motor is provided comprising one or more rotor discs spaced along a rotor shaft, each rotor disc having a plurality of rotor poles fit into the periphery of the rotor disc. Each rotor pole is an axially and substantially radially oriented lamination stack of electrical steel. A stator arrangement comprises a plurality of discrete stator lamination elements distributed circumferentially about the periphery of the one or more rotor discs and spaced angularly for driveably influencing the plurality of rotor poles. Each stator lamination element is a laminate stack of electrical steel oriented axially and radially. Each stator lamination element is formed with a plurality of axially spaced slots forming radially extending stator poles, each slot corresponding with the axial spacing of the rotor discs. Stator lamination elements for use with three rotor discs, controlled using three phases, comprises three slots and four stator poles extending radially inward from an axially extending back iron portion, each a stator pole being axially spaced for providing a pair of stator poles straddling each rotor disc therebetween. A stator coil extends

1 circumferentially about each rotor disc and resides in an annulus formed in each
2 slot and radially between the back iron of the stator lamination element and the rotor
3 disc.

4 Axial air gaps are formed between the straddling stator poles and the
5 energizing stator coil forms a flux path extending between one stator pole, the rotor
6 disc and an axially spaced and straddling stator pole. The entire flux path is
7 substantially within a radial plane having radial or axial components and no
8 circumferential components.

9 Magnetically induced axial loads are neutralized, use of electrical steel
10 is minimized and the windings are simplified and minimizing use of copper.

11

12 BRIEF DESCRIPTION OF THE DRAWINGS

13 Figure 1 is a side cross-sectional view of an embodiment of an axial
14 flux, switched reluctance motor according to one embodiment of the present
15 invention;

16 Figure 2 is a perspective, partial cross-section view of the motor of
17 Fig. 1, more particularly a cross-section of the stator showing stacked rotor discs
18 rotatable therein, the poles of each rotor disc being indexed circumferentially
19 relative to each other. The stator coils are shown removed for illustration of the
20 stator lamination element slots extending over the rotor discs;

21 Figure 3 is a perspective view of the motor housing of Fig. 1;

1 Figure 4 is a perspective view of three rotor discs of Fig. 1 having
2 circumferential stator coils, the top stator coil being removed for illustrating the
3 periphery of the top rotor disc and further including only one of the plurality of stator
4 lamination elements for illustrating the relationship of the stator lamination element
5 and the rotor poles;

6 Figure 5 is a top view of the rotor discs and circumferential coils and
7 illustrating two of the plurality of stator lamination elements for illustrating the
8 orientation and relationship of the stator lamination element and the rotor poles;

9 Figure 6 is a top cross-section view of the three rotor discs, each
10 cross-section of each success rotor disc being fancifully displaced laterally to better
11 illustrate the circumferential offset of the rotor poles;

12 Figure 7 is a side view of a partial arc of the three rotor discs in a flat
13 rolled-out view and with the circumferential coils being partially cutaway to illustrate
14 the rotor poles and one embodiment of the circumferential positioning of each pole
15 for each phase which respect to each other phase;

16 Figure 8 is a perspective, partial cross-section view of the motor of
17 Fig. 1, more particularly a cross-section of the stator housing showing a complete
18 view of stacked rotor discs rotatable therein, the circumferential positioning of each
19 pole, and showing a circumferential coil for each rotor disc fit between the stator
20 lamination elements and the periphery of each rotor disc;

21 Figure 9 is a perspective exploded view of the motor of Fig. 1
22 illustrating the end caps sandwiching the motor shroud, the stator housing, stator

1 lamination elements, rotor shaft and rotor discs, and further illustrating the motor
2 shroud, fan and motor end cap;

3 Figure 10 is a perspective view of the stator housing, stator lamination
4 elements, rotor shaft and rotor discs with one stator lamination element, wedge
5 insulators and clamps in a radially exploded view, and further illustrating the first
6 and second circumferential coils as transparent to show the poles otherwise
7 obscured beneath;

8 Figure 11 is a perspective view of a stator lamination element, wedge
9 insulators and clamps in a radially exploded view;

10 Figures 12A and 12B are top and side cross-sectional views of a
11 single rotor disc embodiment using 5 rotor poles and wherein six stator poles are
12 arranged circumferentially around the rotor disc and are operated on six different
13 phases;

14 Figure 13A is a plan view of one possible efficient manufacturing
15 template for electrical steel laminations for both the stator and rotor;

16 Figure 13B is an alternate plan view of another possible efficient
17 manufacturing template for electrical steel laminations for both the stator and rotor;
18 and

19 Figure 14 is a plan view of a typical prior art manufacturing template
20 for electrical steel laminations for both the stator and rotor.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in cross-section Fig. 1 and fully assembled in Fig. 3, an axial flux electromotive generating device or motor 10 using switch reluctance control has a stator arrangement 12 and a rotor 13. The principles of switched reluctance motors are known to those of ordinary skill in the art. Applicant has provided a heretofore unknown and advantageous arrangement of stator arrangement 12 and rotor 13.

The term "switched reluctance" has now become the popular term for a class of electric machine. The topology of conventional switched reluctance motors (SRM) implement phase coils mounted around diametrically opposite stator poles which are radially spaced about a rotor. A conventional SRM rotor has a plurality of radially extending poles. Energizing of a stator phase will cause a rotor pole to move into alignment with corresponding stator poles, thereby minimizing the reluctance of the magnetic flux path. Rotor position information is used to control energizing of each phase to achieve smooth and continuous torque.

In the present invention, the rotor 13 comprises a rotor shaft 14 about which are mounted one or more radially extending rotor plates or discs 15. The rotor discs 15 support a plurality of rotor poles 20. The stator arrangement 12 forms stator poles 21 spaced axially spaced from the rotor discs 15 and rotor poles 20 for forming axial air gaps G. One or more stator coils 22, one per rotor disc 15 are energized to interact with the stator poles 21 and create a magnetic flux. A flux path F is formed between the stator poles 21 and the rotor poles 20. The orientation of

1 the flux path F extending from the stator poles 21 and through the rotor poles 20 is
2 axial, being substantially parallel to the axis of the rotor 13. The entire flux path F is
3 substantially within a radial plane having radial or axial components and no
4 circumferential components. The flux path F is very short, extending only through
5 the back iron portion 23 of the stator pole 21 equivalent to about the axial thickness
6 of a rotor disc 15 as opposed to the conventional SR motor using $\frac{1}{4}$ to $\frac{1}{2}$ of the
7 circumference of the motor.

8 With reference to Figs. 1 and 2, the stator arrangement 12 is
9 supported in a stator housing 30. The stator arrangement 12 comprises a plurality
10 of discrete stator lamination elements 31 mounted in the stator housing 30 are
11 distributed angularly about the circumferential periphery of the one or more rotor
12 discs 15. Each stator lamination element 31 is formed of a laminate stack
13 31s,31s,31s ... of electrical steel oriented axially and substantially radially to the
14 rotor axis. Each stator lamination element 31 is supported in the stator housing 30
15 such as through mechanical attachment to the stator housing 30. The stator
16 housing 30 is sandwiched between a first, top bearing end cap 32 and a second,
17 bottom bearing end cap 33. The orienting terms top, bottom and related terms used
18 herein with reference to the drawings are only for descriptive convenience for the
19 reader as the motor 10 is not limited in its orientation for operation.

20 The first and second bearing end caps 32,33 can form annular steps
21 or ridges 34 for radially supporting the stator housing 30 in its cylindrical form.

1 The one or more rotor discs 15 extend radially from the rotor shaft 14
2 which is rotatably mounted between first and second bearings 34,35. The first and
3 second bearing 35, 36 are supported in the top and bottom bearing end caps 32,33.
4 Typically one bearing floats axially to accommodate dimensional changes.

5 As shown in Figs. 12A, 12B and in an embodiment implementing only
6 one rotor disc 15, the stator coil 22A, 22B ... associated with multiple phases A, B,
7 ... respectively actuate designated stator lamination elements 31A, 31B, ... stator
8 poles 21A, 21B ... arranged angularly about the disc 15. In such an embodiment,
9 the number of rotor poles 20, 20 ... can be any integer number including odd
10 numbers and the number stator poles 21, 21 ... can be equal to the number of
11 power phases or multiples thereof. With this radial arrangement and using switched
12 reluctance control there is no need to match the number of rotor poles 20 and stator
13 poles 21. This is in contradistinction to both conventional radial and conventional
14 axial flux switched reluctance motor designs in which the rotor poles must be
15 arranged in multiples of two and the stator poles must be arranged in multiples of
16 the number of power phases with a minimum of two times the number of power
17 phases. Typically, pairs of diametrically opposing stator poles are conventionally
18 wired in series for forming each independent phase of a prior art multi-phased
19 switched reluctance motor.

20 With reference again Fig. 2 and Figs. 4 – 8 illustrating an embodiment
21 implementing a plurality of rotor discs 15, the use of multiple rotor discs 15
22 conveniently enables multiple phases A, B, ... to be employed wherein one phase

1 influences one rotor disc at a time wherein all stator poles 21 for that particular disc
2 are energized at once using one stator coil 22.

3 Each rotor disc 15 has a plurality of discrete and circumferentially
4 spaced rotor poles 20 secured into the rotor disc 15 adjacent a radially peripheral
5 edge, preferably at the peripheral edge. As is known by those of skill in the art that
6 each rotor disc 20 and the stator housing 30 are formed of a non-magnetic material
7 such as aluminum, titanium, many stainless steels and fiber-reinforced plastics
8 (FRP). Each rotor pole 20 is formed of a laminate stack 20s, 20s, 20s ... of
9 electrical steel oriented axially and radially. The rotor poles 20,20 ... can be
10 secured in the rotor 12 by such methods as being molded into the disc 15, brazing,
11 gluing or retained by a non-magnetic circumferential restraint or hoop. Methods of
12 affixing the rotor poles 20 in the rotor disc 15 are, for the most part, dependent on
13 the maximum rotational speeds expected. As illustrated, such axial flux motors are
14 capable of about 500 rpm.

15 Each stator lamination element 31 is oriented axially with its stator
16 poles 21 and nested radially into the rotor discs 15. Insulative spacer blocks or
17 wedges 39 can be inserted radially between each successive stator lamination
18 element 31 and secured in place.

19 With reference to Fig. 4, across each stator lamination element 31 is
20 formed a plurality of axially spaced slots 40 corresponding with the axial spacing of
21 the rotor discs. For example, a stator lamination element 31 for two rotor discs
22 15,15 has the form of a capital letter "E", having 2 slots 40,40 straddled by three

1 stator poles 21,21,21 and ultimately resulting in an element 31 having pole 21, slot
2 40, pole 21, slot 40 and pole 21. For three rotor discs 15, as shown, there are three
3 slots 40,40,40 straddled axially by four radial stator poles 21,21,21,21 extending
4 radially from the axially extending back iron 23 portion, each a stator pole 21 being
5 axially spaced by the slots 40 for providing a pair of stator poles 21,21 straddling
6 each rotor disc 15 therebetween.

7 As shown in Fig. 6, eight angularly spaced stator lamination elements
8 31 provide stator poles 21 circumferentially spaced at 45 degree angular spacing
9 about the rotor discs 15. In this embodiment, there are also eight rotor poles 20
10 distributed about each rotor disc 15.

11 As shown in Figs. 6 and 7, the angular position of each rotor disc 15 is
12 rotationally indexed for implementing multi-phase operations wherein each rotor
13 disc represents a different phase and the angular starting position of each rotor pole
14 20 is angularly shifted. For example, as shown in the flat layout of Fig. 7, as the
15 three rotor discs 15 rotated to the left, stator coils 22A and 22C are not energized
16 and stator coil 22B is energized, generating flux path F for attracting rotor pole 20
17 between the stator poles 21,21. Each rotor disc 15 is secured to the rotor shaft 14
18 to maintain the rotationally indexed offset such as by three unique keyed
19 attachments between three different phased rotor discs 15.

20 Returning to Fig. 4, each element slot 40 is sufficiently radially deep,
21 or conversely each stator pole 21 has sufficient extent radially, to form a radial
22 annulus 40a (Figs. 2,4) , sized to accept the circumferentially extending stator coil

1 22 and still have a stator pole 21 portion extending sufficiently radially over the rotor
2 discs 15 to magnetically engage the rotor poles 20.

3 There is a circumferentially extending stator coil 22 for each rotor disc
4 15. The stator coil 22 is located adjacent and spaced radially from the periphery of
5 each rotor disc 15. Coil windings for each stator coil begin at a starting connection,
6 extend circumferentially in a circular loop many times in the stator coil about the
7 rotor disc and preferably end at termination connections at about the same angular
8 position as the starting connection. The power leads for each stator coil 22 can be
9 conveniently routed axially between stator lamination elements and through a
10 bearing end cap for connection to an SRM motor controller of conventional
11 construction. While alternate control algorithms could be developed, a conventional
12 and commercially SR motor controller can be used without modification with the
13 embodiments of the present invention.

14 Each stator coil 22 represents a phase winding. Typically three
15 phases A,B,C are provided and thus three rotor discs 15,15,15 are employed. The
16 coils 22 are electronically switched (electronically commutated) in a predetermined
17 sequence so as to form a stepwise moving magnetic field. The rotor 13 has no
18 phase windings but each of the plurality of rotor poles 20 are closely axially spaced
19 by dual air gap G to the straddling stator poles, one axially above the rotor disc 15
20 and one below the rotor disc 15.

21 The electronic switching of the stator coils 22A,22B,22C for each
22 phase produces a moving magnetic field which induces torque through adjacent

1 rotor poles. The rotor disc 15 rotates to move adjacent rotor poles 20 inline with the
2 energized stator poles 21,21 for minimizing the flux path F (minimum reluctance).
3 Generally, a coil 22 for a phase is switched on and off to capture a rotor pole 20 of
4 its respective rotor disc 15 in its magnetic field when on the phase is turned off
5 when the rotor pole is between the stator poles 21,21. Using predetermined
6 switching of the phases to actuate the appropriate coil and actuate the stator poles
7 for the corresponding rotor disc, the desired rotor speed is achieved, as is control of
8 forward or reverse rotation.

9 As shown in Figs. 6, 7, and 8 the B phase is about ready to switch off
10 and phase C is about to turn on.

11 As shown in Fig. 8, the rotor 13 has rotated from the position shown in
12 Fig. 7 and stator coil 22C for Phase C is on as rotor pole 20 (not seen) is entering
13 between the stator poles 21C,21C and, shortly thereafter, phase A will turn on.
14 Further, as illustrated, the stator poles 21 can be operated with the same polarity so
15 as to minimize eddy current and hysteresis losses. The flux paths F can be
16 oriented to operate so as to ensure that the polarity of the straddling poles 21 is not
17 changed. As shown, stator coil 22A forms a flux path FA and an arbitrary polarity N
18 is assigned to the top stator pole 21i and accordingly, the next lower stator pole 21ii
19 has a polarity of S. When stator coil 22B is actuated with a reverse flux path FB,
20 the polarity remains as S for stator pole 21ii and accordingly, the polarity of next
21 stator pole 21iii is N. Lastly, when the stator coil 22C is actuated with the same flux

1 path FB as flux path FA, the polarity remains as N for stator pole 21iii and
2 accordingly, the polarity of last stator pole 21iv remains as S.

3 With reference to Fig. 4, an encoder disc 50 and sensors 51 (such as
4 hall-effect sensors) provided feedback of rotor 13 position for each of the three rotor
5 discs 15,15,15 representing three phases A,B,C. For control in a first clockwise
6 rotational direction, the sensors and SRM controller and software (conventional)
7 sequentially control the triggering of each phase in sequence A,B,C as they related
8 to each of the first, second and third rotor discs in sequence. In the opposing
9 counter-clockwise rotational directional the sensors and SRM controller and
10 software (conventional) sequentially control the triggering of each phase in
11 sequence A,C,B as they relate to each of the first, second and third rotor discs in
12 sequence.

13 As shown in Figs. 4,8 and 12B, the magnetic flux path F is from one
14 stator pole 21, through the rotor disc 15 and to the next adjacent and straddling
15 stator pole 21 and back to the first stator pole through the axially-oriented back iron
16 portion 23 of the stator lamination element 31. Regardless of any variation in air
17 gap G between stator pole 21 and rotor pole 20, either above or below the subject
18 rotor disc 15, the flux path F is invariant and thus the axial attractive and repulsive
19 forces are balanced across the rotor disc. This arrangement substantially
20 eliminates the axial force fluctuations which can result in flexure and vibrations.
21 Accordingly, there is no built in negative stiffness known to existing other axial flux

1 machines. Further, conventional issues of radial flexure and noise are avoided due
2 to the elimination of radial attraction and repulsion.

3 There are both mechanical and electrical complexities and
4 simplifications introduced by the axial flux motor of the present invention.

5 As shown in Figs. 1 and 9, motor comprises the top and bottom
6 bearing end caps 32, 33 which sandwich the stator arrangement 12, the rotor 13
7 and stator housing 30 therebetween. The rotor shaft 14 supports a cooling fan 60.
8 A motor shroud 61 encloses the stator housing 30, stator arrangement 12 and rotor
9 13 and the fan 60 directs cooling air through the motor 10. Removal of the motor
10 shroud 61 enables access to the stator lamination elements and insulative wedges.
11 Also shown in Fig. 3, a motor end cap 62 competes the motor 10. Stator coil 22
12 power leads (not shown) can exit the shroud 61 or through one of the bearing end
13 caps 32,33 or motor end cap 62.

14 With reference to Figs. 9, 10 and 11, the assembly and disassembly of
15 the motor 10 is more complex compared to a conventional SRM motor where an
16 axially extending and radially constant rotor is easily inserted and removed axially
17 from a circumferential stator. Using the axial flux motor of the present invention, the
18 stator lamination elements 31 must be installed after the rotor discs 15 and coils 22
19 are positioned in the motor 10. Stator lamination elements 21 are inserted radially
20 so as to axially straddle each of the one or more rotor discs 15 and coils 22. In an
21 embodiment using multiple rotor discs 15,15,15, and wherein each rotor disc 15 is a
22 unitary integral disc having a central bore, before installing the stator lamination

1 elements 31, the bore of each rotor disc for each phase is inserted over the rotor
 2 shaft 14 and secured in an axially spaced and rotationally indexed arrangement.
 3 Spacer rings 64 (Fig. 1) or washers can provide the spacing corresponding to the
 4 spacing of the slots 40 in the stator lamination elements 31. The stator coils 22 are
 5 installed before the stator lamination elements 31 are installed radially so as to
 6 straddle both the coils 22 and rotor discs 15. A bearing end cap 32,33 can be
 7 secured to the stator housing 30 and the stator housing 30 arranged about the rotor
 8 discs 15,15,15. The stator lamination elements 31 are installed radially through
 9 slots 69 in the stator housing 30 and secured such as be using stator clamp plates
 10 70 fastened to the stator housing. The insulative wedges 39 can be inserted
 11 through ports 71 through the stator housing 30 and pairs of adjacent wedges can be
 12 retained in place using mechanical clamping plates 72 fastened to the stator
 13 housing 30.

14 The assembly of the mechanical arrangement is out-weighted by the
 15 simplification in electrical, weight characteristics and reduced losses inherent in this
 16 motor 10. Advantages include:

- 17 • The flux path is much shorter requiring less electrical steel,
 18 requiring less than about $\frac{1}{2}$ of the electrical steel used in a
 19 conventional radial flux switched reluctance motor design.
- 20 • The multiple rotor disc embodiment results in
 - 21 ○ a simple hoop or circumferentially extending copper coil
 22 which requires about $\frac{1}{2}$ of the conventional copper due

1 to the elimination of conventional end connectors and
2 lines between series poles and elimination of the
3 conventional ineffective coil ends

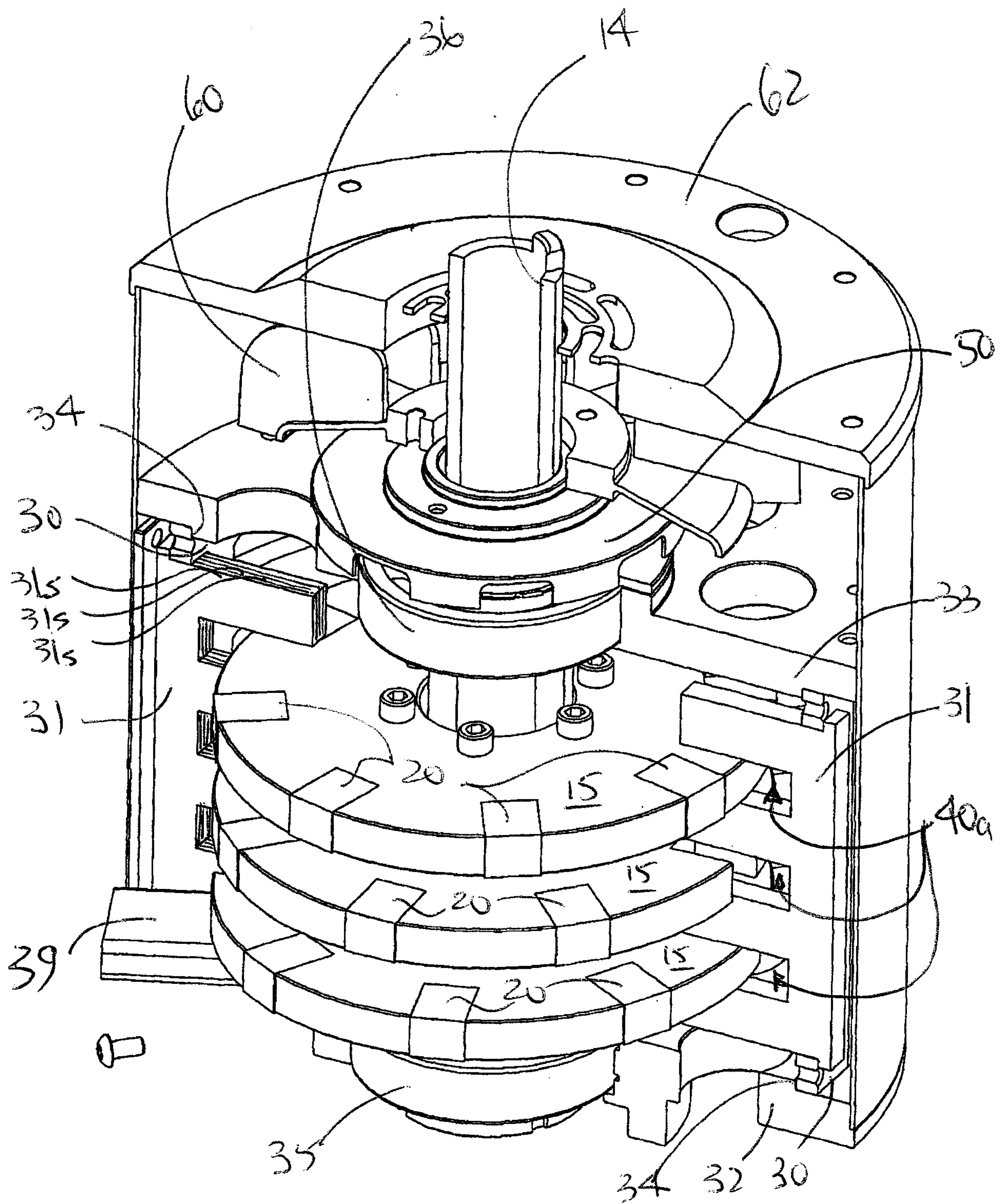
4 o ease of windings manufacture and installation wherein
5 winding complexity prevalent with conventional multiple
6 independent poles is eliminated and replaced with a
7 circular hoop.

- 8 • The polarity of the stator poles does not change and reducing
9 losses.
- 10 • Magnetic flux is balanced axially eliminating axial vibration.
- 11 • Less steel and less copper results in smaller, lighter, cooler and
12 less expensive motors.
- 13 • The magnetic flux path is purely axial, there is no
14 circumferential component to the flux in either the rotor or the
15 stator.

16 As shown in Fig. 14, a single lamination of a prior art circumferential
17 stator and rotor could be cut from electrical steel. The stator and rotor portions
18 could be stamped from the same location in the steel, however, a significant mass
19 of steel is required and wastage is also great. Applicant understands that patterns
20 stamping cannot extend to the edges of the raw steel material due to manufacturing
21 constraints of die stamping such as a loss of dimensional tolerances at said edges.

1 With reference to Fig. 13A, in the manufacture of a single lamination
2 31s of a stator lamination element 31 and rotor pole 20 according to the present
3 invention, much less electrical steel is required, the only loss being to form the
4 annulus 40a where the circumferential coil passes. Further, electrical steel blank or
5 strip material can be fully utilized to its width as the forming action at the edges is
6 merely to shear the material which can be conducted to an edge.

7 Similarly, with reference to Fig. 13B, a single lamination 31s of a stator
8 lamination element 31 and rotor pole 20 can be oriented axially rather than
9 transversely as shown in Fig. 13A. A narrow electrical steel blank or strip material
10 can be fully utilized to its width with notching of the slots and shearing of each axial
11 element 31 for each successive element 31.

**Fig. 2**

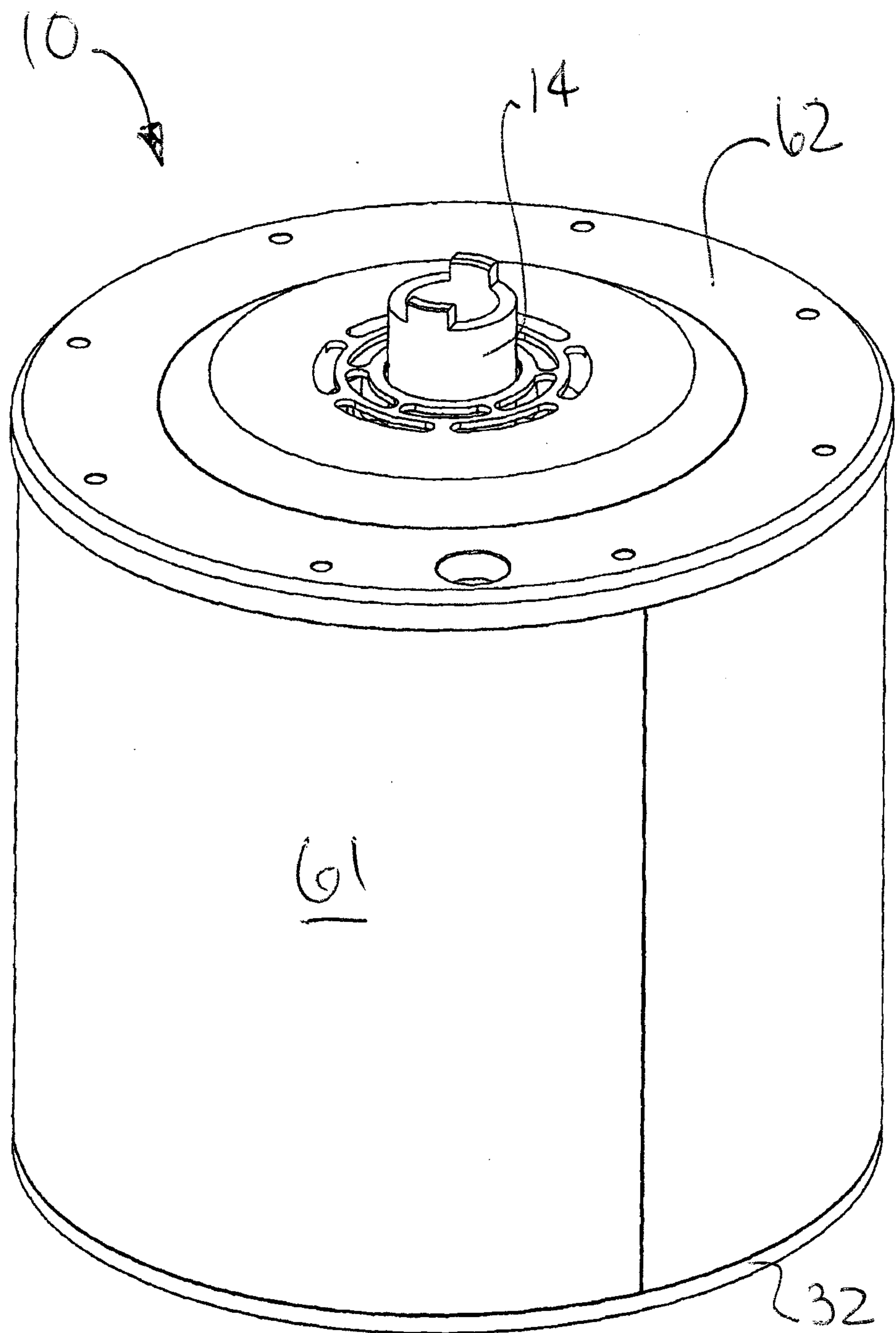


Fig. 3

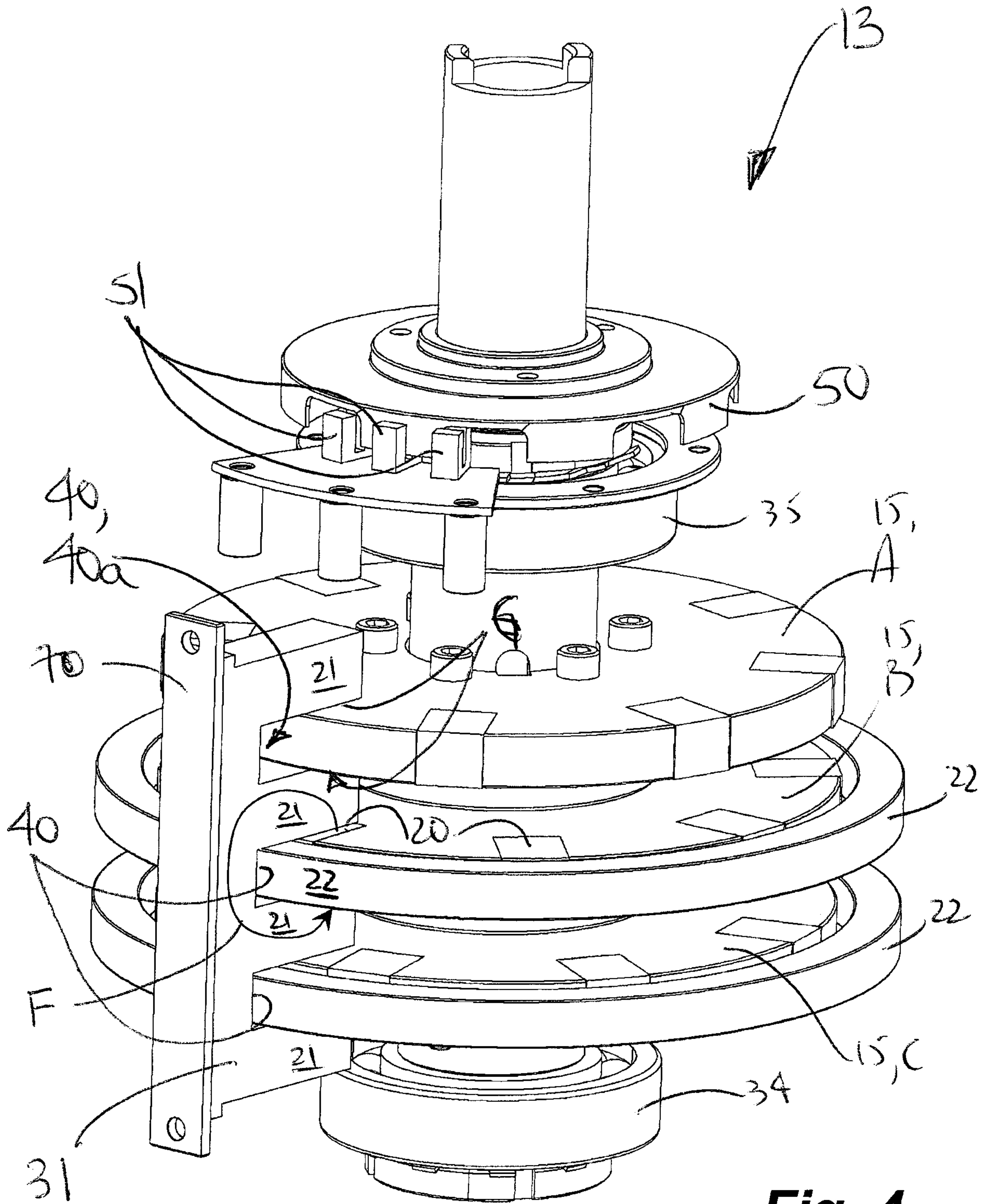


Fig. 4

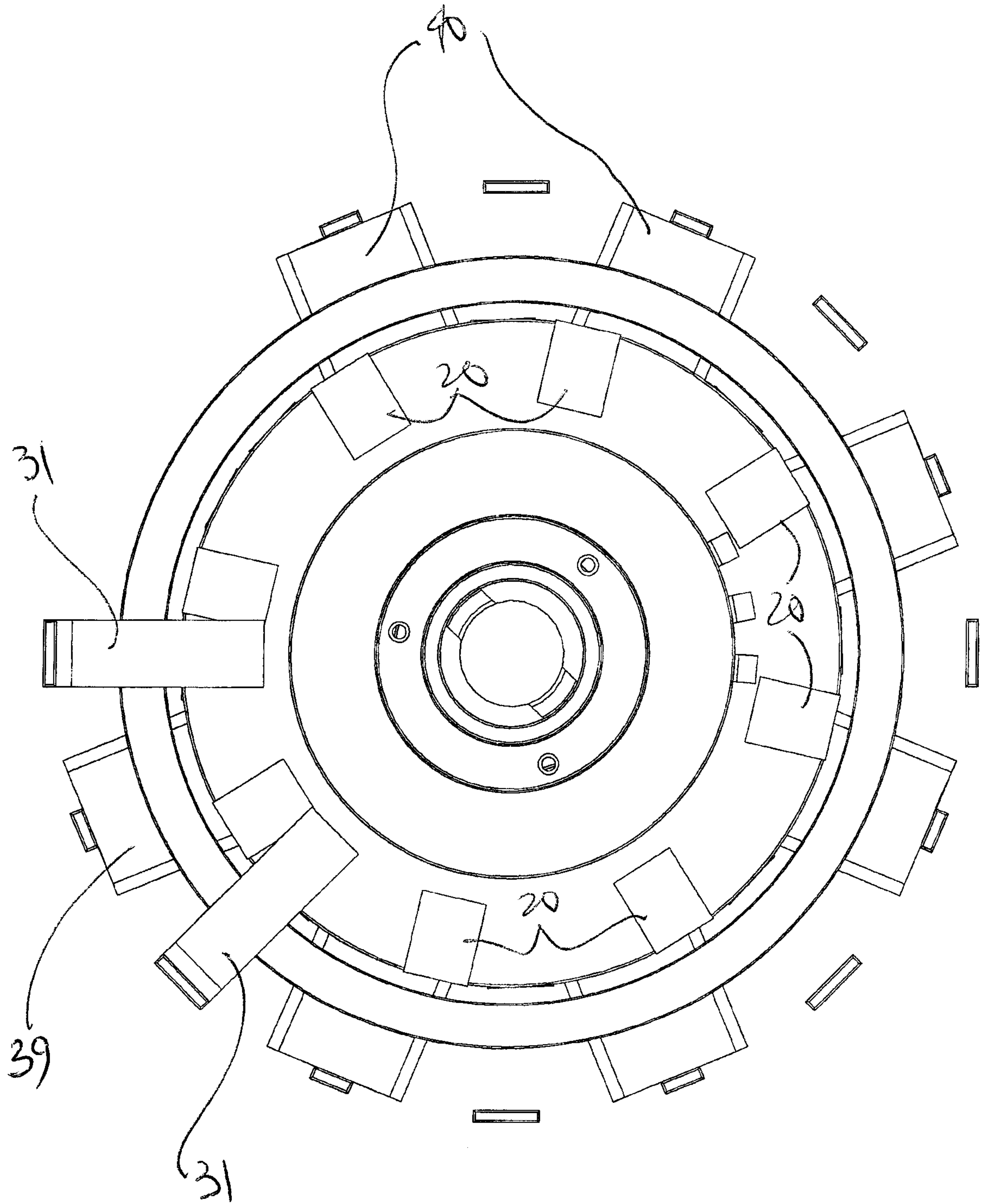


Fig. 5

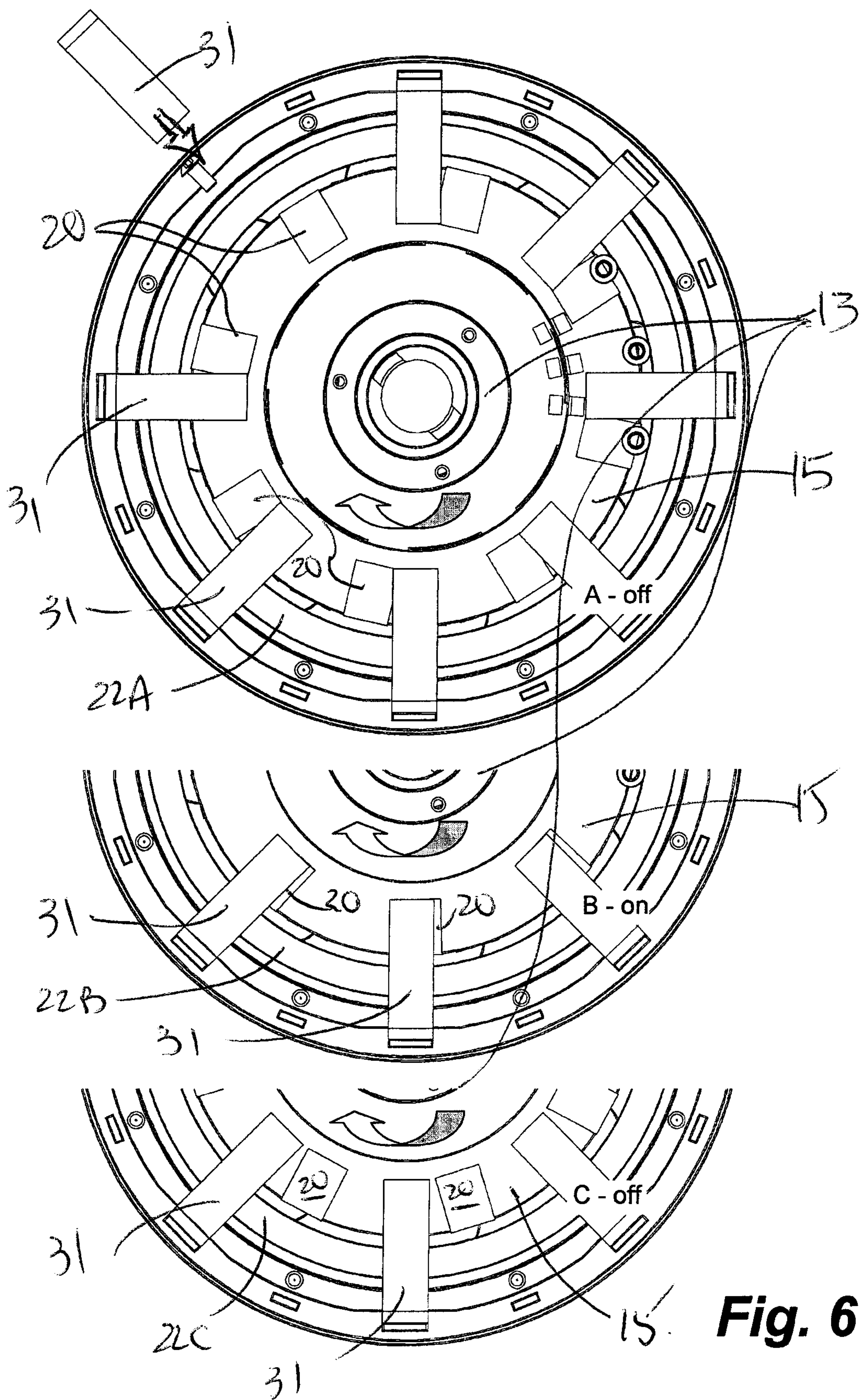


Fig. 6

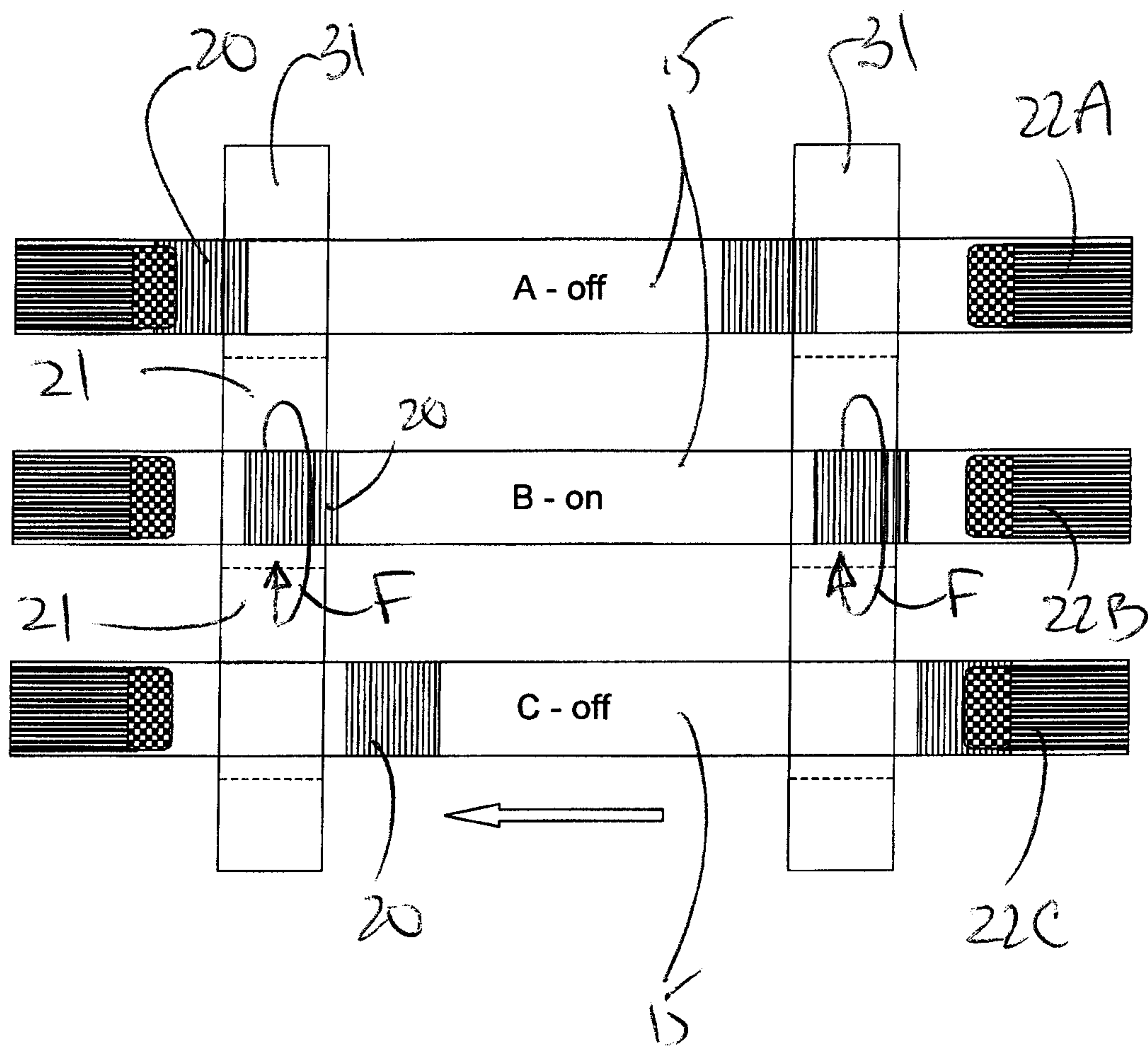


Fig. 7

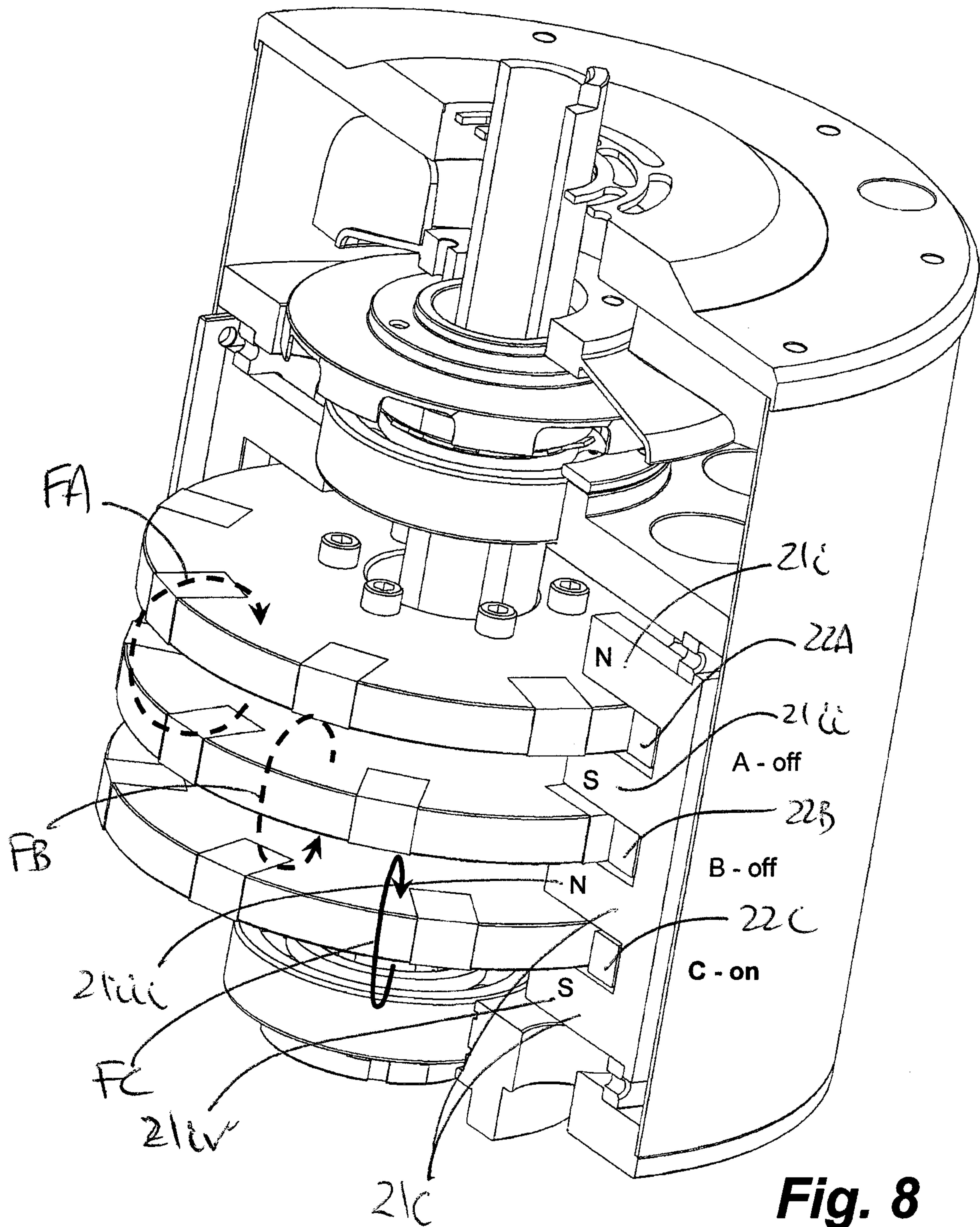


Fig. 8

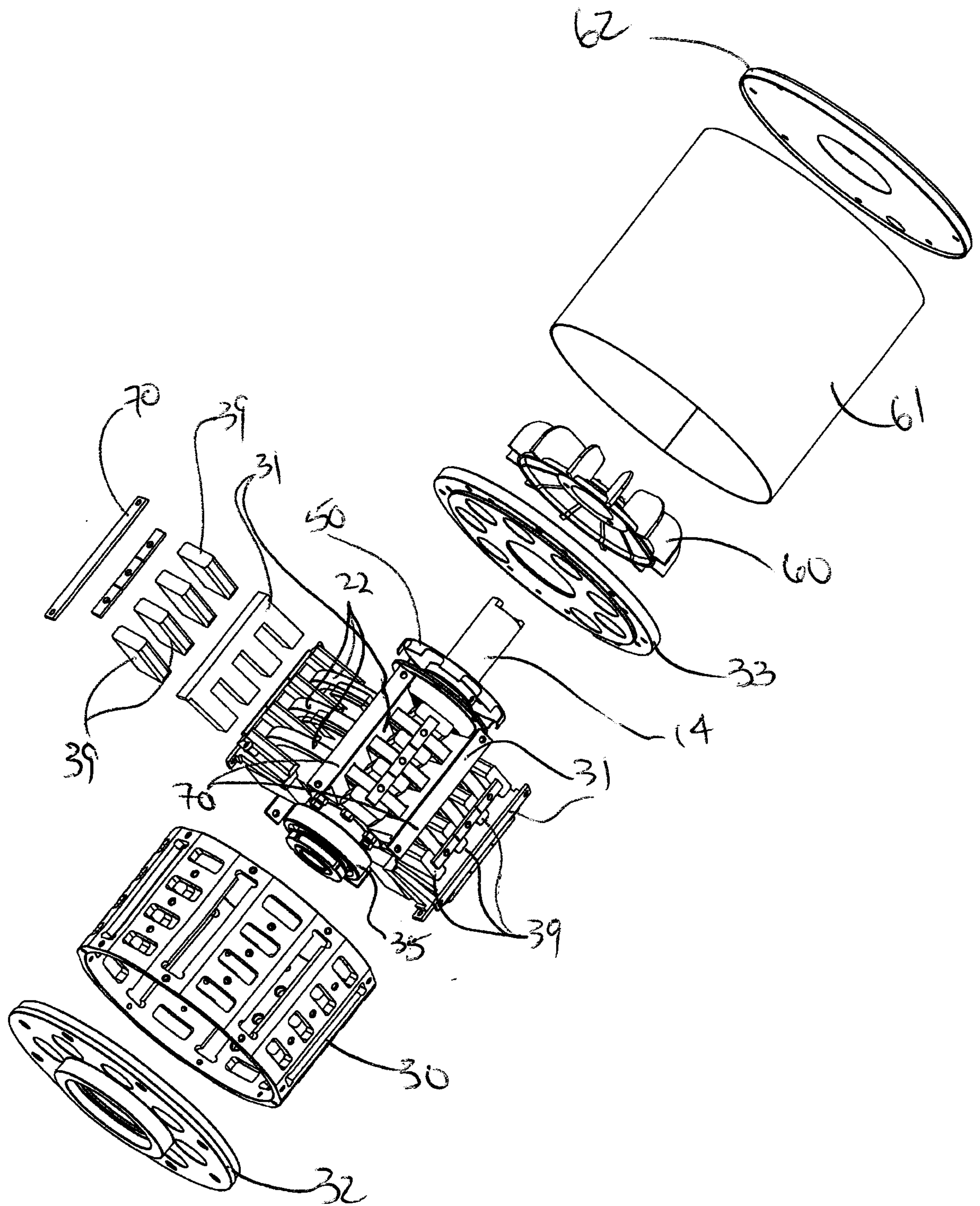


Fig. 9

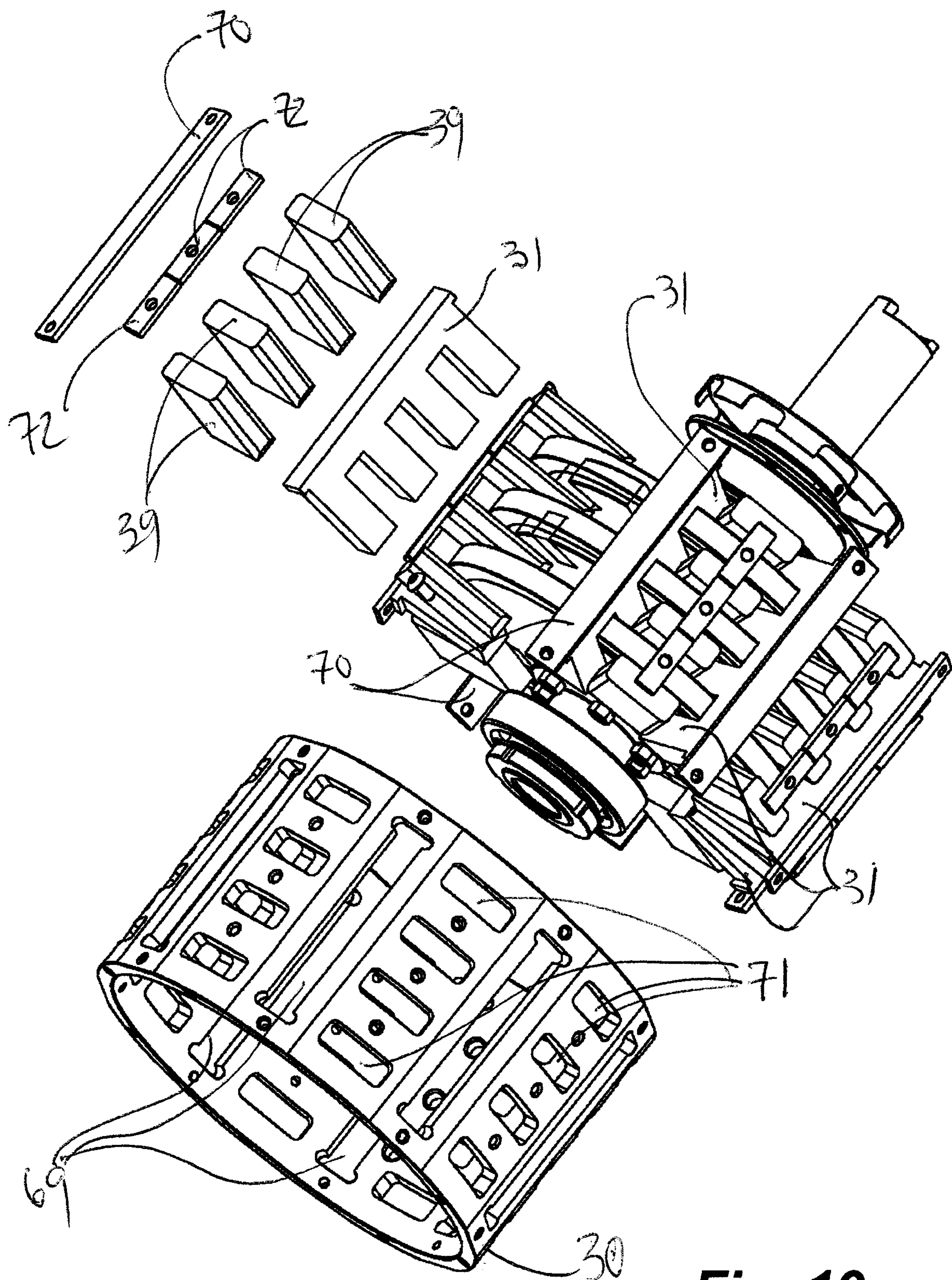


Fig. 10

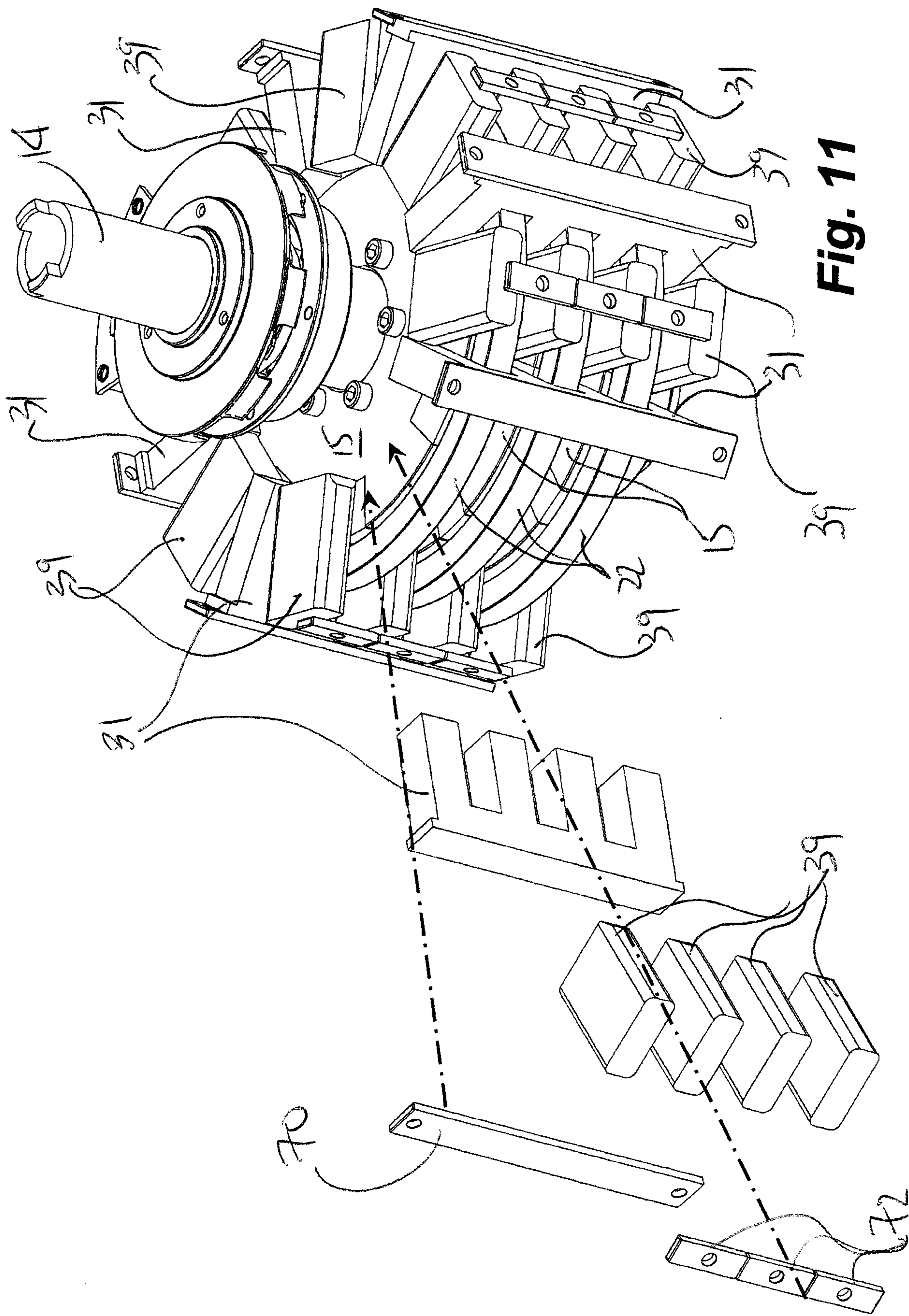


Fig. 11

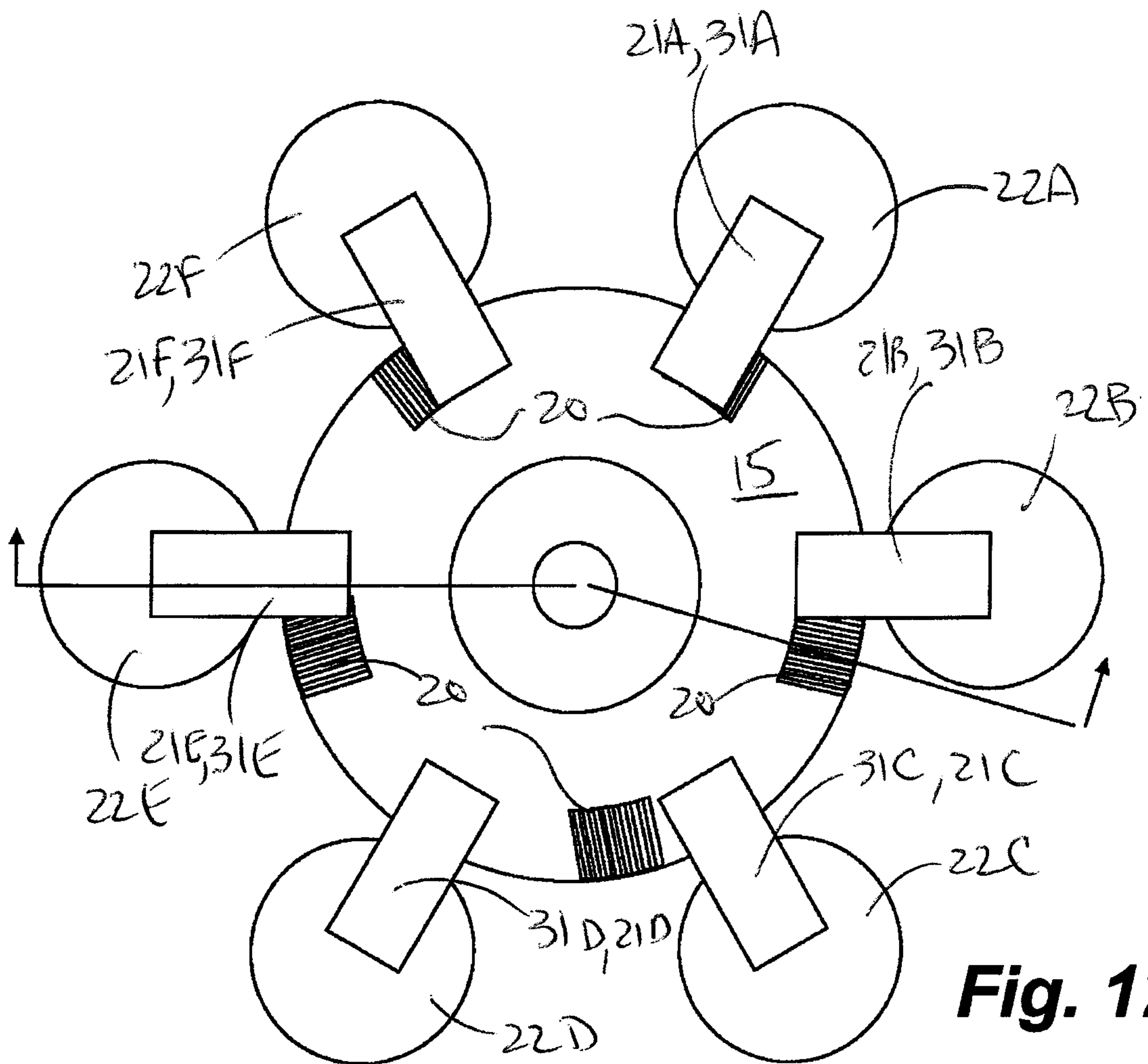


Fig. 12A

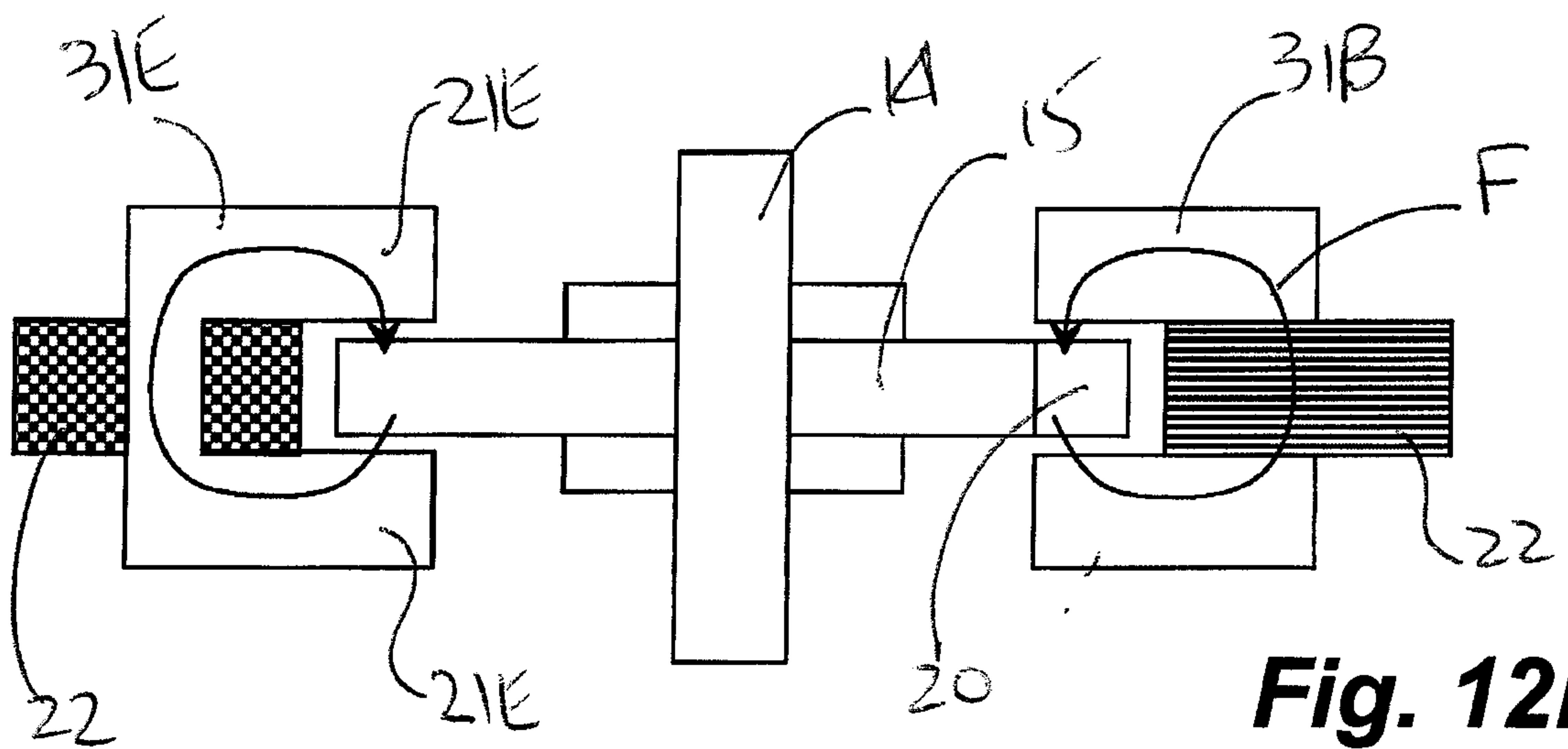
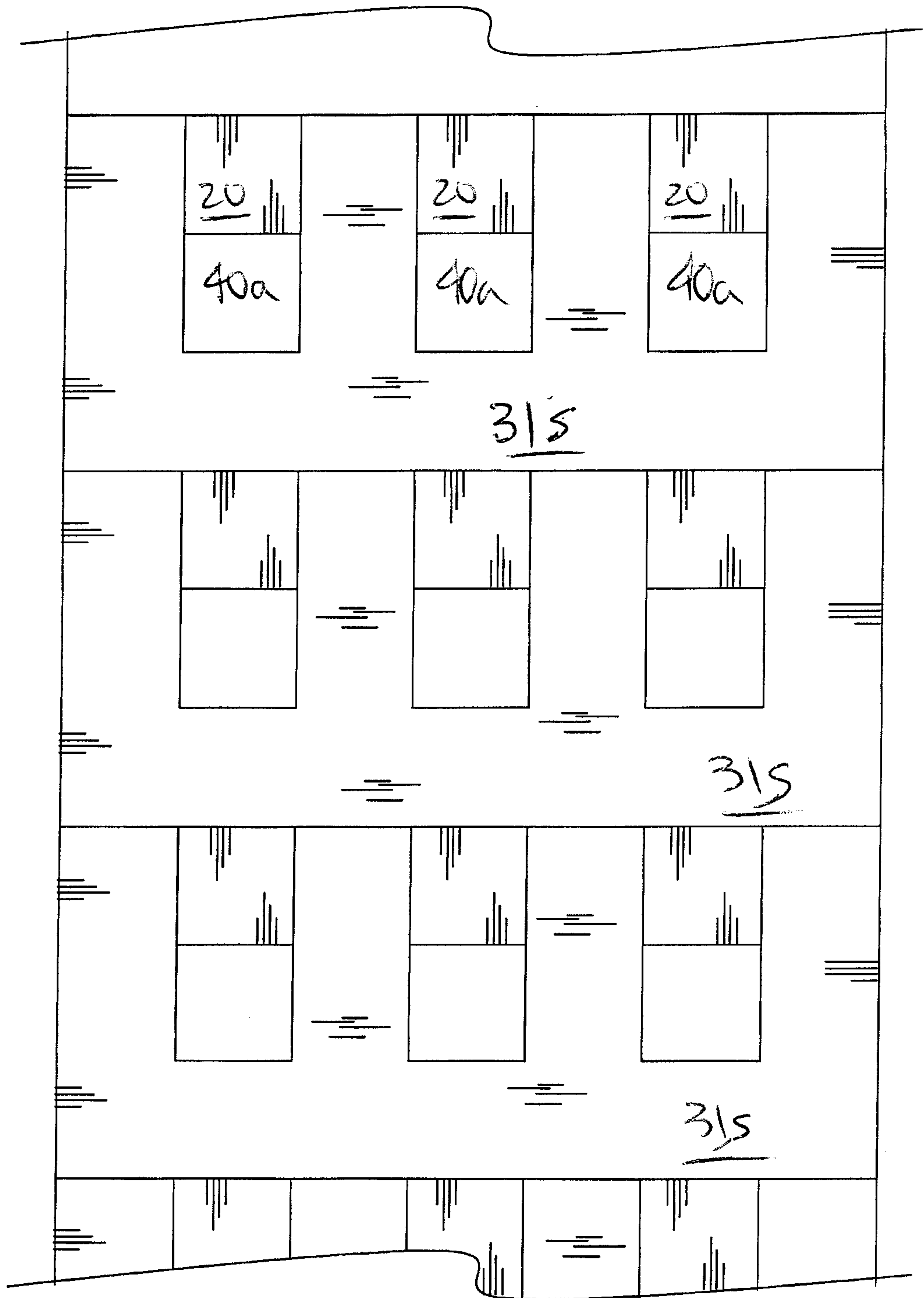
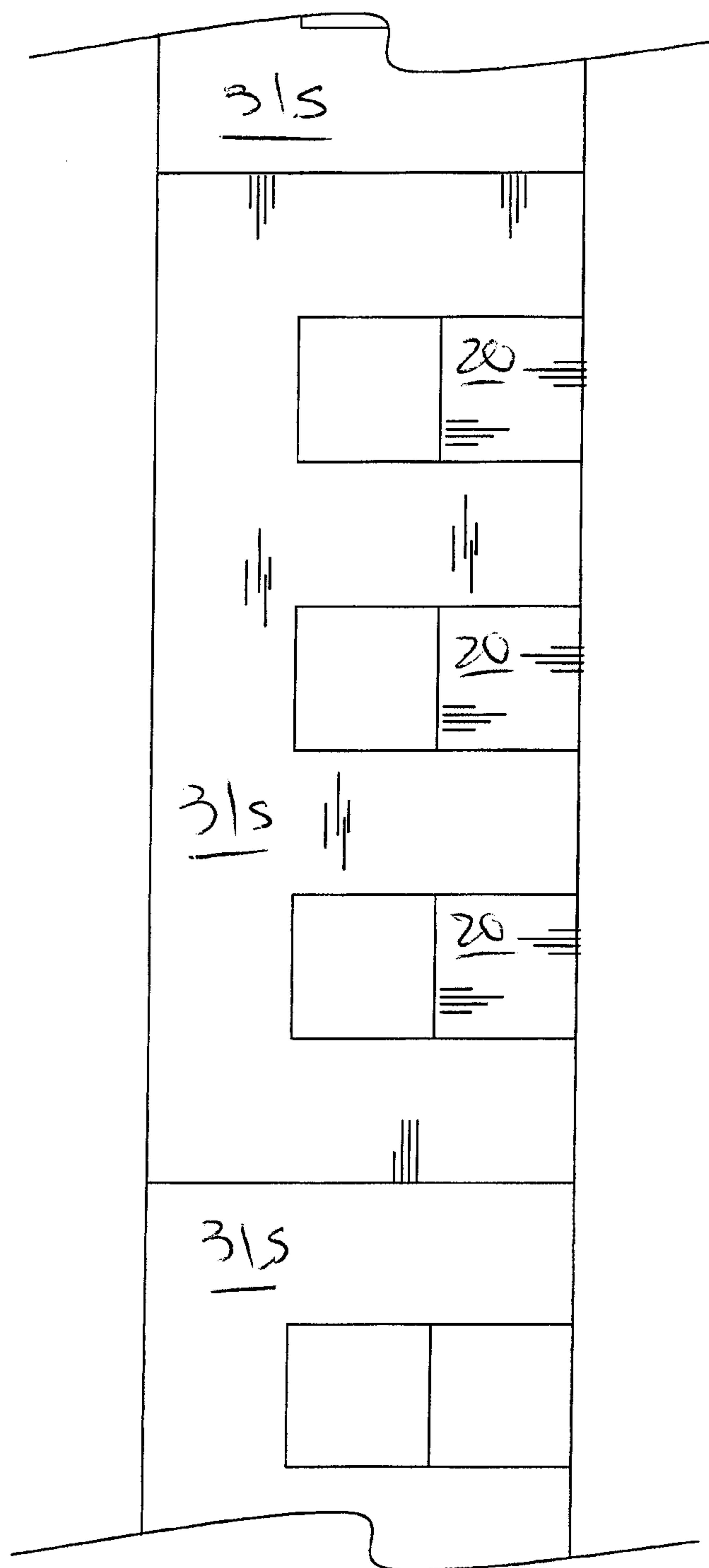


Fig. 12B

**Fig. 13A**

**Fig. 13B**

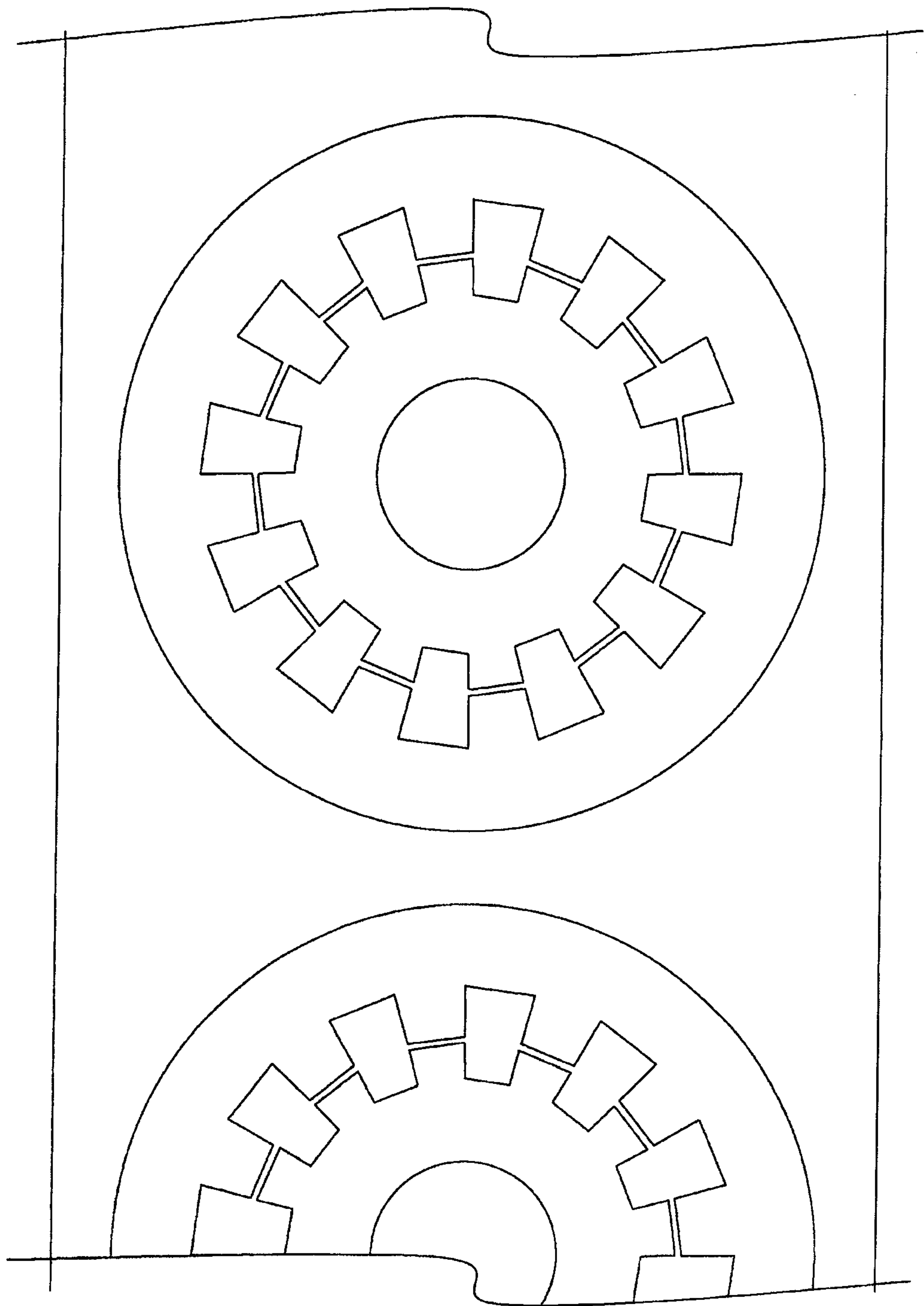


Fig. 14 – Prior Art

