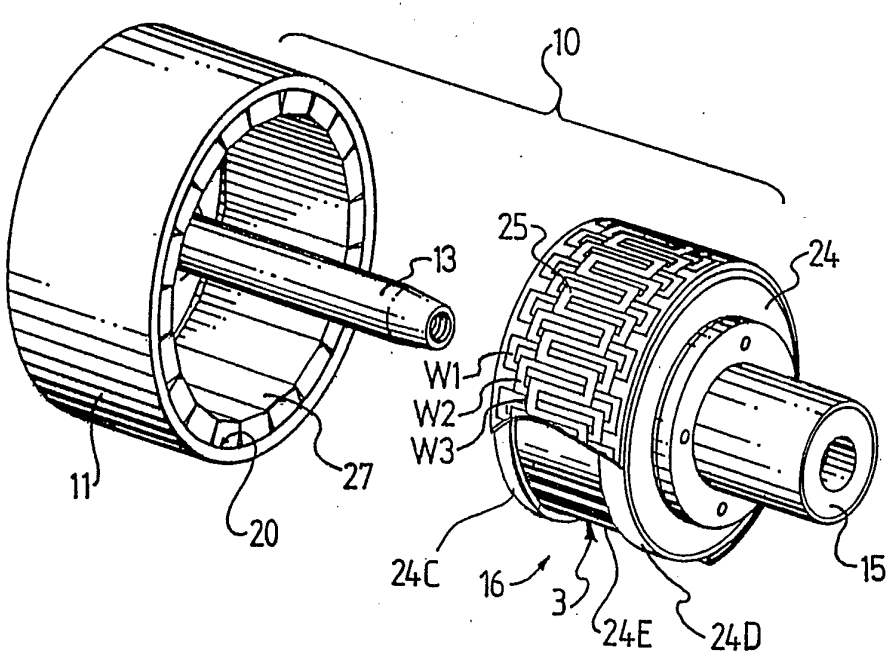




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(54) Title: DYNAMOELECTRIC MACHINE AND STATORS THEREFOR 		
(57) Abstract <p>A co-axial cylindrical brushless DC motor has an internal cylindrical stator (16) and an external rotor (11) containing permanent magnets (27). The cylindrical stator (16) has a substrate (24) of reinforced plastics in the shape of a reel having outer flanges (24C, 24D) surrounding a shallow recess (24E) containing one or more lengths of strip (3) formed from a soft magnetic material. The strip (3) has a width equivalent to the width of the recess (24E). The strip is wound about the substrate (24) and has an outer surface flush with the outer circumference of the flanges (24C, 24D). The strip (3) is wound in a spiral similar to the shape of a clock spring. Wound poles (25) are superimposed on the strip (3) and extend over the flanges (24C, 24D) of the substrate.</p>		

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DYNAMOELECTRIC MACHINE AND STATORS THEREFOR

FIELD

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This invention relates to dynamoelectric machines, and has particular application to brushless DC electric motors.

BACKGROUND

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Conventional electric motors have an internal rotor and an external stator. Typically both the rotor and stator include a number of iron or steel laminations, stamped into relatively complex shapes, in order to increase the interaction of magnetic flux of either permanent-magnet or electromagnetic origin with the magnetic fields generated by electric currents flowing in the windings of the motor. Disadvantages associated with such laminations include mass, weight, expense, complexity, and evolved heat caused by eddy currents or hysteric losses within the mass of ferrous material. In practice it is found that motors of the "Universal AC/DC" type as are commonly used in vacuum cleaners and the like cannot run for extended periods because of the rise in temperature within the laminations.

20

For these and other reasons (such as higher rate of operation, lower inertia, and simpler sequencing/controlling) the evolution of ironless electric motors has been an area of development. We have already described several such motors, in our commonly assigned PCT/GB 8800742.

25

There remains a need to increase the power output of such "ironless" motors, but without incurring the disadvantages of stacked iron or steel laminations, i.e. increased weight, current losses, and more importantly the resultant high inductance of such conventional steel lamination motors, which among other problems renders sequencing by back-EMF detection more difficult. One solution has been described in our earlier application PCT/GB91/00155 in which several layers of steel wire are wound in a helical fashion around the substrate before the stator windings are superimposed on the steel wire and substrate. This has the advantage of increasing the power output but increases the cost of manufacture. There is a need to obtain similar power increases but at a lower cost of manufacture.

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OBJECT

5 It is an object of this invention to go some way towards meeting the above mentioned need, and to provide an improved stator for dynamoelectric machines, and/or an electric motor which at least provides the public with a useful choice.

STATEMENT OF INVENTION

10 The present invention is an improvement over the dynamoelectric machine stators described in PCT/GB91/00155.

15 In one aspect, the invention provides a stator for a dynamoelectric machine of any configuration wherein said stator comprises a substrate, and one or more layers of elongate yet flattened ferromagnetic material are provided on or close to the surface of the substrate, with wound poles superimposed on said layer(s) of elongate material, wherein said ferromagnetic material is comprised of a "soft magnetic" material having a magnetic permeability greater than 20.

20 Preferably the dynamoelectric machine has a substantially cylindrical rotor and a substantially cylindrical stator.

25 Preferably the one or more layers of ferromagnetic material exhibits low hysteresis and low eddy current losses.

Preferably the stator has a substrate of substantially nonconducting, substantially nonmagnetic material, and said one or more layers of ferromagnetic material of high magnetic permeability are positioned on or close to the surface of the substrate.

30 Alternatively the stator substrate could be formed from a steel pressing or other metallic material.

35 Preferably the ferromagnetic material is provided in the form of a tape or strip of indefinite length having a cross sectioned shape wherein the thickness is substantially less than the width.

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5 Preferably each layer of ferromagnetic material within the assembled stator is comprised of a single turn of said material, and multiple layers of said material are preferably built up by wrapping each layer over the preceding layer, in the manner of a clock spring, or a roll of adhesive tape.

Preferably the material has electrically insulating layer(s) on one or both main surfaces to minimise conduction across superimposed layers.

10 It is preferred that the ferromagnetic material consists of a single coil of tape or strip but it will be appreciated that the coil would be made up of several strips wound one on another.

15 The ferromagnetic strip or tape is generally referred to herein as a "coiled strip".

The ferromagnetic material is preferably formed from a "soft magnetic" material such as an annealed steel strip of suitably thin dimensions wound on said substrate. Any "soft magnetic" material may be used, but we have found that annealed low carbon steel is inexpensive and is readily available. A silicon steel is also preferable. A "soft
20 magnetic" material is one that can be easily magnetised and which has a hysteresis (b/H) loop including a minimal area. The term "soft" refers to the magnetic property of the material and not its mechanical property. The preferred "soft magnetic" materials have a large saturation magnetisation.

25 Preferably multiple layers of coiled strip are used in applications wherein the magnetic flux is liable to saturate a lesser number of layers.

The invention is particularly suited to brushless DC motors, although it can be used with any dynamoelectric machines of any configuration including cylindrical motors
30 and alternators, pancake motors and alternators, commutator motors, and linear motors. In the case of our preferred embodiment of the invention of a brushless DC motor the stator may be an internal or external cylindrical stator, although for larger machines we prefer to use an internal stator and an external rotor.

35 In another aspect, the invention provides a stator for a cylindrical dynamoelectric machine wherein said stator includes a generally cylindrical support having one or more

layers of coiled strip formed from a soft magnetic material on said support, and wound poles superimposed on said layer(s) of coiled strip.

5 In another aspect, the invention provides a stator for a cylindrical dynamoelectric machine, comprising a generally cylindrical stator having an outer stator surface wherein said stator has a generally cylindrical substrate of a first material having outer
10 flanges defining a shallow circumferential recess and a thin annular substantially cylindrical layer in said recess, said annular layer having an outer annular surface, a plurality of wound poles superimposed on said outer annular surface, and characterised
15 in that said thin annular substantially cylindrical layer is formed from one or more lengths of strip of width comparable to the width of the recess, and said strip comprises a soft magnetic material having a magnetic permeability greater than 20.

15 In another aspect, the invention provides a rotary dynamoelectric machine comprising: a generally cylindrical stator having a stator surface,
a generally cylindrical external rotor rotatable about a rotational axis and having an interior generally cylindrical rotor surface surrounding said stator and spaced apart
20 therefrom by a generally cylindrical gap, a plurality of magnetic poles on said interior generally cylindrical rotor surface and positioned adjacent said generally cylindrical gap, wherein said stator has a generally cylindrical substrate of a first material having outer flanges defining a shallow circumferential recess and a thin annular cylindrical
25 layer in said recess, said annular layer having an outer annular surface, a plurality of wound poles superimposed on said outer annular surface, so that the wound poles are adjacent said cylindrical gap and face said rotor and at least a majority of the wound
30 poles are positioned substantially parallel to the rotational axis of the rotor, and characterised in that said thin annular cylindrical layer is formed from one or more lengths of strip of width comparable to the width of the recess, and said strip comprises a soft magnetic material having a magnetic permeability greater than 20.

30 In another aspect, the invention provides a dynamoelectric machine having a generally cylindrical stator comprising a generally cylindrical substrate of substantially nonconducting, substantially nonmagnetic material, having one or more layers of coiled strip formed from a soft magnetic material on said substrate, with wound poles
35 superimposed on said layer(s) of coiled strip and surrounded by an external substantially cylindrical rotor having a plurality of permanent magnetic poles on the

inner cylindrical surface of said rotor.

5 In another aspect, the invention provides a brushless DC electric motor comprising a generally cylindrical rotor having a plurality of permanent magnetic poles associated therewith; and a stator having a generally cylindrical substrate having one or more layers of coiled strip formed from a soft magnetic material on said substrate, and wound poles superimposed on said layer of coiled strip and facing towards said rotor.

10 The invention may be utilised with machines having a low number of poles, e.g. 2 or 4 pole machines, however the invention is most advantageous where medium or high pole numbers are used and more preferably where the permanent magnetic poles are closely spaced around the periphery of the rotor. For machines of 6 to 30 poles for example, the layer(s) of soft magnetic coiled strip can be relatively thin (in the range of
15 1 to 4mm) and thus a smaller amount of steel coiled strip is used than for a 2 pole machine. The exact number of poles will depend on the rotor size but for most applications we prefer to manufacture machines with 6 to 20 poles.

20 Preferably the magnetic layer or layers of coiled strip formed on the stator consists of coiled strip (such as steel coiled strip wound in one or more overlaid layers. Alternatively, the layer or layers may be formed of discrete and preferably tightly apposed loops of steel strip of soft magnetic properties placed on the cylindrical stator.

25 For a medium speed machine having a stator diameter of about 110 mm, a magnetic depth of about 4 to 5mm deep may be made from multiple layers of coiled strip of preferably 0.2mm - a kind of "shim" to about 1mm in thickness.

30 In another embodiment the width of the strip is preferably 48 mm and the thickness is 0.5 mm, and eleven layers of the strip are used.

Preferably the coiled strip is used with its oxide coating intact, to serve as insulation, though optionally further layers of insulating material may be applied between the turns of the coiled strip.

35 Preferably the surface of the coiled strip is of low conductivity (and an annealed steel coiled strip has relatively low surface conductivity) or the coiled strip may be coated

with an insulating layer such as varnish, or a thin insulating sheath (such as a synthetic plastics material), or wrapped together with an adjacent layer of paper or other insulating sheet material.

5

It will be generally preferable to keep any insulating sheath or covering as thin as possible, in order to maximise the magnetic content of the layer or layers of coiled strip.

10

Such a machine having a stator formed from one or more layers of a soft magnetic material in the form of one or more coiled strips or tapes wound on or laid on the surface of the substrate enables a machine to be made at low cost, and have low inductance. Such a machine can be used with relatively low cost electronic commutation systems, so that a brushless DC motor can be produced having simple electronic controls.

15

DRAWINGS

These and other aspects of this invention, which should be considered in all its novel aspects, will become apparent from the following description which is given by way of example only, with reference to the accompanying drawings in which:

20

Figure 1a: is a drive end view (with mounting plate removed) of a permanent magnet rotary dynamo electric machine of the type used with the coiled strip showing the external rotor construction using bar magnets.

25

Figure 1b: is a section on line AA of Figure 1, (with mounting plate in position), showing the placement of the bar magnets in the outer rotor, and the relative position of the stator within the rotor.

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Figure 1c: is an exploded perspective view of the rotor and stator of Figures 1a and 1b showing the layers of steel coiled strip beneath the wound poles.

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Figure 1d: is an expanded sectional view of the stator of Figure 1b, with the depth of the four layers of steel coiled strip and the depth of the wound poles exaggerated for the purpose of identification.

5 Figure 2a: shows the drive end view of a permanent magnet rotary dynamo electric machine having an external rotor formed from a one piece ring magnet. (The stator construction has been omitted from this drawing.)

Figure 2b: is a section on line BB of Figure 2a, showing the construction of the rotor only.

10 Figure 3: shows a flux diagram for a 12 pole permanent magnet rotary dynamo electric machine of this invention.

Figure 4: shows a three phase winding construction for a typical permanent magnet rotary dynamo electric machine of this invention.

15 Figure 5a: shows the drive end view (end cover removed) of a permanent magnet rotary dynamo electric machine showing an internal rotor construction using a cylindrical magnet.

20 Figure 5b: shows a section on line CC of Figure 5a, in exploded view, of the end cover, internal rotor, and external stator.

Figure 6: (reproduced together with Figure 3) shows an expanded view of the magnetic flux path through the steel coiled strips.

25 Figure 7: is a graph of the magnetic properties of the preferred annealed steel coiled strip.

Figure 8a: shows an end view of a stator and rotor for a 6 pole permanent magnet rotary dynamo electric machine using 12 bar magnets in pairs.

30 Figure 8b: shows a voltage graph for a typical permanent magnet rotary dynamo electric machine of this invention.

PREFERRED EMBODIMENT

5 The motor/alternator of this invention is preferably constructed using a series of adjacent bar magnets inside a steel annulus to form the rotor as shown in Figure 1a. The steel annulus provides two important functions:

- 10 1. A mechanical support for the magnets against the high centrifugal forces encountered when the rotor is running at high rpm. It will be apparent that ceramic and rare earth magnets have a low tensile strength when compared to the steel cup shaped rotor of Figure 1b.
- 15 2. A return path for the magnetic flux between adjacent magnets. The bar magnets could equally well be replaced by a cylindrical "ring" magnet, as shown in Figure 2a, with alternate north and south poles around its circumference.

20 The motor alternator of this invention can also be constructed with the rotor as the inner element and the stator as the outside element, see Figures 5a and 5b, but is not as advantageous as the external rotor construction because of the lower maximum rpm that the rotor of Figure 5b can sustain without flying apart due to the low tensile strength of ceramic and rare earth magnets or adhesive attachments when compared to the steel cup shaped rotor of Figure 1b.

25 The internal rotor construction does have applications in the low to middle speed area as it lends itself to current construction techniques as used to manufacture small induction motors and alternators.

30 In the following examples, it is most convenient to provide the permanent magnets on the rotor so that electrical connections can be readily made to the wound poles on the stator.

Preferably the direct current motor employing a co-axial steel-coiled strip stator is controlled by electronic means to provide a brushless DC motor.

EXAMPLE 1 - FIGURES 1a to 1d

5 In this example, a co-axial motor or alternator is illustrated, having an external rotor construction utilizing bar magnets. Whether the unit is used as a motor or an alternator will depend upon the application required, and whether or not current is extracted from the stator windings, or whether current is supplied to the stator windings to operate the unit as a motor.

10 Preferably the motor/alternator 10 has a cylindrical sleeve 11 which is conveniently in the form of a cup having an end face 12, which is attached to a central shaft 13. This shaft is preferably mounted within bearings 14, 15 mounted within a stator 16. Conveniently, the shaft has a tapped end 17 for connection to other machinery.

15 Preferably, the inner face 20 of the sleeve 11 is provided with a plurality of side by side bar magnets 27, aligned with their long axes parallel to the axis of the rotor and are magnetised radially (as shown in Figures 1a, 1b, 3 and 8a). Alternatively an annular magnetic material may be magnetised so as to form a number of poles, as shown in Figures 2a and 5a. It will be appreciated that there will be an even number of such
20 closely spaced magnets, so that the polarity of the permanent magnetic poles alternates as one travels around the inner circumference presented by these magnets. [This differs from traditional motor designs where the magnetic poles are widely spaced and there are much longer flux paths through the steel laminations of the stator/core].

25 The magnets 27 are preferably rare earth or ceramic bar magnets, and 20 such magnets are shown in Figure 1a, for the purpose of illustration. Any even number of such magnets can be used depending upon design criteria such as size, weight, price, availability and frequency. For medium speed machines 6 to 30 poles are preferred, with 6-20 permanent magnetic poles providing optimum performance for a motor of the
30 type illustrated in Figures 1a and 1b. By closely spacing the magnets around the rotor circumference, the motor can be used with a minimal amount of steel coiled strip on the stator and can also be used with relatively low cost electronic commutation.

35 Preferably the bar magnets are formed from either rare earth or ceramic magnets, and have a high field strength enabling them to provide a higher magnetic flux across a much wider air gap than is possible with conventional magnets, but at the same time it

- 10 -

is preferred that the adjacent permanent magnetic poles are close together - in fact preferably in contact - to provide a short magnetic flux path between adjacent magnetic poles.

5

Preferably, the rotor sleeve and end face are formed of steel although other materials could be used.

10

It is preferred that the rotor and stator are spaced apart by a relatively large cylindrical air gap 28 of the order of 0.25mm to 1.5mm and preferably 0.75mm for the 20 pole motor/alternator of this example. This enables the wound poles to intersect the magnetic flux path as shown in Figure 3a. The air gap is preferably less than the depth of the magnets and should be of such a size as to allow for normal engineering clearances and tolerances.

15

20

The stator has an annular generally cylindrical substrate 24 of low magnetic permeability material (i.e. less than 20 relative to air) covered with a plurality of layers of silicon steel coiled strip 3 of small cross section. Such coiled strip may be say, 0.5mm in thickness and is wound in a tight spiral on the outer surface of the cylindrical stator. With such a small strip thickness a number of layers may be wound one on top of the other, and in this illustrative example (1d) four such layers are used to give a depth of magnetic material of approximately 1.5mm.

25

A plurality of wound poles 25 are provided on top of the outermost layer of steel coiled strip. Typically the wound poles would have a thickness approximately equivalent to that of the steel coiled strip layer(s).

30

The substrate of the stator is preferably formed from a synthetic plastics material such as "Tufnol" or a glass reinforced plastics as this can be formed into a sufficiently rigid cylindrical surface. ("Tufnol" is the trade mark of a plastics product containing layers of cotton fabric impregnated with phenolic resin which can be machined to form the stator.) The steel coiled strip and wound poles may also be covered with a similar resin so that neither the steel coiled strip or wound poles could be said to be on the surface of the stator (although they would be close to the resulting resin surface). 24A and 24B refer to capped exterior surfaces on the stator. 22 (Figure 1b) indicates a mounting plate for the motor.

35

Individual turns of the coiled strip 4 are particularly shown in Figure 1c and in the cross-sectional view of Figure 1d. Four spiral wound or wrapped layers of 0.5mm diameter steel coiled strip represented by the numeral 3 making up the totality of the included soft magnetic material. (Three such layers 4', 4'', 4''' - with insulating layers not shown - are shown in Figure 6 with the magnets and coiled strip projected onto a flat plane). These layers of steel coiled strip have an axial length substantially equivalent to that of the length of the rotor magnets but preferably less than the length of the wound poles 25, as shown in Figure 1d. The steel coiled strip is preferably wound within a slot machined in the surface of the cylindrical substrate 24.

The number of wound poles correspond to the number of permanent magnetic poles inside the rotor. The wound poles are relatively shallow in that they are formed on or close to the surface of the substrate (unlike conventional wound poles which are wound within slots formed in steel laminations). The depth of the wound poles on or close to the surface of the stator will depend upon the size of the stator and required rating of the motor. In the example shown, the depth would be of the order of 1mm to 10mm, and preferably about 3mm.

It will be generally convenient to provide the wound poles as wave or lap windings on that surface of the stator facing the permanent magnetic poles. For example Figure 4 shows the wave windings W1, W2, W3 each providing a plurality of wound poles 201 - 211, 201A - 211A, and 201B - 211B on the surface of a substrate for a three phase stator winding as used in the motor/alternator of Figures 1a/1b. As will be discussed below a three phase winding is preferred for most applications but other phases have their uses for particular applications. They may be exposed to the air or encapsulated in a plastic resin of low magnetic permeability.

The wound poles may be provided in a variety of forms and may provide for one or more phases. They are shown schematically in Figures 1b, 1c and 4 as wave windings on a flexible substrate. However, it is preferred that in most cases the windings are lap windings having turned-over ends as shown in Figures 1d and 5b. The wound poles on the surface of the stator are so positioned as to intersect the magnetic flux lines connecting adjacent ceramic magnets as the flux lines essentially form a series of loops from one magnet to the next as one travels around the inner circumference of the rotor. This is shown in Figure 3a which illustrates the relative position of the wound poles 25

and the soft magnetic layer - the layers of steel coiled strip 3, and the relatively short magnetic flux paths between adjacent permanent magnetic poles on the rotor.

5 **EXAMPLE 2 - FIGURES 2a & 2b**

10 This arrangement is similar to that of example 1 except that a single cylindrical ring magnet 30 is provided on the inside of the cup shaped rotor 31. The stator (not shown) can be the same as that of Figure 1d. This ring magnet has 8 poles. Figure 2a is an end view of the rotor from the open end, and Figure 2b is a section through B--B of Figure 2a.

15 **EXAMPLE 3 - FIGURE 3**

15 This example motor has 12 closely spaced permanent magnetic poles around the periphery of an external cylindrical rotor. Figure 3 shows the average magnetic flux path originating in a permanent magnet rotor comprising an outer shell 11 holding an array of permanent magnets 27, with the flux from the magnets passing across the space 28, then amongst the windings 25 comprising a plurality of wound poles and entering that part of the stator 3 comprising the layers of steel coiled strip 4', 4'', and 4''' to complete the circuit. This Figure shows that the flux path becomes substantially confined to the high permeability layer(s) formed from the steel coiled strip.

20 **EXAMPLE 4 - FIGURES 5a & 5b**

25 This arrangement has a single cylindrical ring magnet 41 on an internal rotor 40, i.e. the permanent magnetic poles are on the outer face of the rotor 40, and are surrounded by the wound poles 42 on the inner cylindrical face of the stator 43. The wound poles 42 contact a layer 51 of soft magnetic material wound from annealed steel tape, in a spiral configuration. This spiral layer 51 of steel tape is embedded in a low-magnetic permeability substrate 44 forming part of the stator. The rotor is mounted on a shaft 45 which is mounted in bearings 46, 47 in end plates 48, 49.

EXAMPLE 5 - FIGURES 8a & 8b

5 Figure 8a shows a 6 pole machine using 12 bar magnets 27 in pairs to create the effect of wider magnets. This is similar to Figure 3 but without showing the flux paths. Again, 25 represents the windings, 11 represents the outer shell of the rotor which holds the magnets, and 3 represents the ferromagnetic layer, the coiled strip.

10 Figure 8b shows the stator voltage for different rotor positions for one phase only of the three phase stator windings of the motor/alternator of Figures 1a to 1c. The degrees scale refers to electrical phase, not to mechanical rotation of the motor. The closely spaced magnetic poles create "flat-topped" waveforms, and this is a characteristic of all of the motors illustrated in the accompanying Figures.

15 **SOFT MAGNETIC MATERIAL - FIGURE 7**

Figure 7 is a graph of magnetic coercivity H (in Ampere-turns metre⁻¹) against flux B in Teslas for a soft magnetic material such as annealed steel coiled strip. The designation "A" refers to Ampere-turns, i.e. 1 Ampere in 1 turn coil. The equivalent
20 American values in Gauss and Oersteds are also shown. [1 Tesla = 10,000 Gauss, 1 A/m = 0.01257 Oe]. Note that the area within the graph is small, i.e. the material exhibits low hysteresis.

25 Silicon steel is preferred in building prototypes of the invention as it is inexpensive and readily available. It is often used in transformer laminations. However other soft magnetic materials in coiled strip or tape form may be used. Examples include iron; iron alloys such as iron-cobalt alloys, Permendur*, Supermendur*; iron-silicon alloys; nickel-iron alloys, Mumetal*, Supermumetal*, Supermalloy*, Invars*, Elinvars, Amorphous Alloys; steel alloys; and ferrites. [An asterisk denotes a trade name
30 mentioned on pages 95-104 of *Magnetism and Magnetic Materials* by J P Jakubovics, published by The Institute of Metals, 1987, ISBN 0-904357-95-3, which contains a useful discussion of "soft magnetic" materials]. The material should have a magnetic permeability of more than 20 (relative to air) and most probably will have a permeability in the range of 100-1000 (relative to air). Some materials, such as Mu-
35 metal, may require an annealing process after deformation into a coil if the strip thickness is large in comparison with the bending radius and the crystal structure of the

alloy is damaged.

5 If an annealed steel coiled strip is used the depth of soft magnetic material preferably would not exceed 4 to 5mm for most medium speed motors. For example, a 16 pole motor with a stator diameter of 110mm and operating at 1500 rpm (a frequency of 200 Hz), may have 3 layers of annealed steel of between 1 and 1.6mm diameter giving a depth of magnetic material of approximately 3-5mm. As iron losses are proportional to the square of the operating frequency, it is preferable that for medium speed motors the
10 coiled strip thickness is not greater than about 1mm, to keep eddy current losses down, and to allow wrapping. For very large slow motors a larger coiled strip thickness could be used. There should be a sufficient depth of coiled strip to provide a good magnetic path between adjacent poles. A large slow motor (operating at say 50 Hz) could perhaps use 6 layers of annealed steel coiled strip up to 3mm in diameter.

15

20 POLE CYLINDRICAL MOTOR

Such a motor as shown in Figures 1a-1c may have a stator diameter of 150mm with 3 spiral layers of steel coiled strip of 1mm diameter providing a magnetic layer of 3mm
20 thickness and covered with a wound pole layer of 3mm thickness.

2 POLE MOTOR

By way of contrast a similar diameter 2 pole motor requires a much thicker magnetic
25 layer, of approximately 20mm thick, typically 10 layers of 2mm diameter steel coiled strip. Such a motor will suffer from much greater steel losses - with resulting evolution of heat - than the 20 pole machine unless it is operated only at slow speeds.

HIGHER POLE NUMBER MACHINES

30

By constructing machine with 6 or more poles it is possible to use a thin layer of small diameter steel coiled strip and allow the machines to operate at high speeds with relatively low inductance and low steel losses. At higher pole numbers the frequency of the electrical noise generated by commutation will be above the resonant frequencies of
35 the mechanical enclosure of the machine. Higher pole number machines (typically in the range of 6-30 poles) preferably have the permanent magnetic poles closely spaced

around the periphery of the rotor as this provides the best wave forms for use with fully electronic commutation circuits. However, if Hall effect sensors or optical sensors are used to detect the rotor position it may be advantageous to use widely spaced poles with the steel coiled strip configuration of this invention.

It will be noted that the tight winding of the steel coiled strip layers on the cylindrical substrate allows each coiled strip to approximate a circumferential loop. Instead of a spiral winding each layer could be formed from a plurality of loops on the substrate.

10

DIFFERENT PHASES

In the above examples a three phase motor/alternator is described but other phase windings may be used, and in particular 1, 2 and 4 phase configurations will now be described.

15

SINGLE PHASE CO-AXIAL MOTORS/ALTERNATORS

1. Single phase co-axial alternators are the most simple configuration of stator for this machine and can find uses where simplicity of construction outweighs absolute output power. The three phase equivalent produces twice the output power for the same resistive losses, and 50 per cent additional copper in the stator windings.

20

2. Single phase co-axial motors are the most simple configuration of stator for this machine, but required some means of starting (similar to single phase induction motors) and therefore require an additional winding or mechanical means to ensure starting. In areas of low starting torque requirements i.e. direct coupled fans there could be a use for single phase motors.

25

TWO PHASE CO-AXIAL MOTORS/ALTERNATORS

1. Two Phase Co-axial Alternators. This machine provides a 40% increase in output power for the same resistive losses of a single phase machine.

2. Two Phase Co-Axial Motors. Due to two phase operation there are no starting problems, but if the machine is to be electronically controlled from a direct current

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supply then efficiency could be low if 180 degree current injection is used. The two phase motor could be electronically controlled to provide the 180 degree current injection just for starting and reduce to 120 degrees or less for normal running operation.

THREE PHASE CO-AXIAL MOTORS/ALTERNATORS

1. Three Phase Co-axial Alternators. This machine provides an increase in output power for the same resistive losses as a single or double phase machine. If the three phase machine uses the same amount of copper as a two phase machine and the stator windings of both machines occupy the full 360° available, then the three phase machine can produce a further 7% output power over the two phase machine for the same resistive losses (i.e. 47% increase over the single phase machine).
2. Three Phase Co-Axial Motors. Due to three phase operation there are no starting problems, and the machine can easily be electronically controlled from a direct current supply. Due to the 120 degree split with three phase operation sufficient back EMF voltage exists over the 120 degrees to provide efficient current injection from a direct current supply, and this design allows for accurate control of the rotor position, e.g. for a stepper motor.

GREATER THAN THREE PHASE CO-AXIAL MOTORS/ALTERNATORS

1. Co-axial Motors. Slightly higher efficiency possible due to possible smaller current injection angle. The four phase motor has possible applications, due to simplicity of electronically controlled reversing of rotor direction.
2. Co-axial Alternators. No additional benefits other than a slightly higher efficiency and lower ripple voltage if the output of the alternator is being rectified to provide a direct current power supply.

VARIATIONS

- In all of these examples the wound poles are formed on one or the other of the rotor or the stator and the permanent magnetic poles are provided on the remaining one of the

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5 stator or the rotor. However it is possible to provide other configurations, e.g. the steel
coiled strip may be provided on the stator of a linear motor or on the stator or rotor of a
pancake motor. The rotor may be provided with a band of permanent magnetic poles
10 then a band of wound poles and associated steel coiled strip layer(s) (which may be
repeated along its length) and the stator would then be provided with the opposite
configuration so that a band of wound poles and layer(s) of steel coiled strip on the
stator face the band of permanent magnetic poles on the rotor, and a band of permanent
15 magnetic poles on the stator face the band of wound poles and layer(s) of steel coiled
strip on the rotor.

Finally it will be appreciated that various other alterations or modifications may be
made to the foregoing without departing from the scope of this invention.

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CLAIMS:

1. A stator for a cylindrical dynamoelectric machine, comprising a generally
5 cylindrical stator having an outer stator surface wherein said stator has a
generally cylindrical substrate of a first material having outer flanges defining a
shallow circumferential recess having a width and depth, and a thin annular
substantially cylindrical layer substantially filling said recess, said thin annular
layer having an outer annular surface, and a plurality of wound poles
10 superimposed on said outer annular surface,
CHARACTERISED IN THAT said thin annular substantially cylindrical layer
is formed from one or more lengths of strip of width comparable to the width of
the recess, and the or each length of strip having a thickness which is
substantially less than the depth of the recess, and said strip comprises a soft
15 magnetic material having a magnetic permeability greater than 20.
2. A stator as claimed in claim 1 CHARACTERISED IN THAT said strip
comprises an annealed steel strip wound in a spiral around said substrate.
- 20 3. A stator as claimed in claim 1 CHARACTERISED IN THAT the recess
contains at least three layers of said strip when viewed in cross-section.
4. A rotary dynamoelectric machine comprising:
a generally cylindrical stator having a stator surface,
25 a generally cylindrical external rotor rotatable about a rotational axis and having
an interior generally cylindrical rotor surface surrounding said stator and spaced
apart therefrom by a generally cylindrical gap,
a plurality of magnetic poles on said interior generally cylindrical rotor surface
and positioned adjacent said generally cylindrical gap,
30 wherein said stator has a generally cylindrical substrate of a first material having
outer flanges defining a shallow circumferential recess having a width and a
depth and a thin annular cylindrical layer in said recess, said annular layer
having an outer annular surface, a plurality of wound poles superimposed on
said outer annular surface, so that the wound poles are adjacent said cylindrical
35 gap and face said rotor and at least a majority of the wound poles are positioned
substantially parallel to the rotational axis of the rotor,

CHARACTERISED IN THAT said thin annular cylindrical layer is formed from one or more lengths of strip of width comparable to the width of the recess, and said strip comprises a soft magnetic material having a magnetic permeability greater than 20.

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5. A rotary dynamoelectric machine as claimed in claim 4 CHARACTERISED IN THAT said first material of said substrate is a substantially non-conducting, substantially non-magnetic material.

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6. A rotary dynamoelectric machine as claimed in claim 4 CHARACTERISED IN THAT :
the magnetic poles of the rotor are permanent magnetic poles and are closely spaced around the generally cylindrical rotor surface.

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7. A rotary dynamoelectric machine as claimed in claim 6 CHARACTERISED IN THAT there are between 6 and 20 permanent magnetic poles.

8. A rotary dynamoelectric machine as claimed in claim 7 CHARACTERISED IN THAT said strip comprises an annealed steel strip.

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9. A rotary dynamoelectric machine as claimed in claim 8 CHARACTERISED IN THAT said strip is wound in a spiral around said substrate.

10. A stator as claimed in claim 9 CHARACTERISED IN THAT the recess contains at least three layers of said strip when viewed in cross-section.

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FIG. 1a

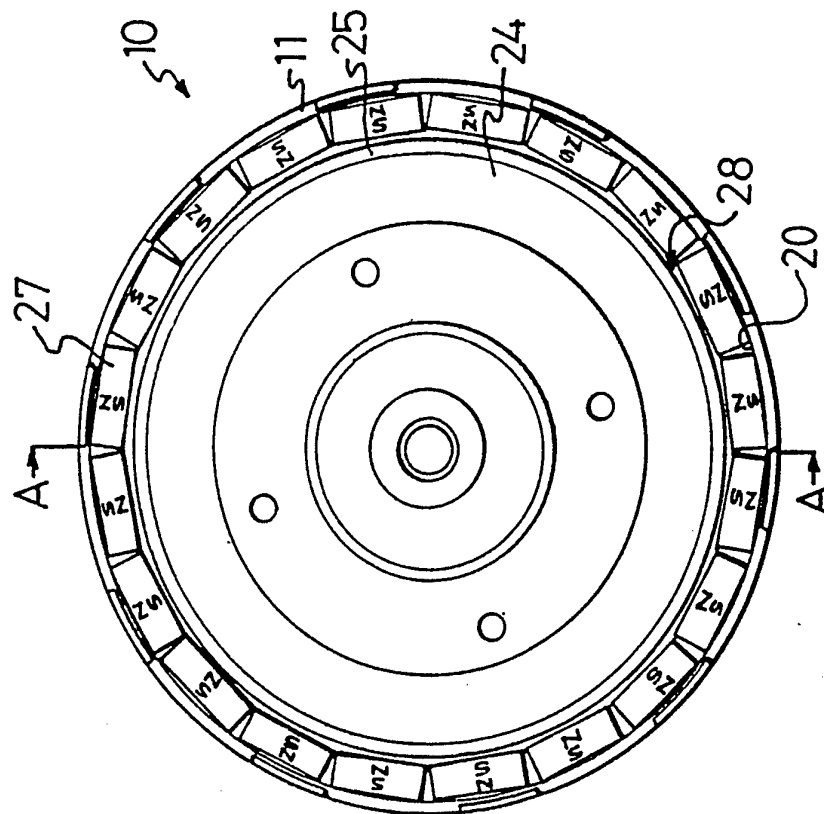
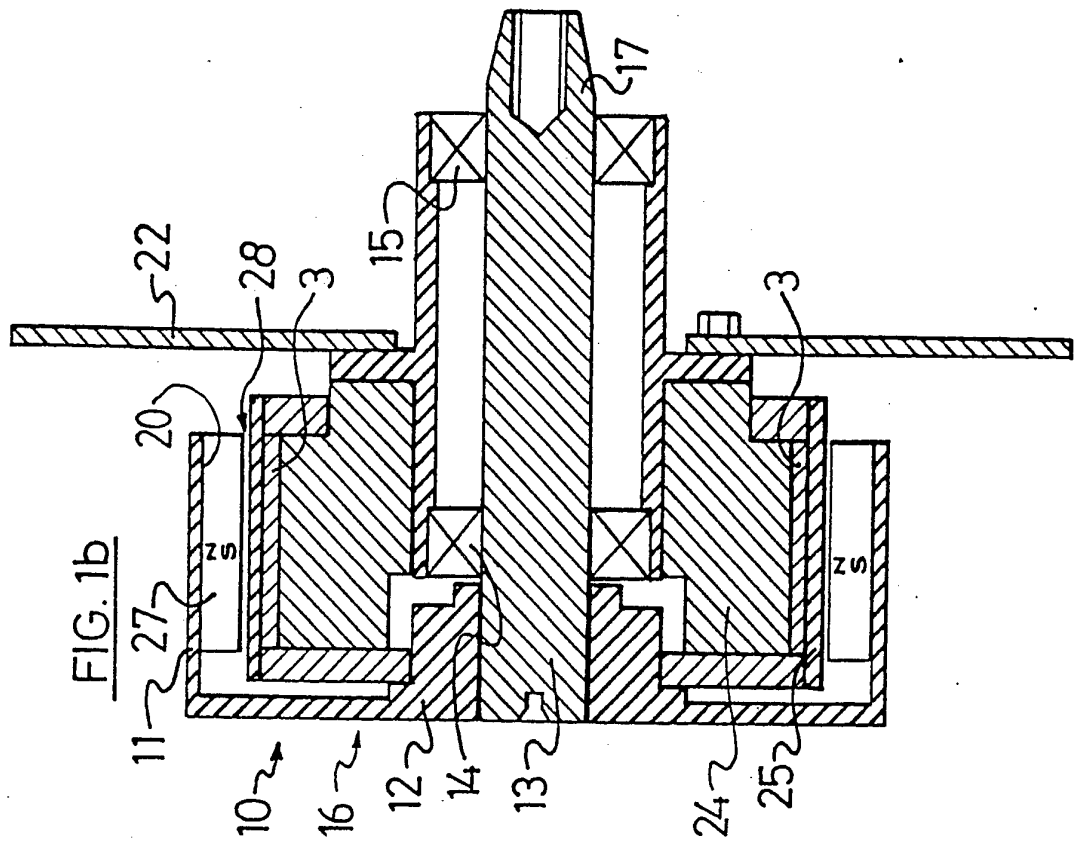


FIG. 1b



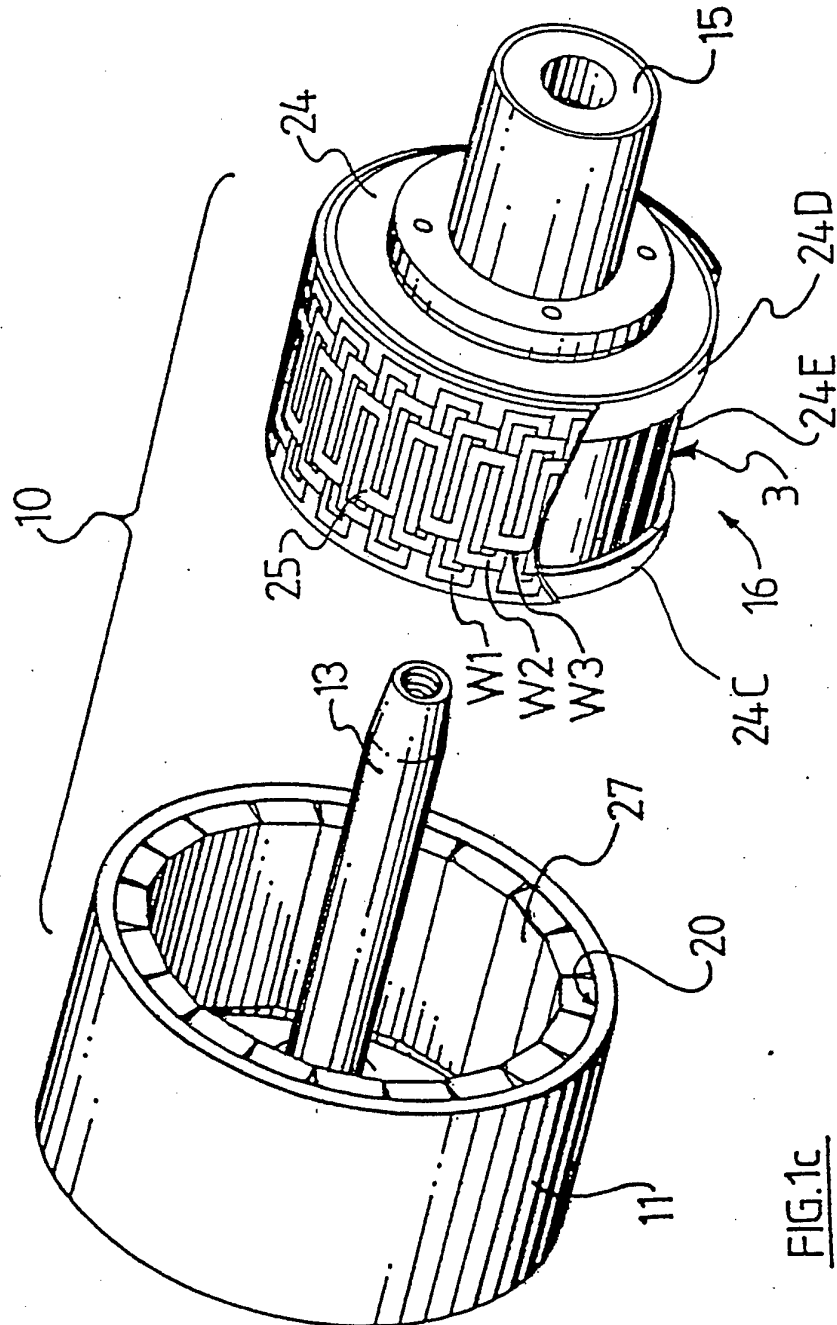
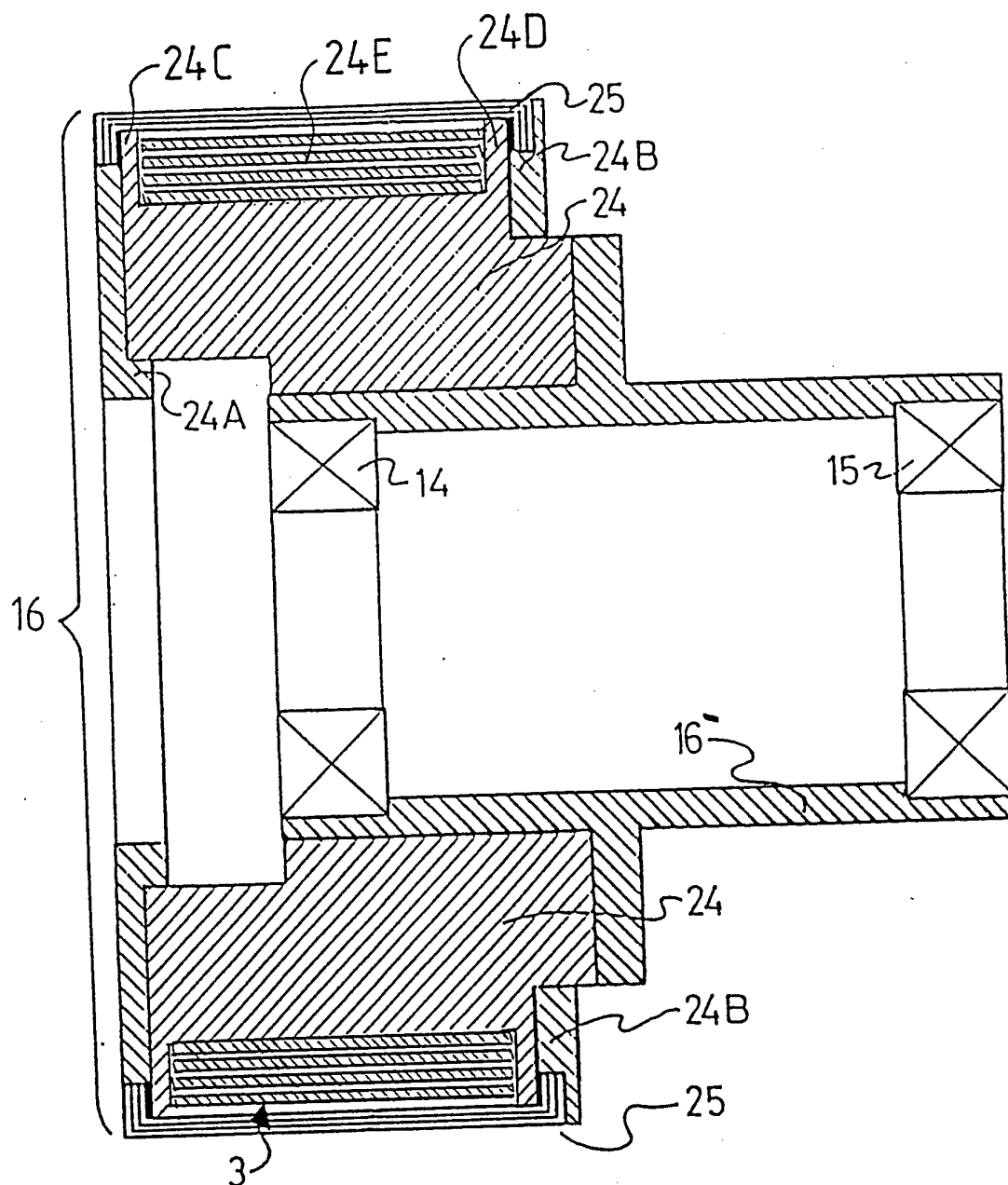
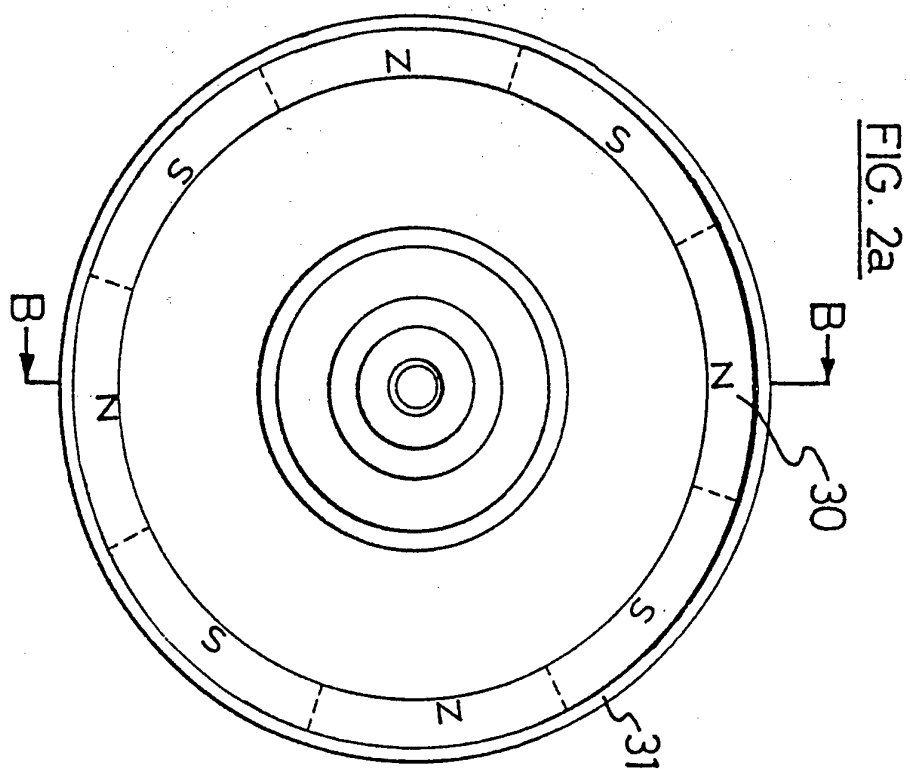
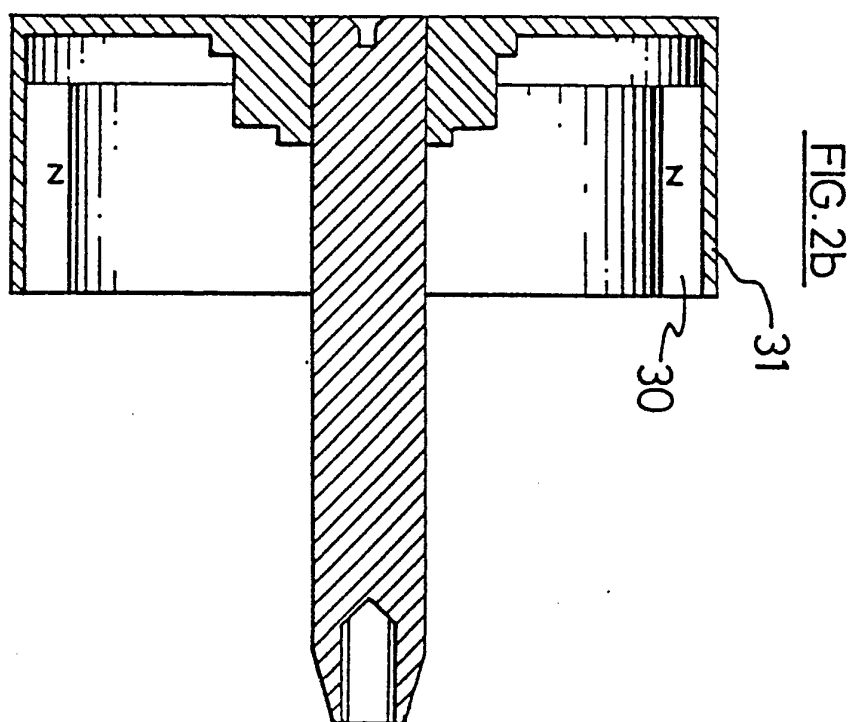
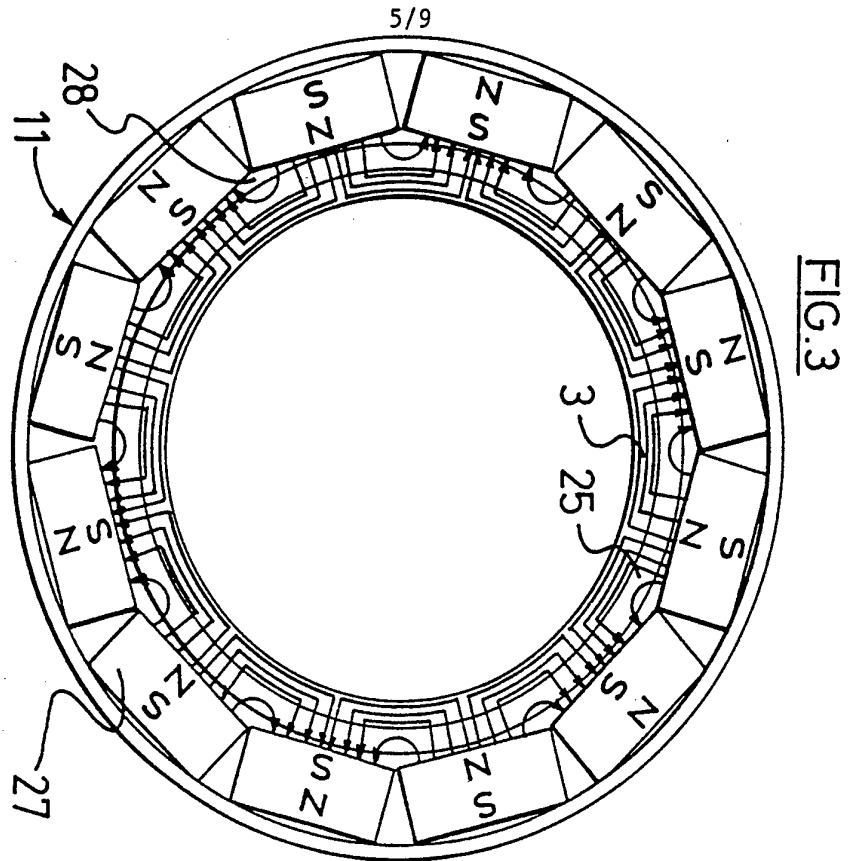
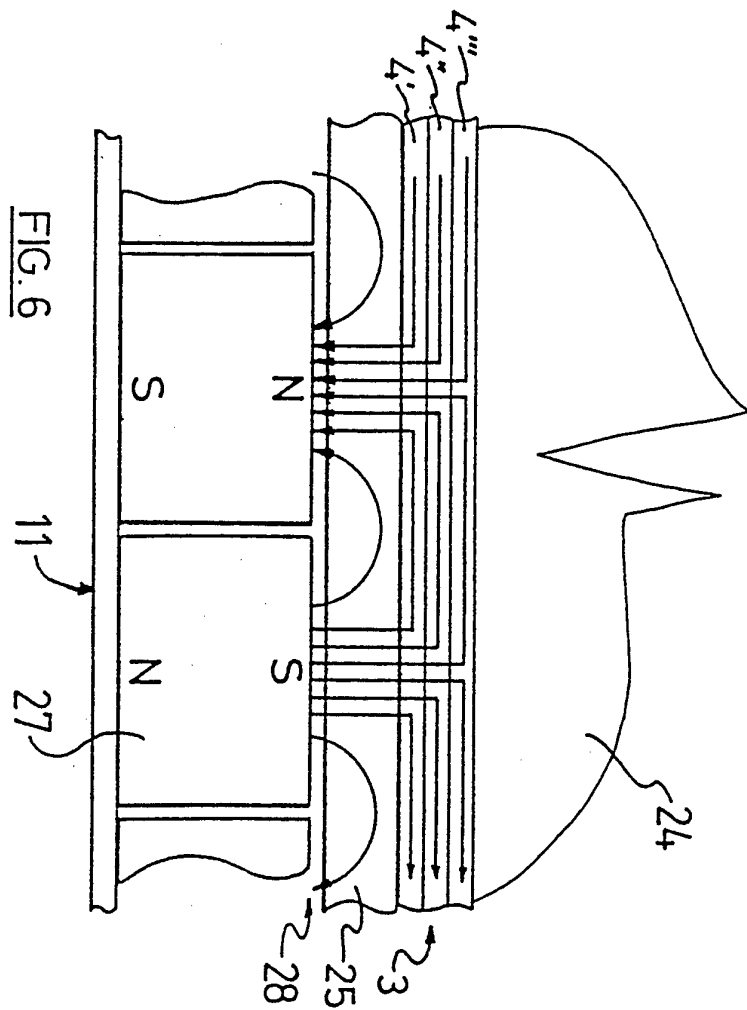


FIG. 1d







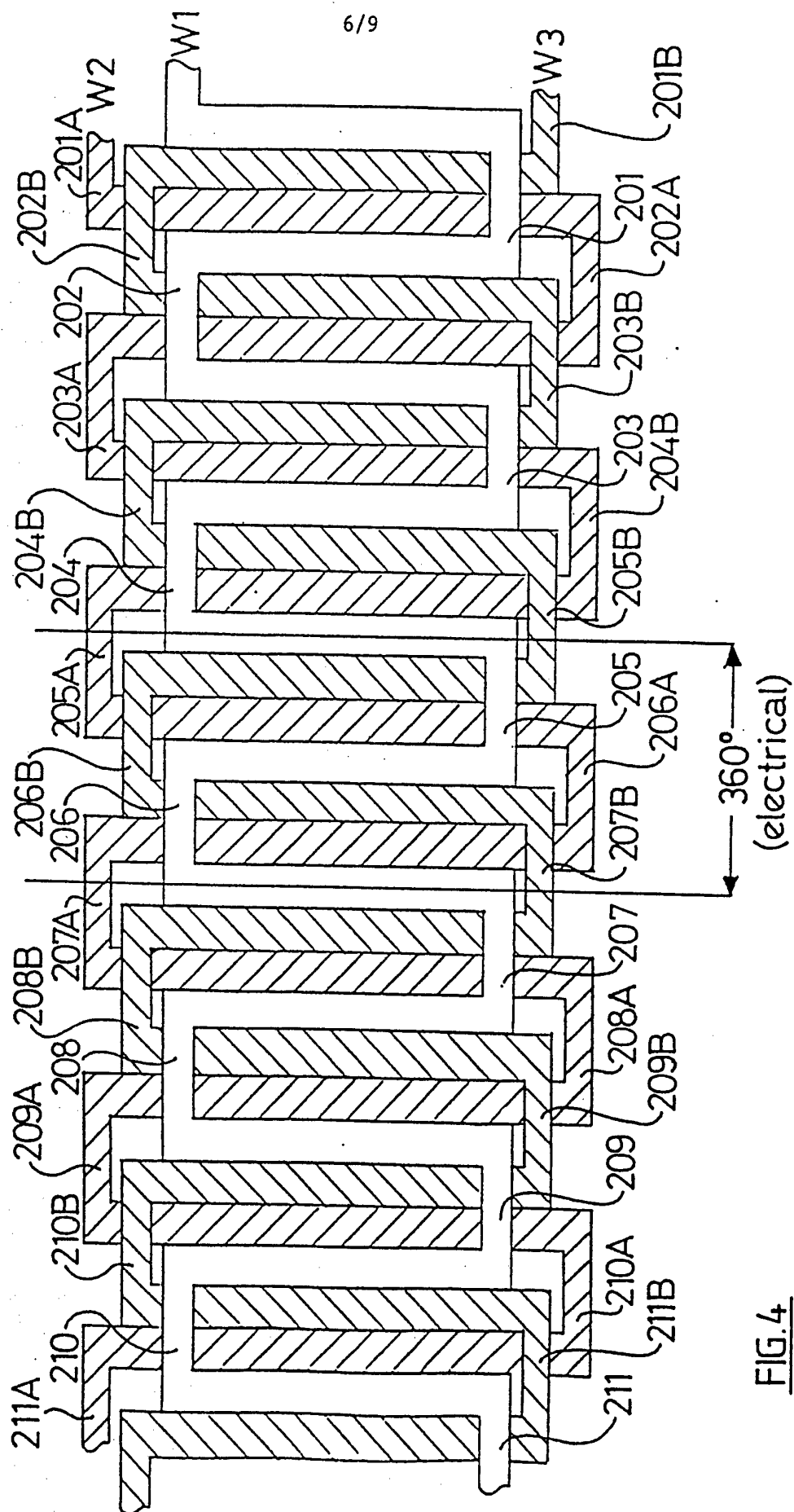
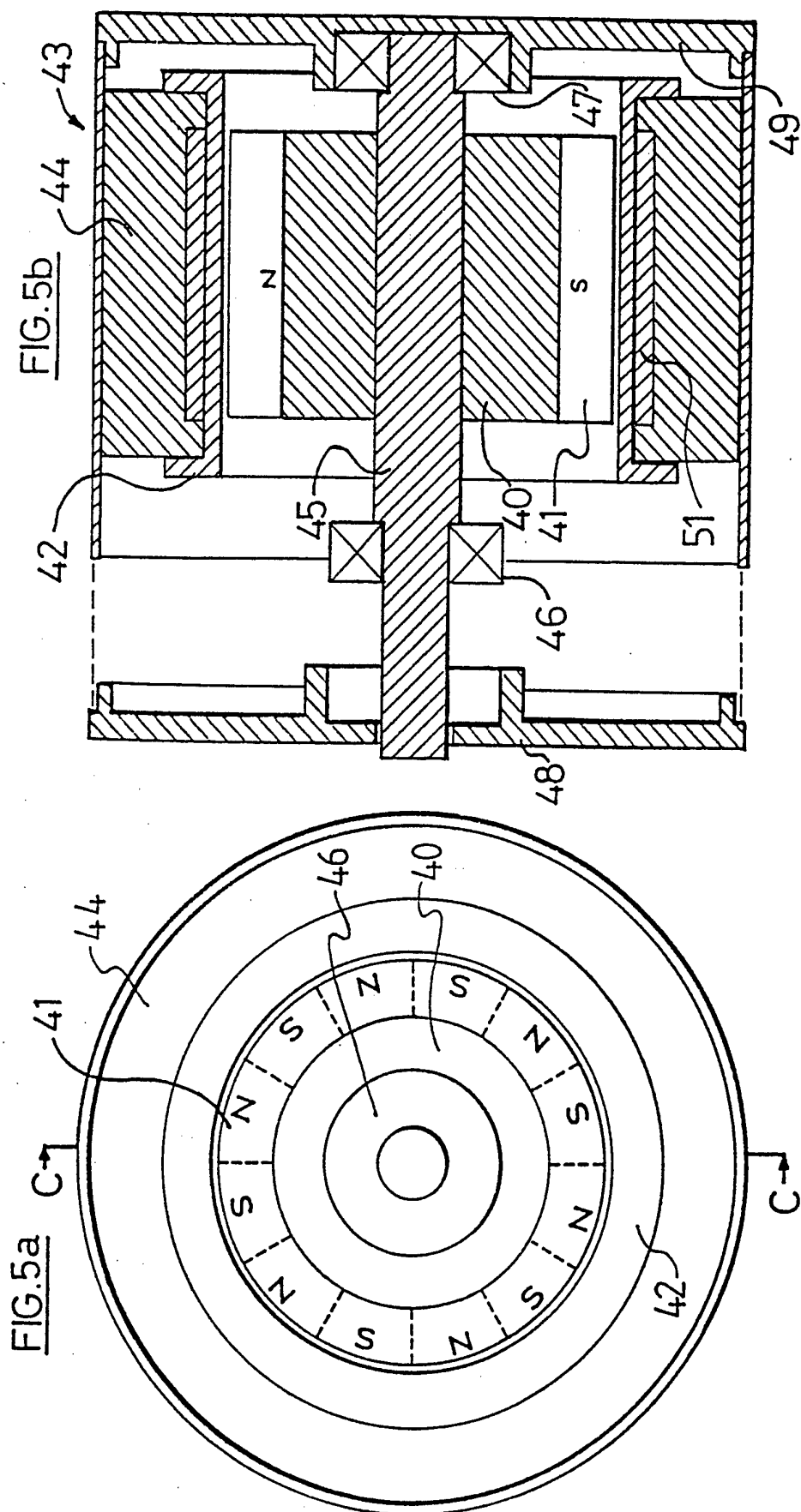


FIG. 4



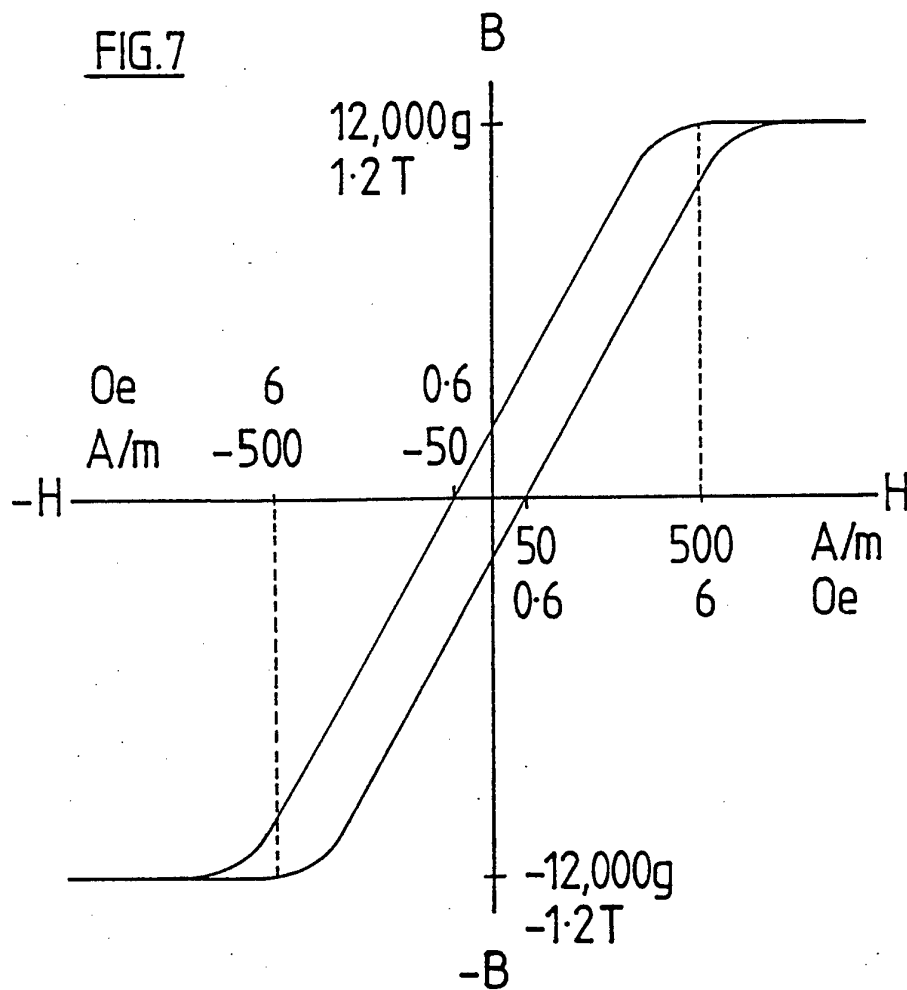


FIG. 8a

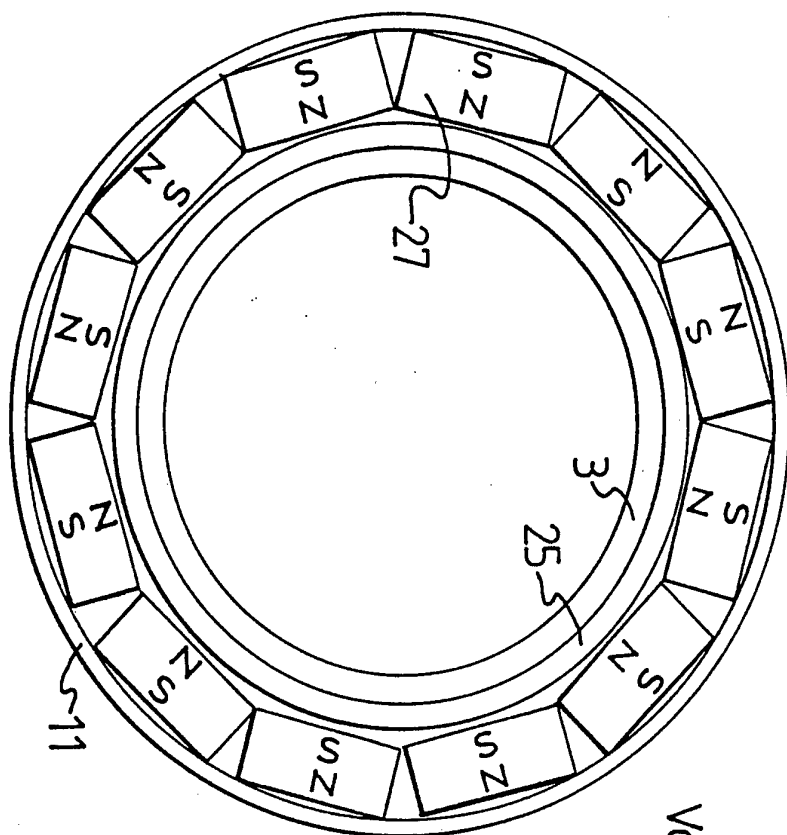
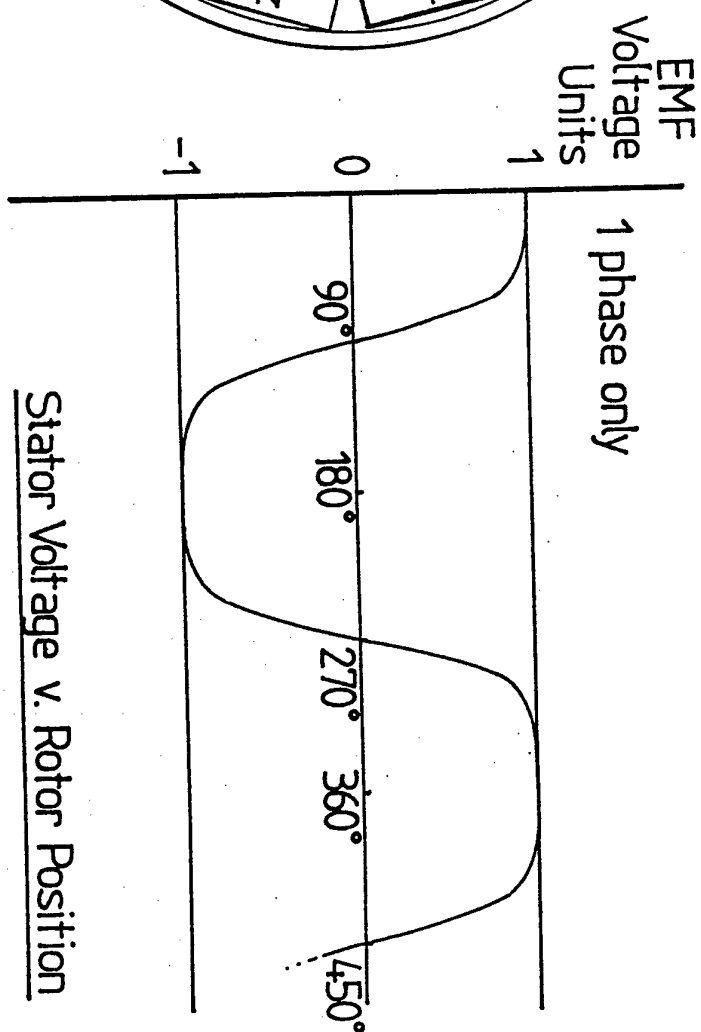
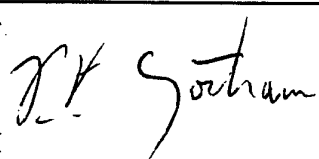


FIG. 8b



Stator Voltage v. Rotor Position

A. CLASSIFICATION OF SUBJECT MATTER Int. Cl. ⁵ H02K 1/12 According to International Patent Classification (IPC) or to both national classification and IPC					
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC H02K 1/06, 1/12 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU : IPC as above Electronic data base consulted during the international search (name of data base, and where practicable, search terms used) DERWENT : H02K 1/- and STRIP, RIBBON, TAPE					
C. DOCUMENTS CONSIDERED TO BE RELEVANT					
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.			
Y	WO,A, 91/11842 (PIPER) 8 August 1991 (08.08.91) Whole document	1-10			
Y	CA,A, 1136200 (HONSINGER et al) 23 November 1982 (23.11.82) Fig 1,2 Pages 3-6	1-10			
Y	AU,A, 73072/74 (WESTINGHOUSE ELECTRIC CORPORATION) 11 March 1976 (11.03.76) Fig 2,3 Page 12 lines 7-12	1-10			
A	DE,A, 3920549 (SCHMIDT) 24 January 1991 (24.01.91) Fig 1,2A	1-10			
<div style="display: flex; justify-content: space-between; align-items: center;"> <div> ☐ Further documents are listed in the continuation of Box C. </div> <div> ☒ See patent family annex. </div> </div>					
<table style="width: 100%; border: none;"> <tr> <td style="width: 33%; vertical-align: top;"> <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </td> <td style="width: 33%; vertical-align: top;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p> </td> <td style="width: 33%;"></td> </tr> </table>			<p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>	
<p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>				
Date of the actual completion of the international search 20 October 1993 (20.10.93)		Date of mailing of the international search report 26 OCT 1993 (26.10.93)			
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No. 06 2853929		Authorized officer <div style="text-align: center;">  P.F. GOTHAM </div> Telephone No. (06) 2832165			

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
WO	9111842	AU JP	72318/91 5504042	CA	2074360	EP	513094
AU	73072/74	CA	1029788	DE	2443255		
END OF ANNEX							