United States Patent [19]

Ohyama et al.

[11] **3,777,296**

[45] **Dec. 4, 1973**

[54] **ELECTROMAGNETIC INDUCTION APPARATUS**

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[73] Assignee: **Matsushita Electric Industrial Co., Ltd.,** Osaka-fu, Japan

[22] Filed: **May 8, 1972**

[21] Appl. No.: **251,539**

[30] **Foreign Application Priority Data**

May 10, 1971	Japan	46/31016
June 16, 1971	Japan	46/43119
June 18, 1971	Japan	46/44372
June 18, 1971	Japan	46/44404
June 18, 1971	Japan	46/44405

[52] **U.S. Cl.** **336/120,** 336/135

[51] **Int. Cl.** **H01f 21/00**

[58] **Field of Search** 336/119, 120, 118, 336/117, 115, 135, 180

[56] **References Cited**

UNITED STATES PATENTS

2,550,663	5/1951	Bechberger et al.	336/120 X
3,178,663	4/1965	Kahn	336/120
1,672,703	6/1928	West	336/120
2,882,483	4/1959	Stephenson	336/120 X
2,885,645	5/1959	Wennerberg	336/120
2,823,363	2/1958	McKenney et al.	336/120
2,872,603	2/1959	Herr	336/120 X

Primary Examiner—Thomas J. Kozma
Attorney—Milton J. Wayne et al.

[57] **ABSTRACT**

An electromagnetic induction apparatus is provided which comprises outer and inner cores and first and second windings on the outer and inner cores. Depending upon the relative angular position between the first and second windings the effects of the magnetic fluxes produced by the first and second windings upon the other or the degree of the inductive coupling between the first and second windings may be varied, so that the output voltage may be varied accordingly. That is, the magnetic flux which is produced by one winding remains unchanged in magnitude, and links the other winding, changes its direction, or the number of turns of the other winding linked with the magnetic flux produced by said one winding is increased or decreased. Hence the output voltage is varied. The leakage impedances may be minimized.

18 Claims, 128 Drawing Figures

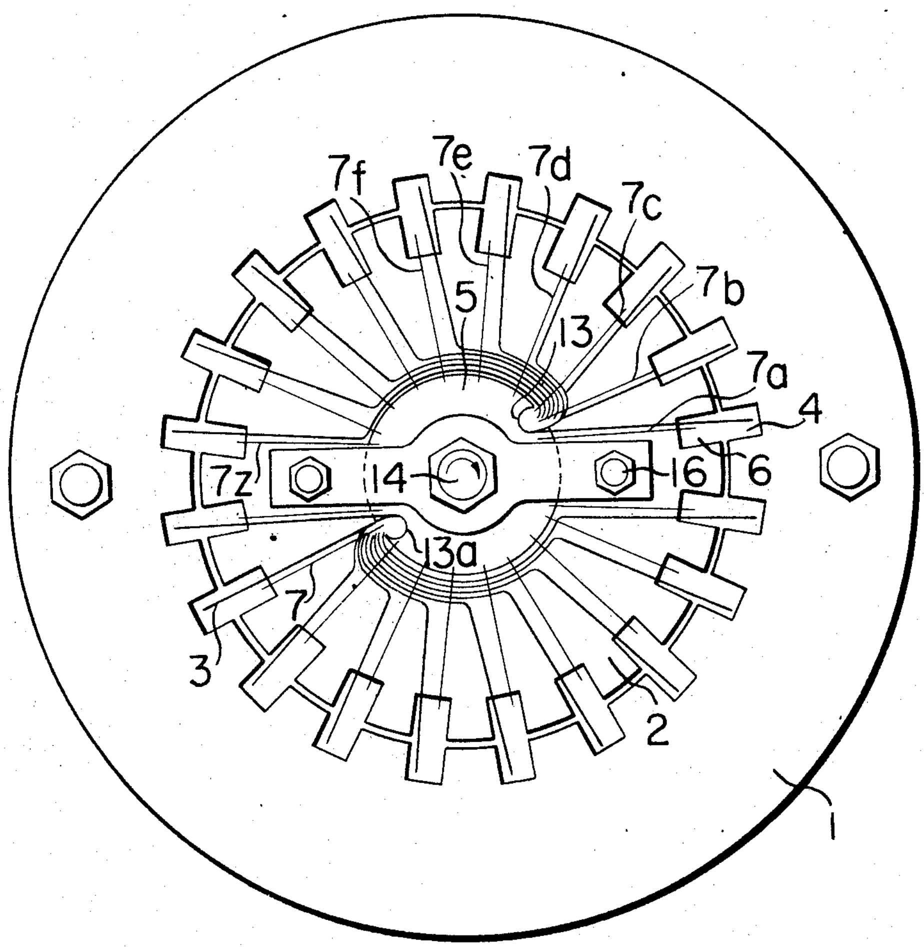


FIG. 1

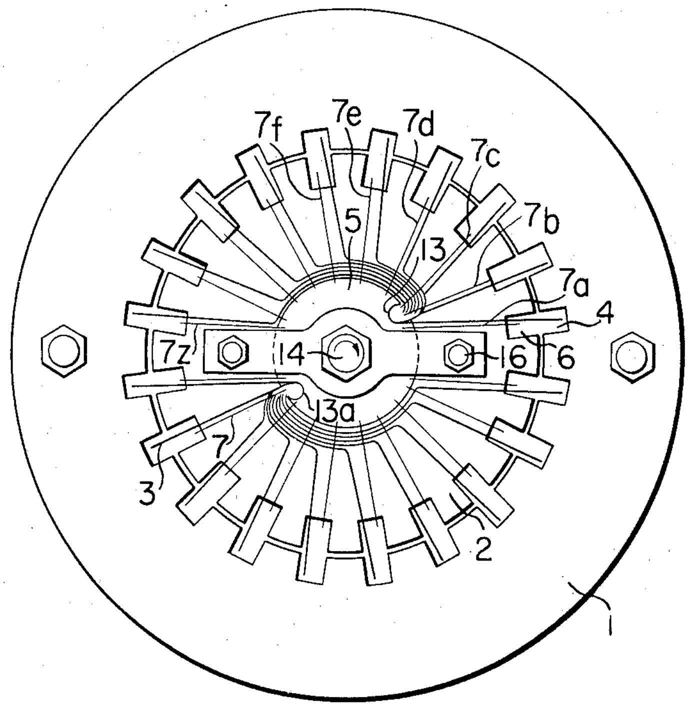

7f
7e
7d
7c
7b
7a
5
13
4
6
7z
14
16
13a
7
3
2
1

FIG. 2

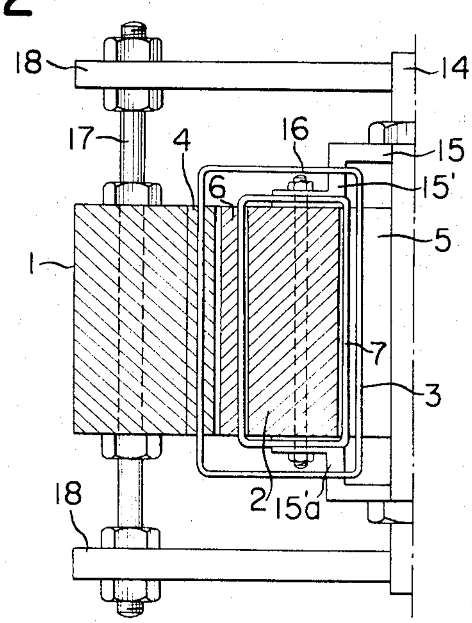

18
14
17
4
16
15
6
15'
5
1
7
3
18
2
15'a

FIG. 3

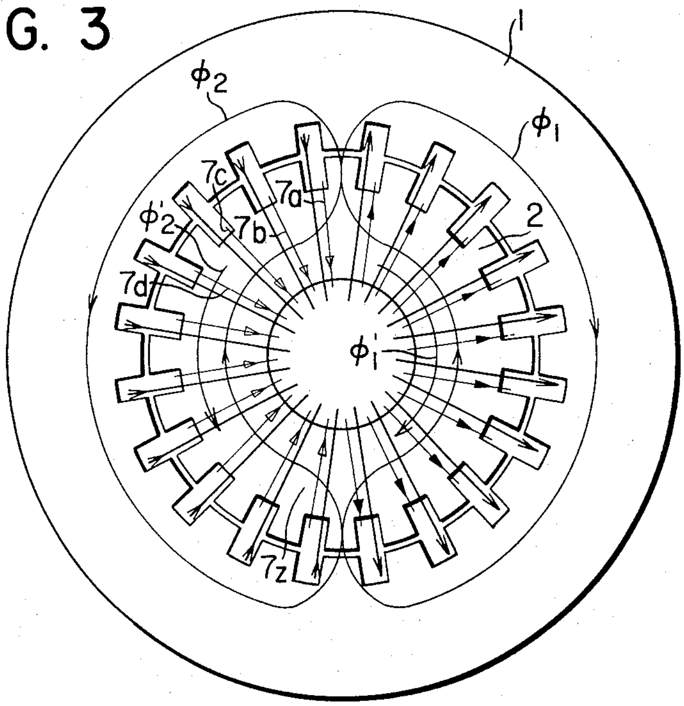


FIG. 4

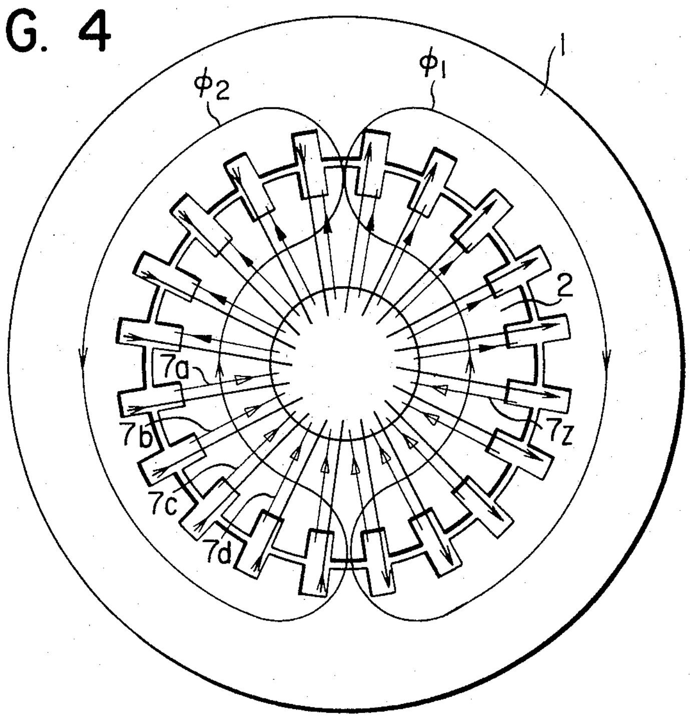


FIG. 5

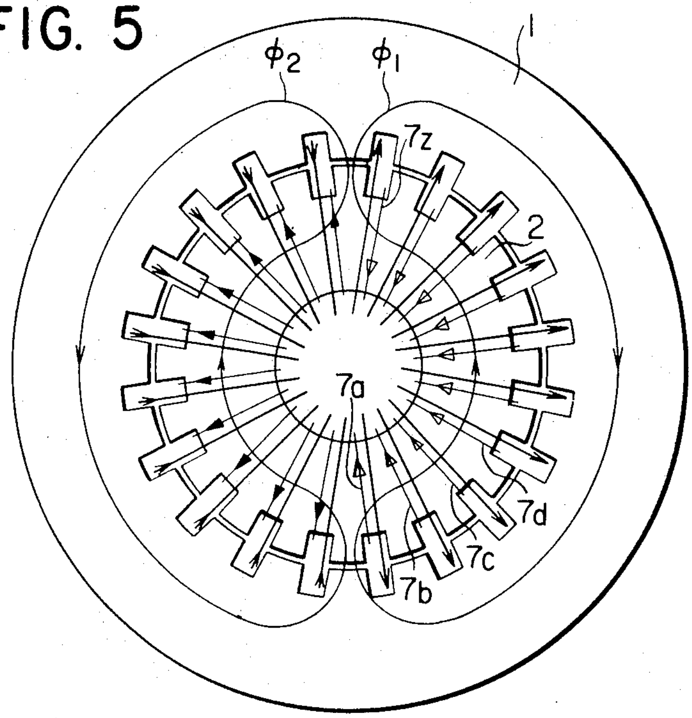

φ2
φ1
1
7z
2
7a
7d
7c
7b

FIG. 7

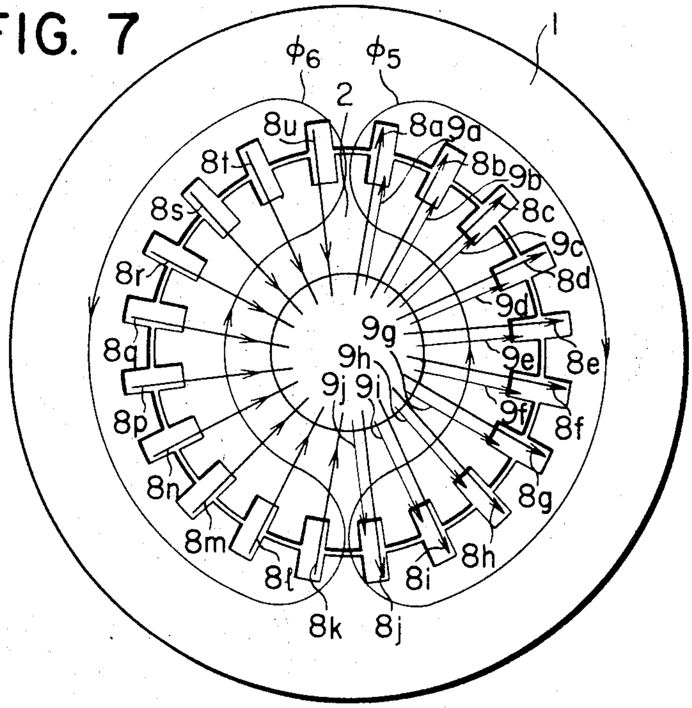

φ6
φ5
1
2
8u
8a
9a
8t
8b
9b
8s
8c
9c
8r
8d
9d
9g
8q
9h
9e
8e
9j
9i
8p
9f
8f
8n
8g
8m
8h
8l
8i
8k
8j

FIG. 6A

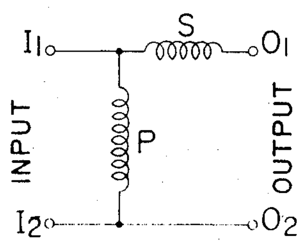


FIG. 6Aa

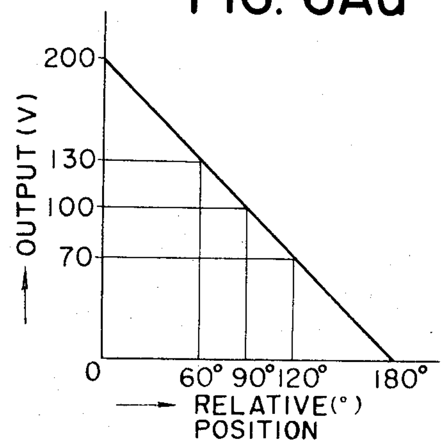


FIG. 6B

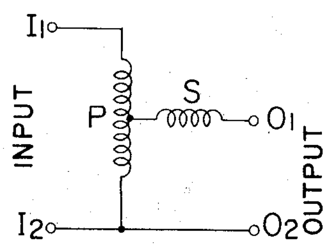


FIG. 6Ba

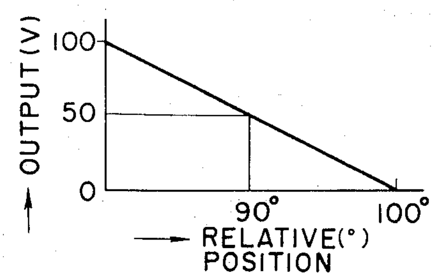


FIG. 6C

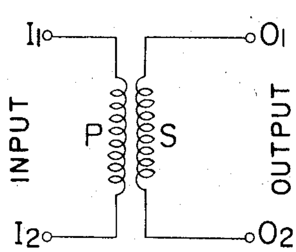


FIG. 6Ca

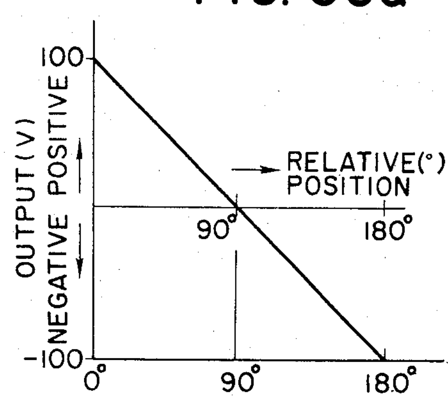


FIG. 6D

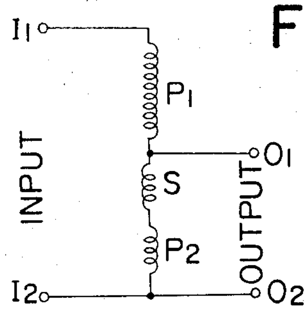


FIG. 8A

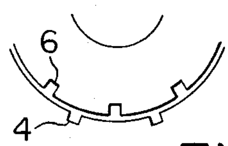


FIG. 9A

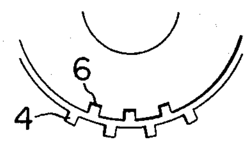


FIG. 8B

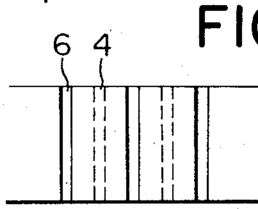


FIG. 9B

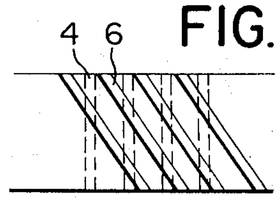


FIG. 9C

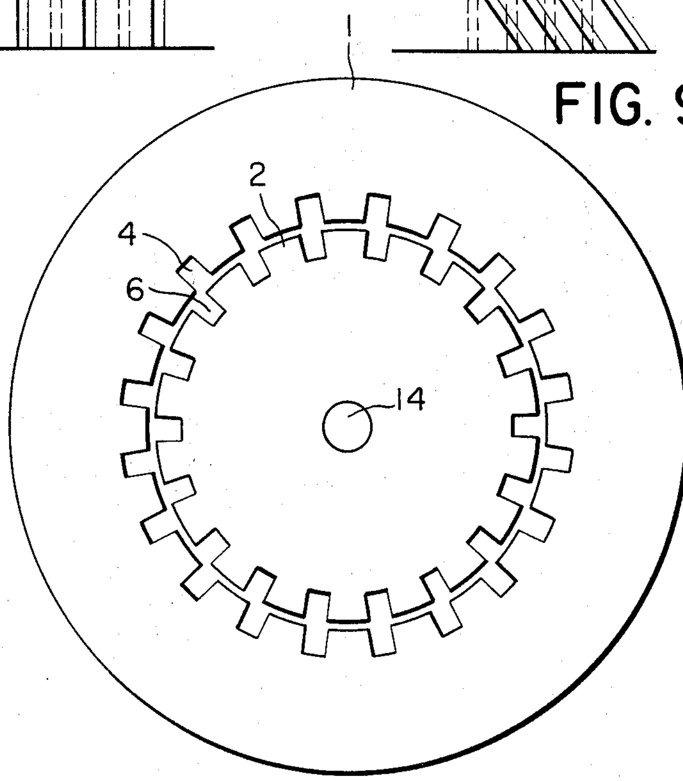


FIG. 10

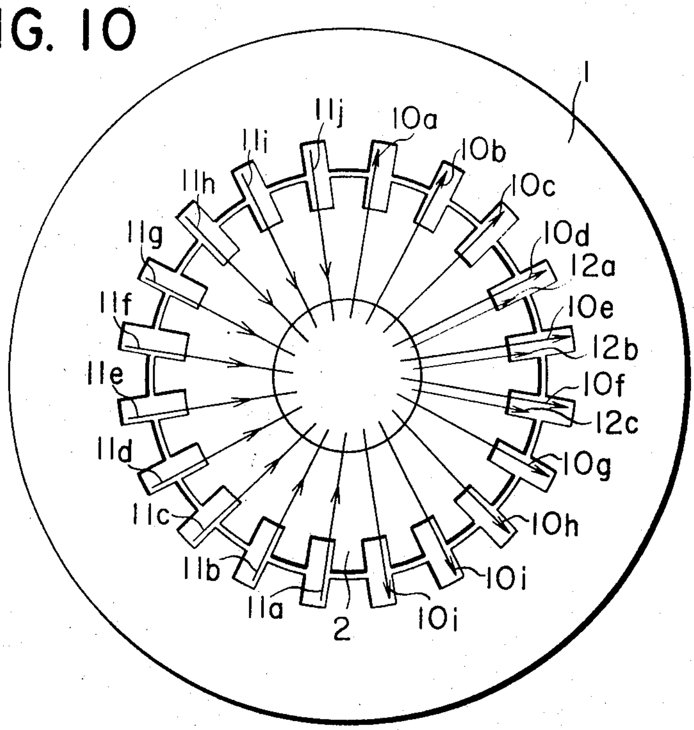


FIG. 11A

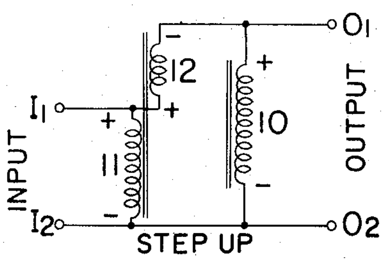


FIG. 11B

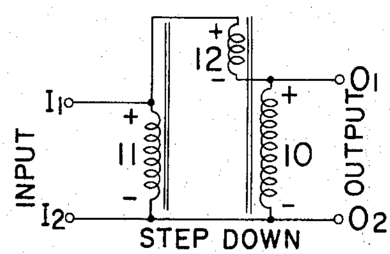


FIG. 12A

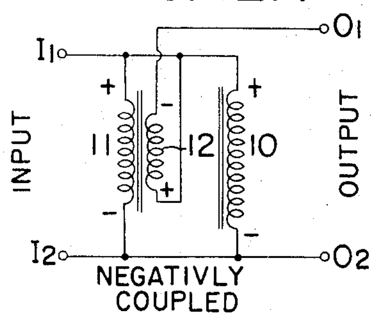


FIG. 12B

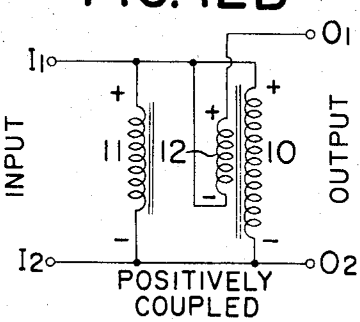


FIG. 13

FIG. 14A

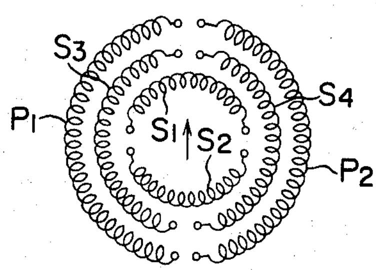


FIG. 14B

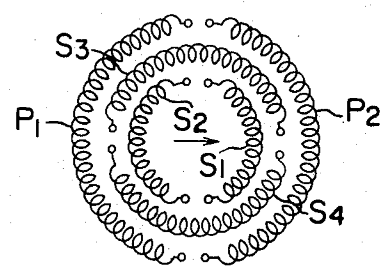


FIG. 14C

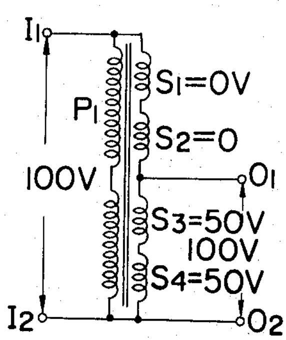


FIG. 14D

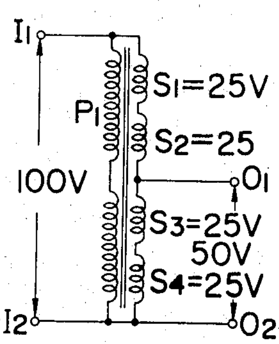


FIG. 14E

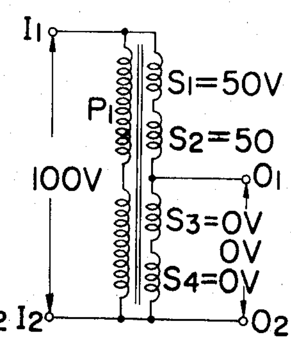


FIG. 14F

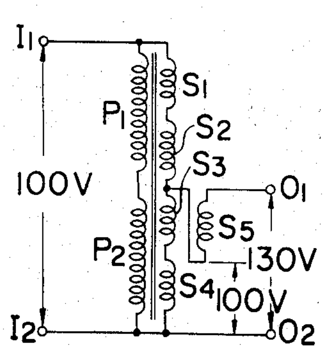


FIG. 14G

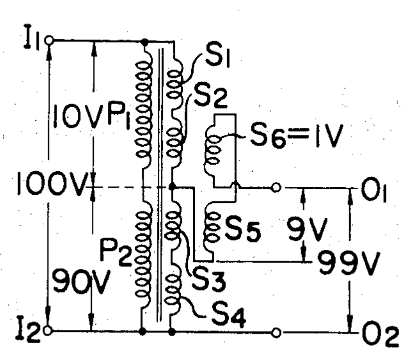


FIG. 15A

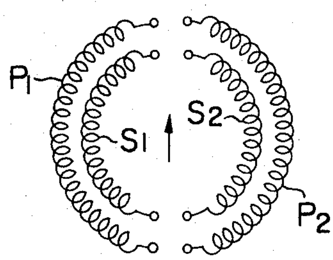


FIG. 15D

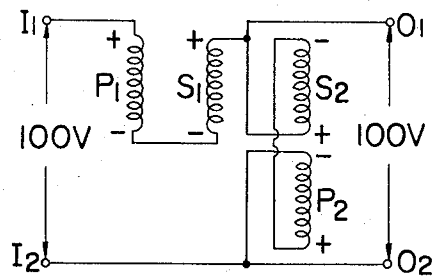


FIG. 15B

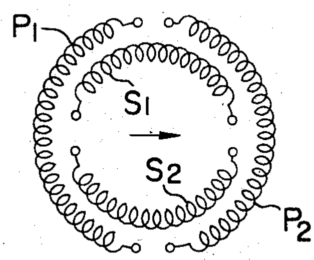


FIG. 15E

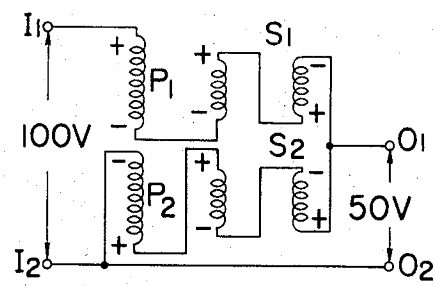


FIG. 15C

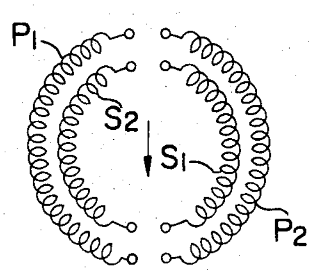


FIG. 15F

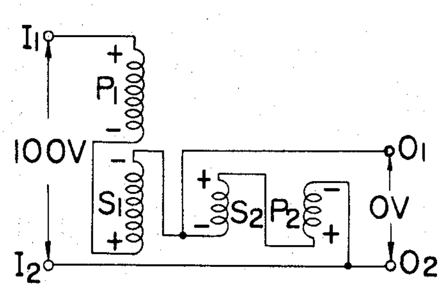


FIG. 16

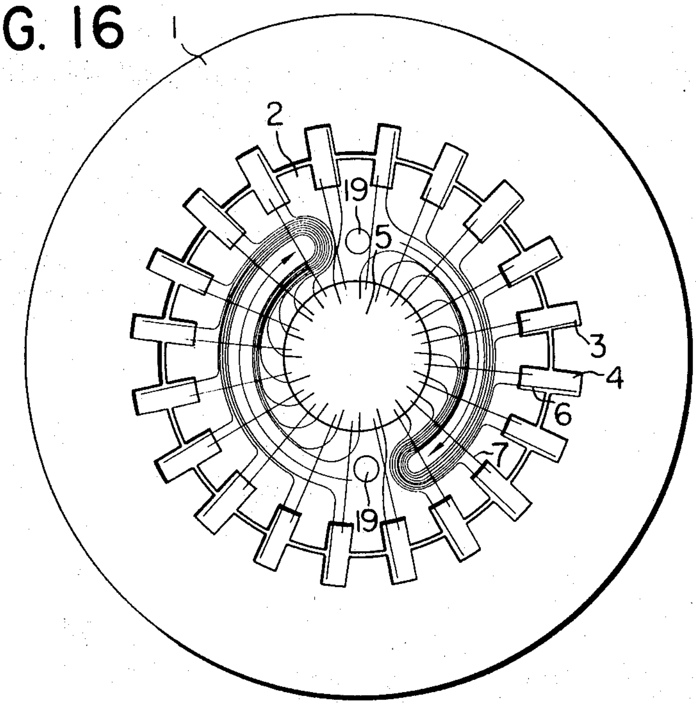

1
2
19
5
3
4
6
7
19

FIG. 17

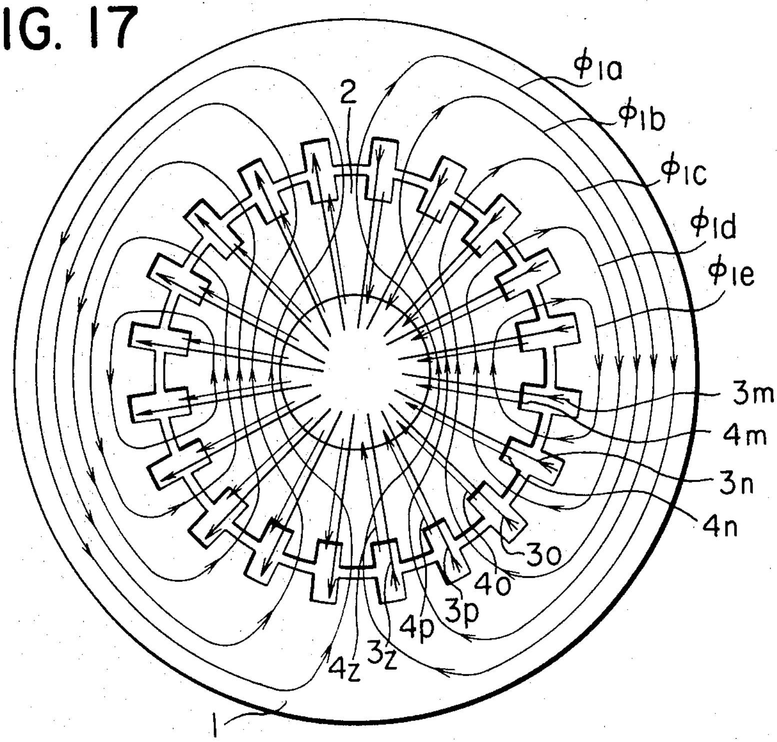

ϕ_{1a}
ϕ_{1b}
ϕ_{1c}
ϕ_{1d}
ϕ_{1e}
2
3m
4m
3n
4n
3o
4o
3p
4p
3z
4z
1

FIG. 18

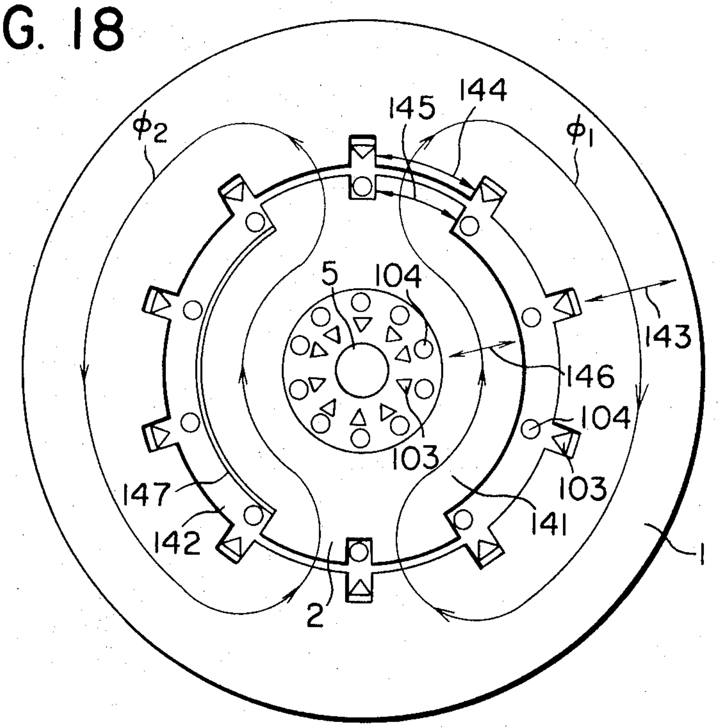

145
144
φ2
φ1
5
104
143
146
104
103
103
147
141
142
1
2

FIG. 19

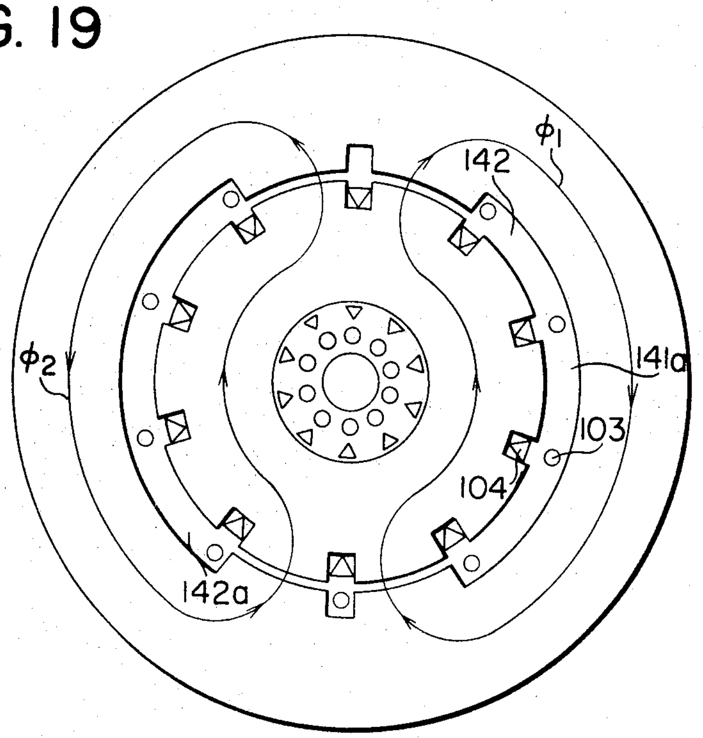

φ1
142
141a
φ2
103
104
142a

FIG. 20

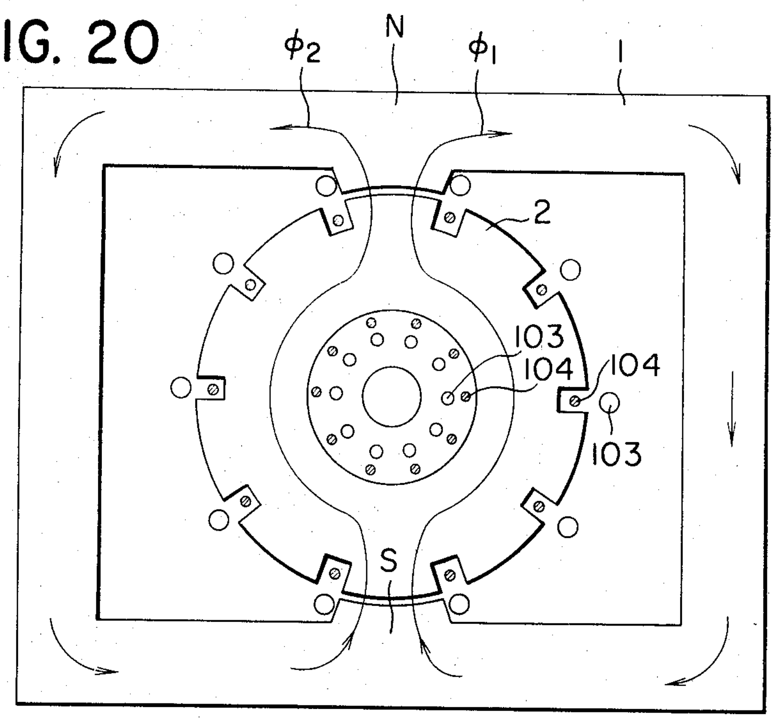

φ2
N
φ1
1
2
103
104
104
103
S

FIG. 21

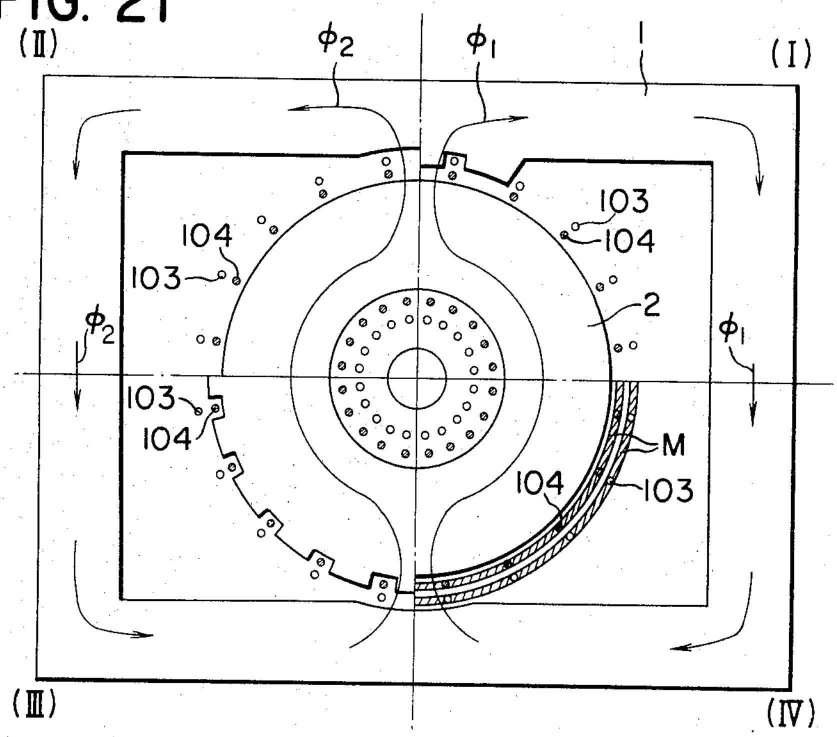

(II)
φ2
φ1
1
(I)
103
104
104
103
2
φ2
φ1
103
104
M
104
103
(III)
(IV)

FIG. 22

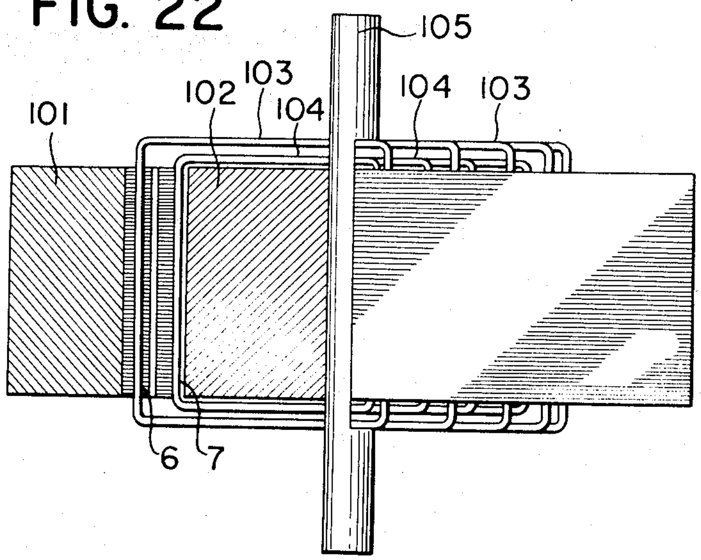

105
103
102
104
104
103
101
6
7

FIG. 23

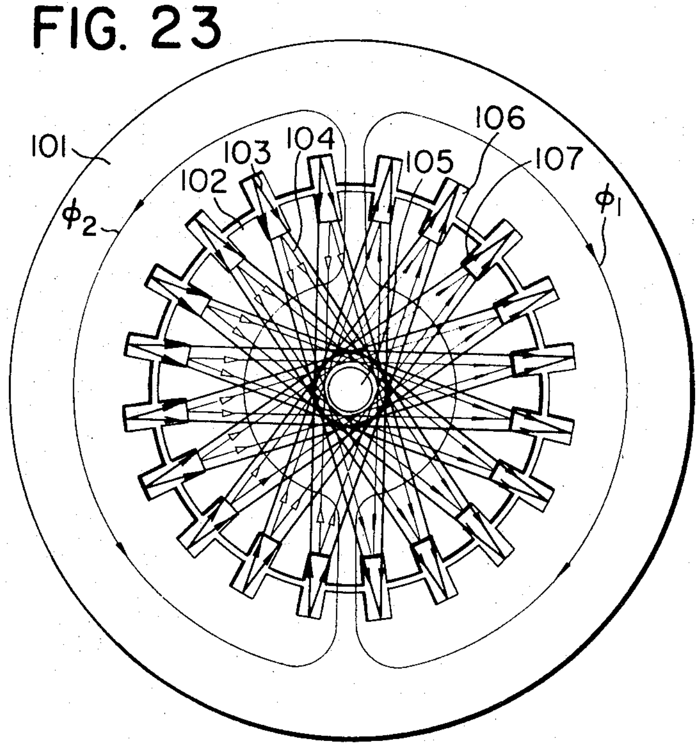

106
101
103
104
105
107
102
ϕ_1
ϕ_2

FIG. 24

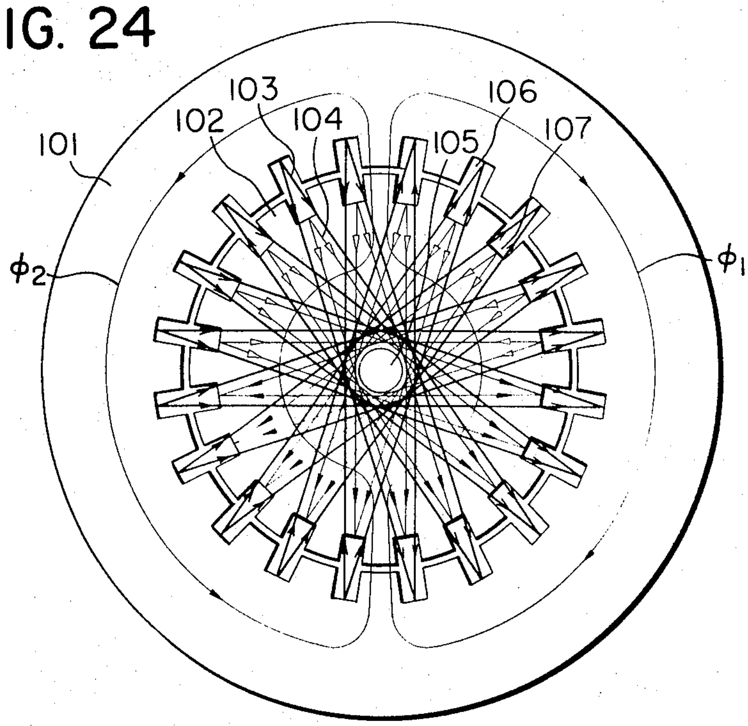

101
102
103
104
105
106
107
ϕ_2
ϕ_1

FIG. 25

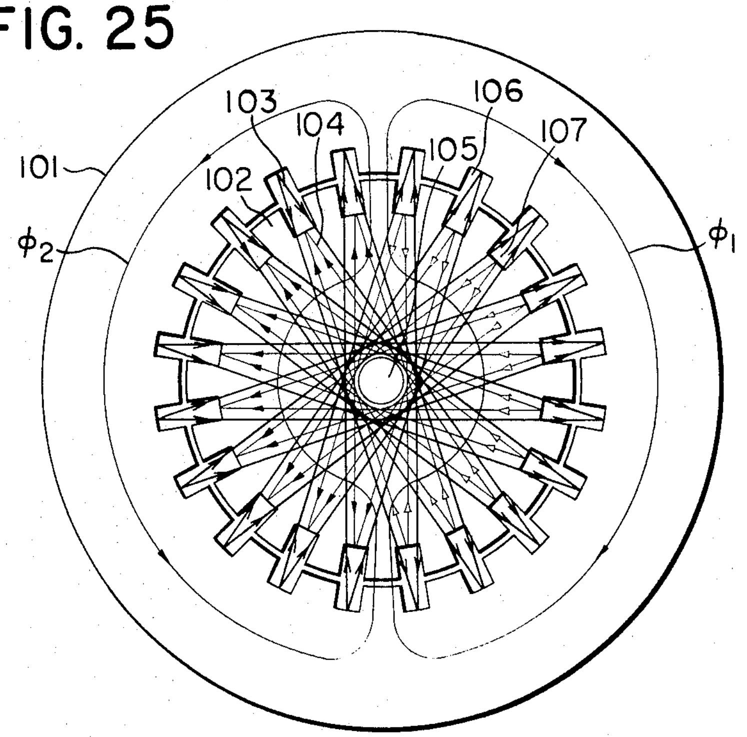

101
102
103
104
105
106
107
ϕ_2
ϕ_1

FIG. 26

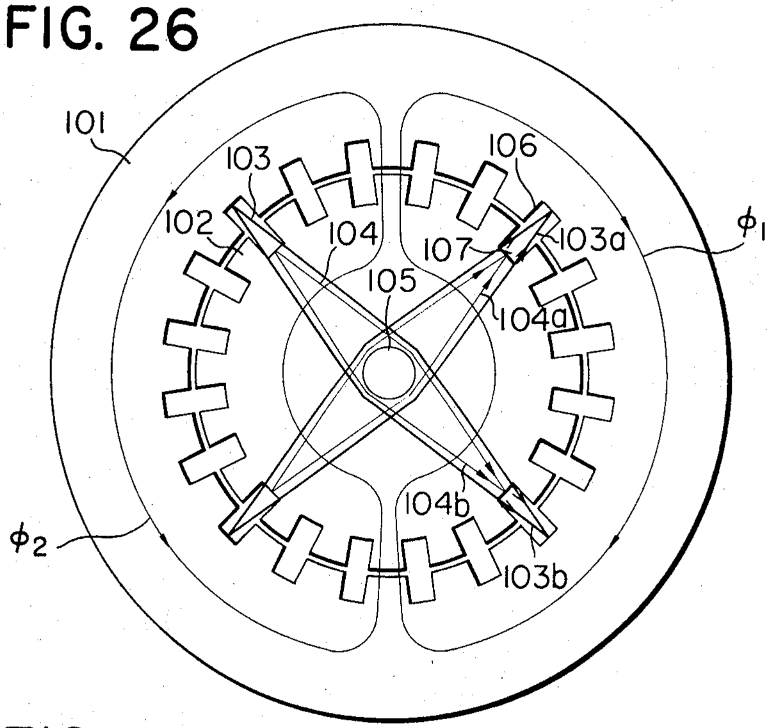

101
103
106
102
104
107
103a
ϕ_1
105
104a
104b
ϕ_2
103b

FIG. 27

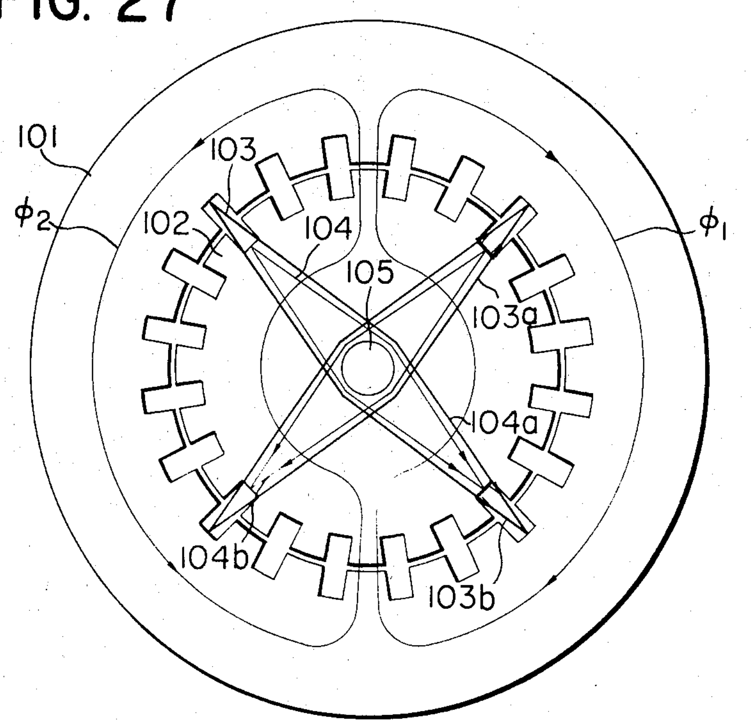

101
103
ϕ_2
102
104
ϕ_1
105
103a
104a
104b
103b

FIG. 28

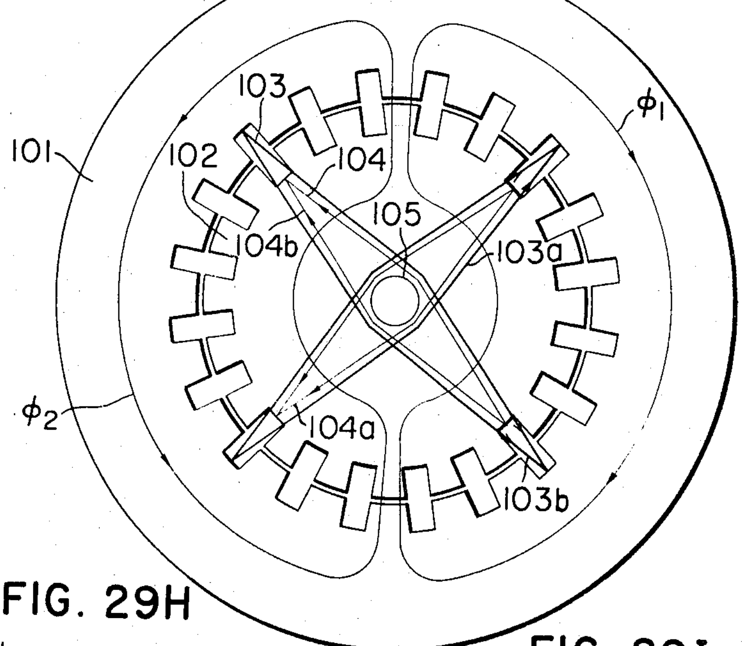


FIG. 29H

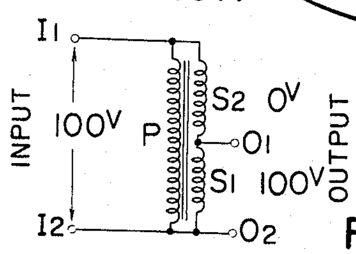


FIG. 29I

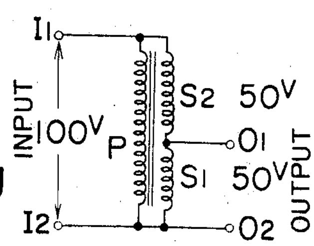


FIG. 29J

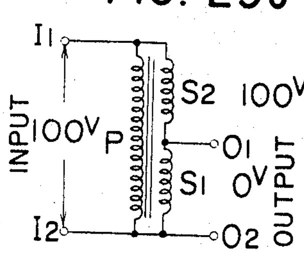


FIG. 29L

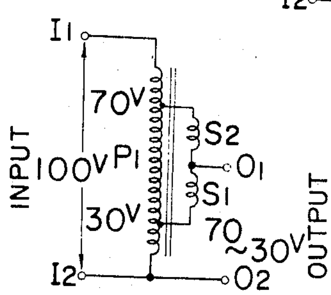


FIG. 29M

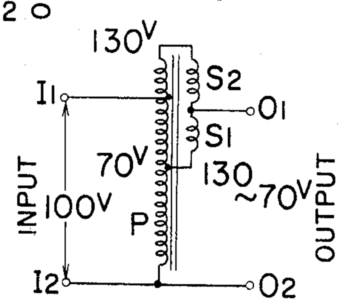


FIG. 29A

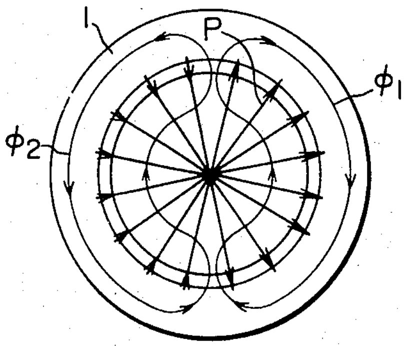


FIG. 29K

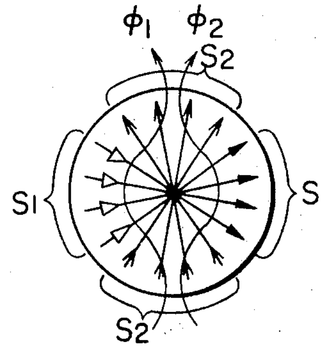
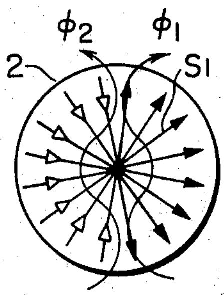
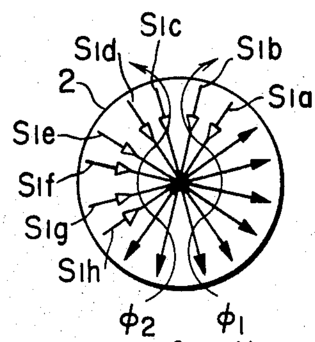


FIG. 29B



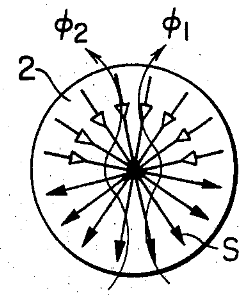
0°(100V)

FIG. 29C



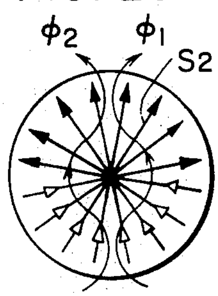
45°(50V)

FIG. 29D



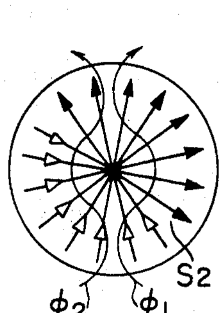
90°(0V)

FIG. 29E



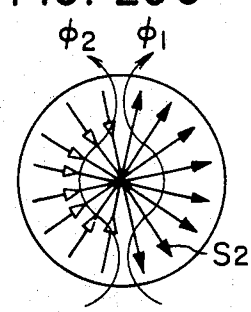
0°

FIG. 29F



45°

FIG. 29G



90°

FIG. 29N

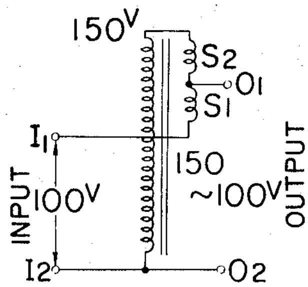


FIG. 29O

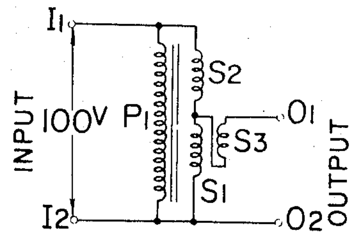


FIG. 30H

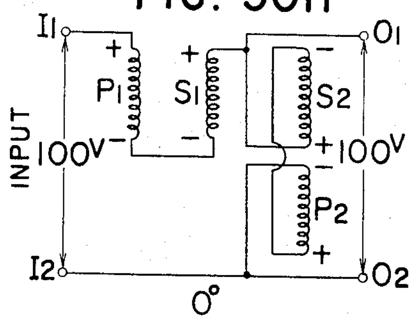


FIG. 30K

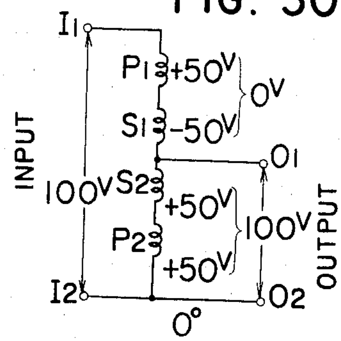


FIG. 30I

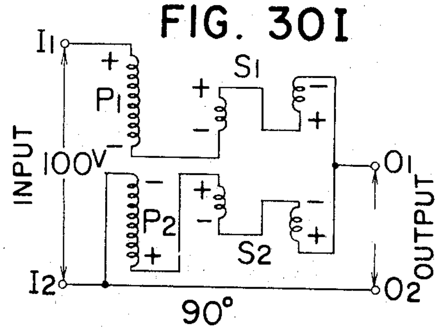


FIG. 30L

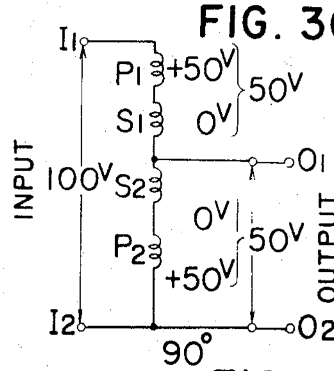


FIG. 30J

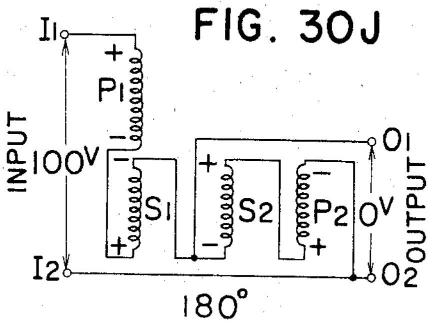


FIG. 30M

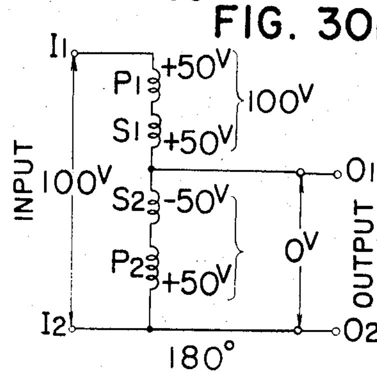


FIG. 30A

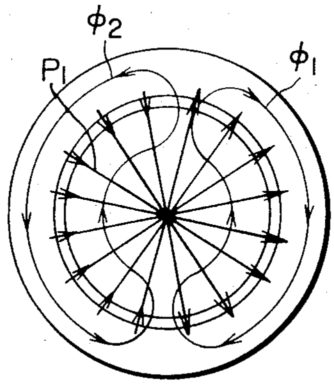


FIG. 30N

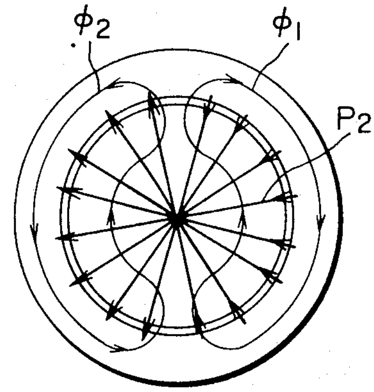


FIG. 30B

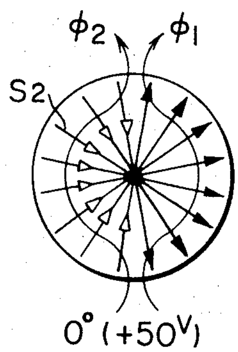


FIG. 30C

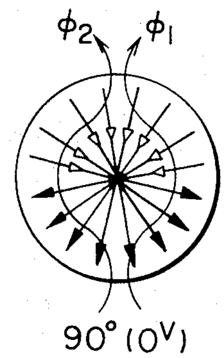


FIG. 30D

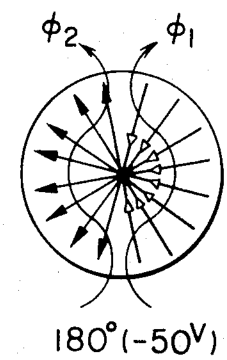


FIG. 30E

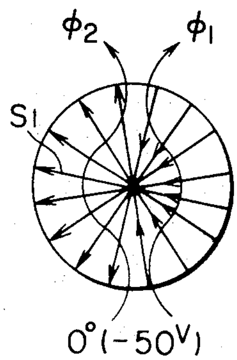


FIG. 30F

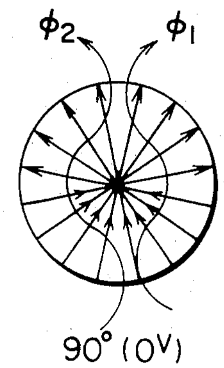


FIG. 30G

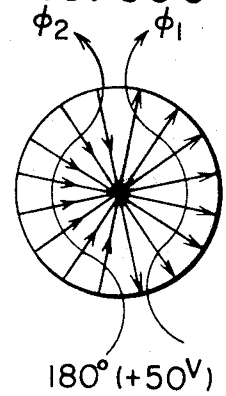


FIG. 31

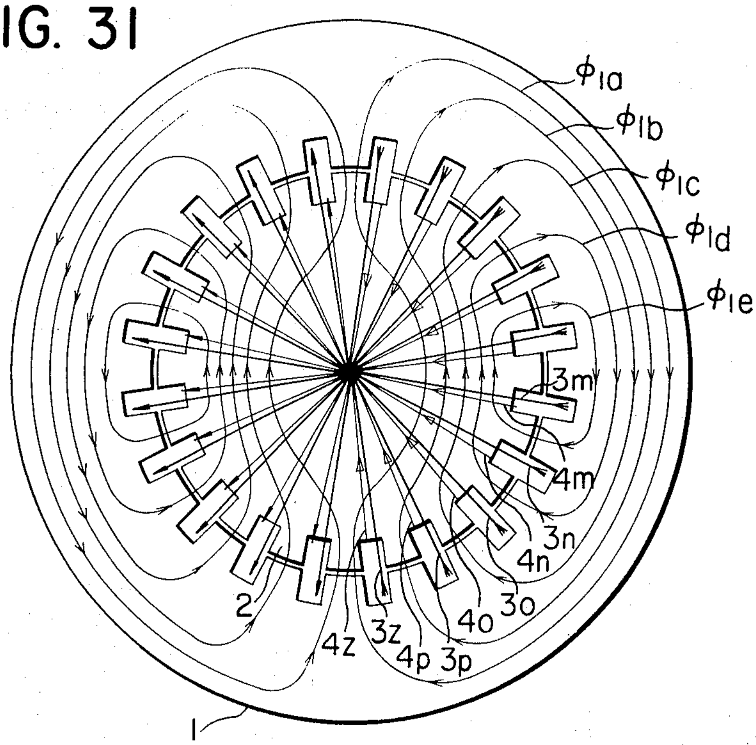

φ1a
φ1b
φ1c
φ1d
φ1e
3m
4m
3n
4n
3o
4o
3p
4p
3z
4z
2
1

FIG. 32

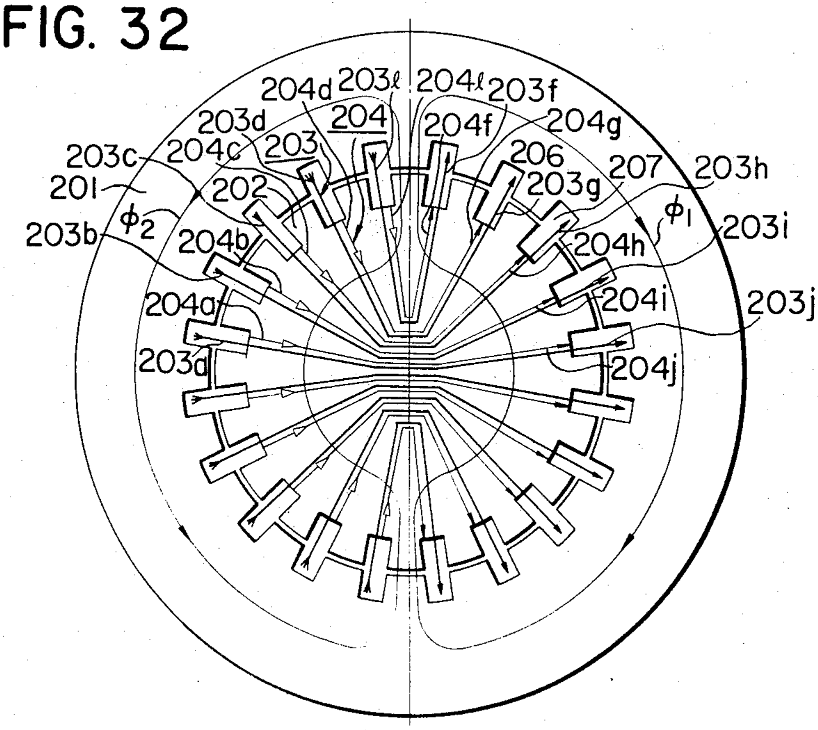

204d
203ℓ
204ℓ
203f
204
204f
204g
203d
203
206
203c
204c
207
203h
201
202
203g
φ1
203i
203b
φ2
204b
204h
204a
204i
203j
203d
204j

FIG. 33

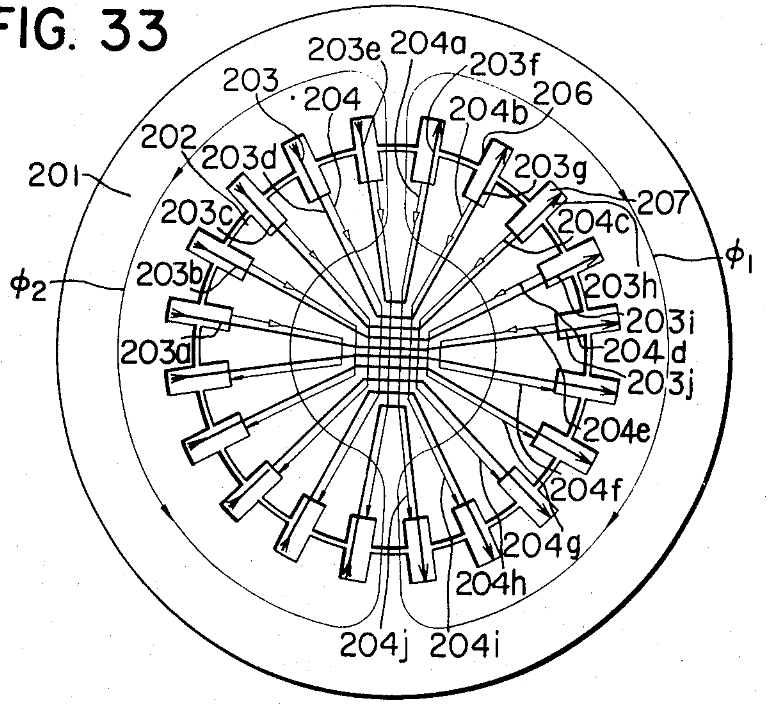

203e
204a
203f
203
204
206
204b
202
203d
203g
201
207
203c
204c
ϕ_1
ϕ_2
203b
203h
203i
203a
204d
203j
204e
204f
204g
204h
204j
204i

FIG. 34

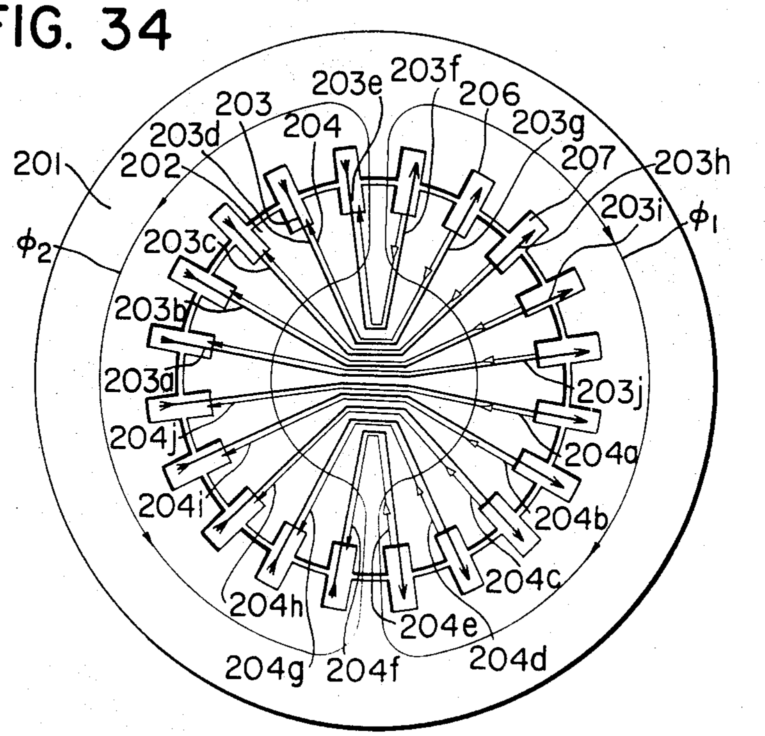

203e
203f
203
206
203d
204
203g
201
202
207
203h
203i
ϕ_1
ϕ_2
203c
203b
203a
203j
204j
204a
204i
204b
204c
204h
204e
204g
204f
204d

FIG. 35

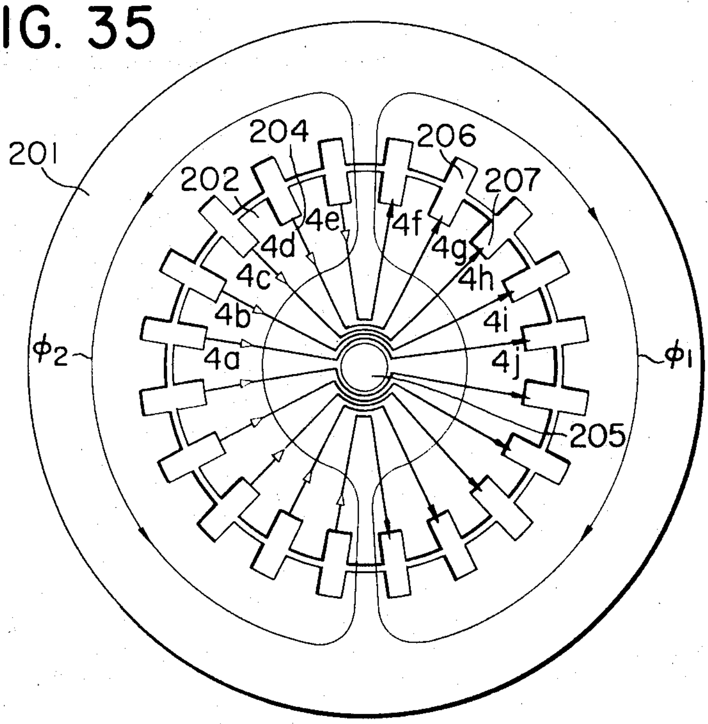

201
202
204
206
207
4a
4b
4c
4d
4e
4f
4g
4h
4i
4j
205
ϕ_2
ϕ_1

FIG. 36

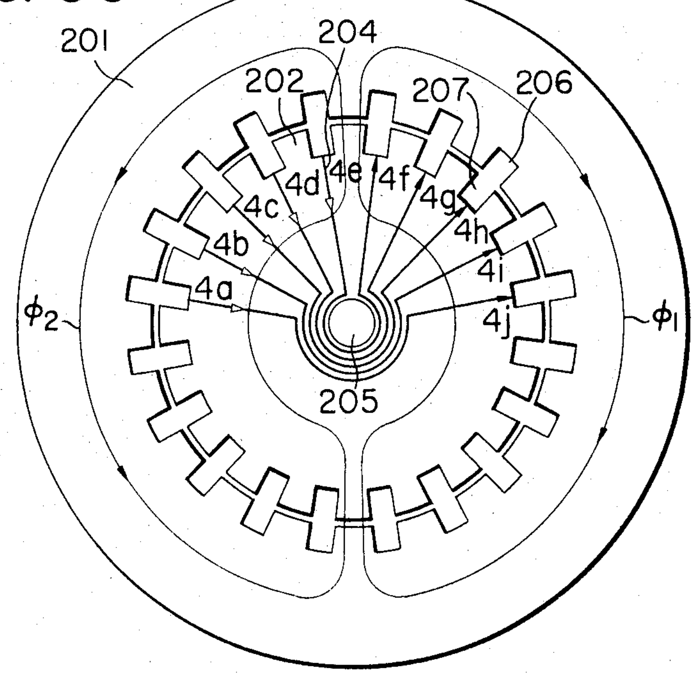

201
204
202
207
206
4a
4b
4c
4d
4e
4f
4g
4h
4i
4j
205
ϕ_2
ϕ_1

FIG. 44

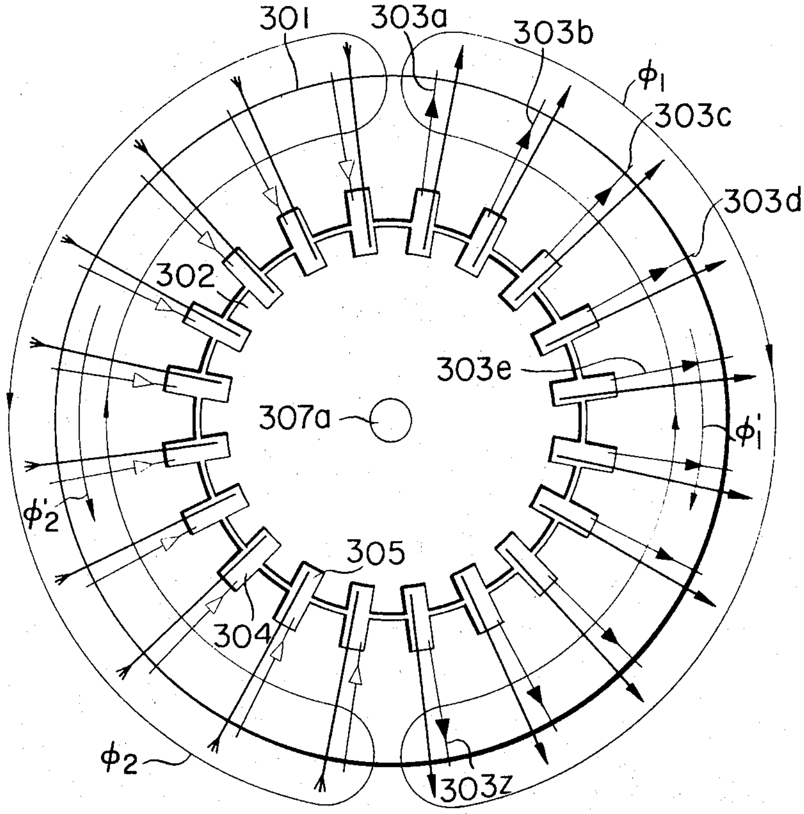

301
303a
303b
ϕ_1
303c
303d
302
303e
307a
ϕ'_1
ϕ'_2
305
304
ϕ_2
303z

FIG. 37

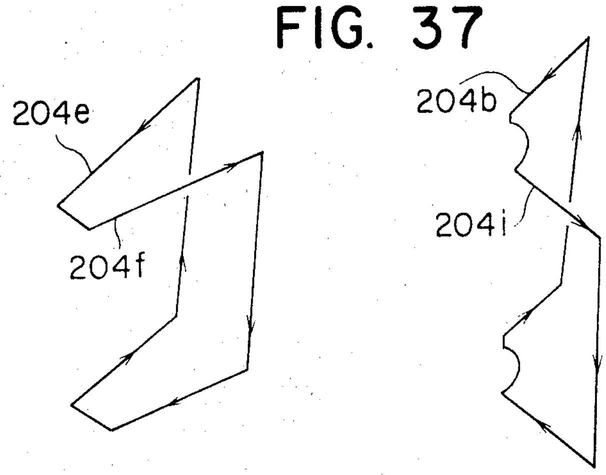

204e
204f
204b
204i

FIG. 45

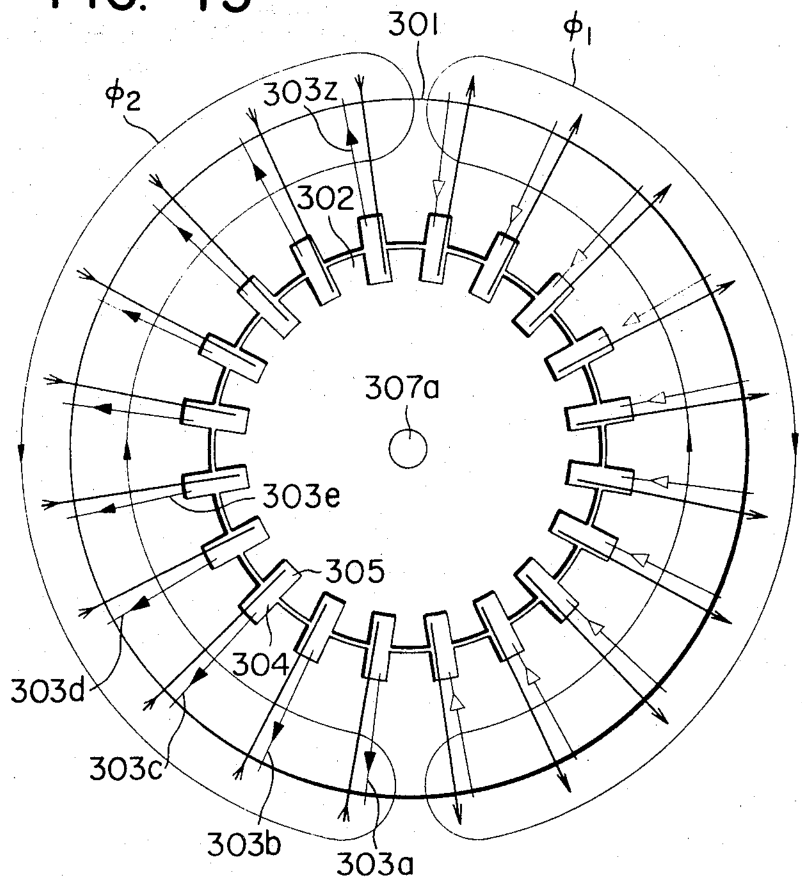

301
ϕ_1
ϕ_2
303z
302
307a
303e
305
304
303d
303c
303b
303a

FIG. 38

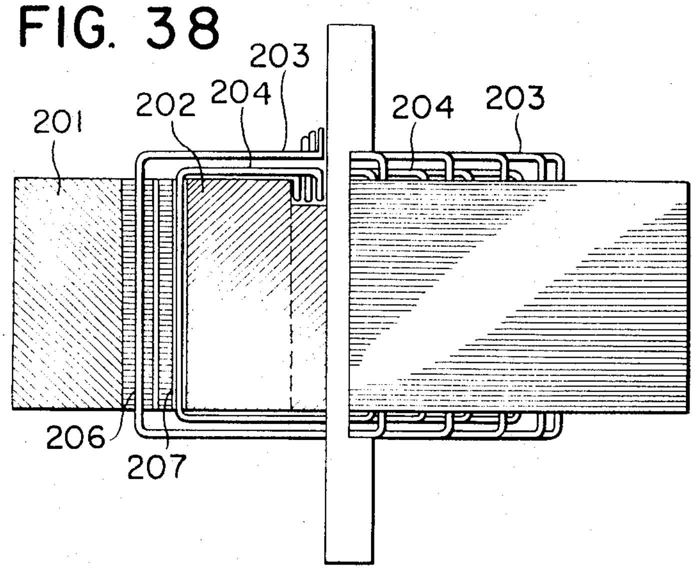

203
202
204
201
204
203
206
207

FIG. 39A

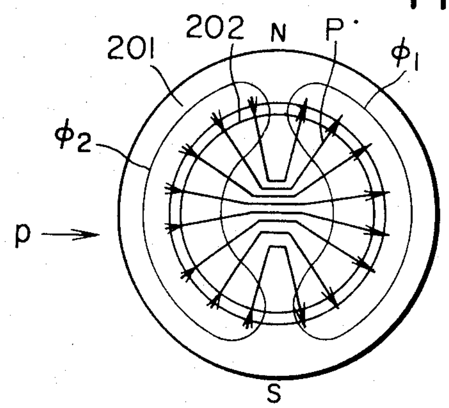


FIG. 39B

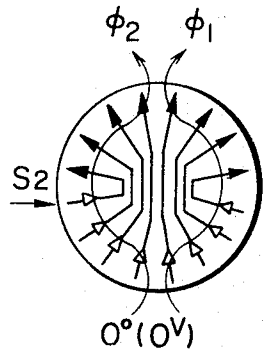


FIG. 39C

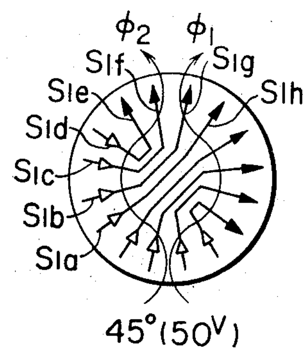


FIG. 39D

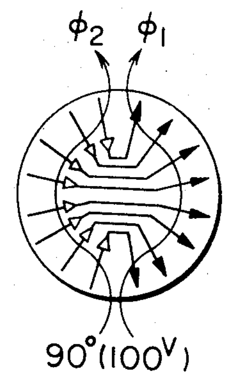


FIG. 39E

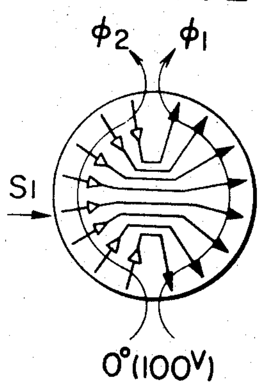


FIG. 39F

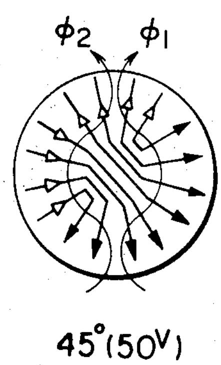


FIG. 39G

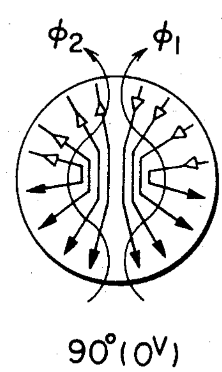


FIG. 39H

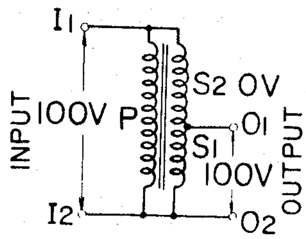


FIG. 39I

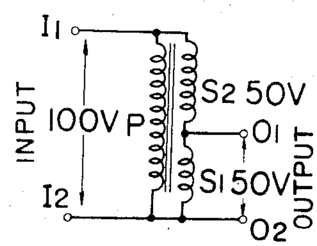


FIG. 39J

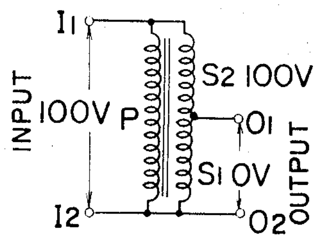


FIG. 39L

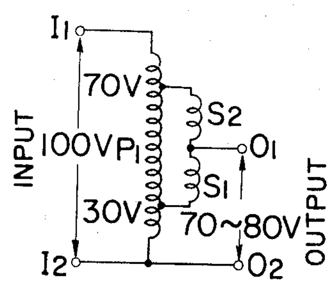


FIG. 39M

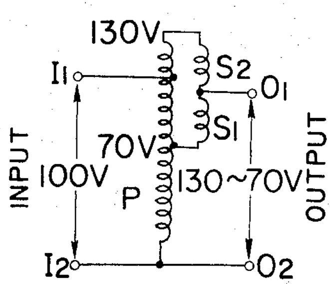


FIG. 39N

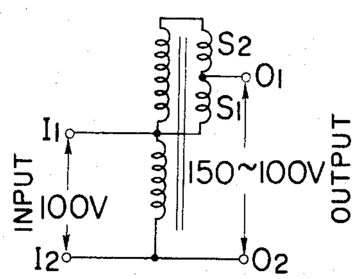


FIG. 39O

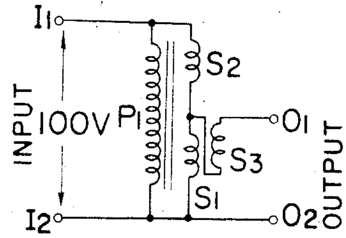
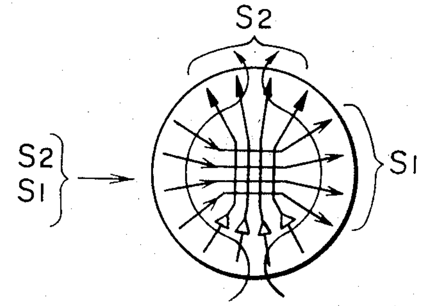
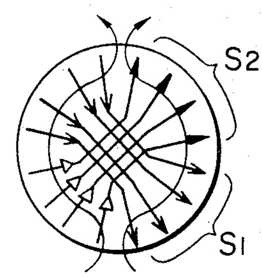


FIG. 39K



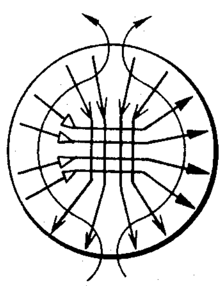
0° {S2(⊵)=0V
S1(≷)=100V

FIG. 39P



45° {S2(⊴)=50V
S1(≷)=50V

FIG. 39Q



90° {(⊵) = 100V
(≷) = 0 V

FIG. 39R

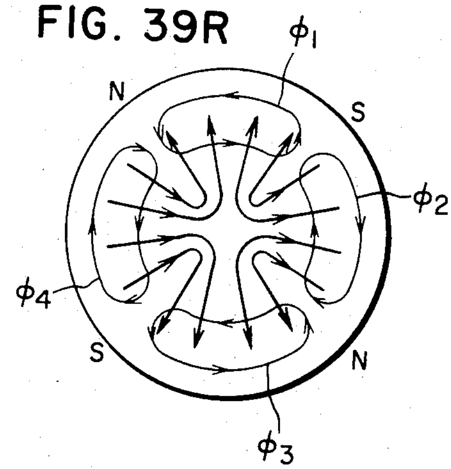


FIG. 40A

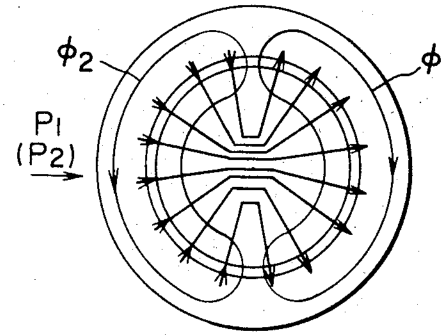


FIG. 40N

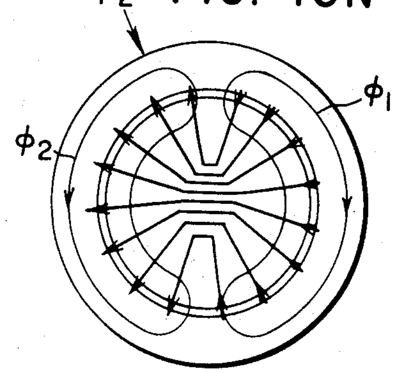
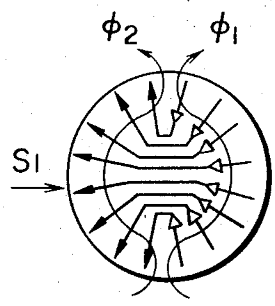
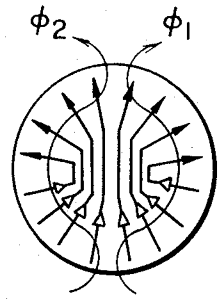


FIG. 40B



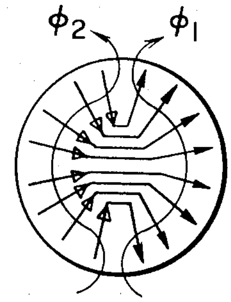
-50^V

FIG. 40C



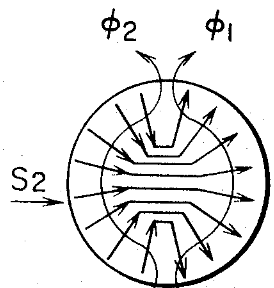
0^V

FIG. 40D



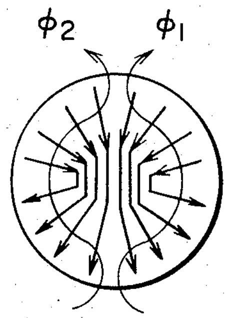
-50^V

FIG. 40E



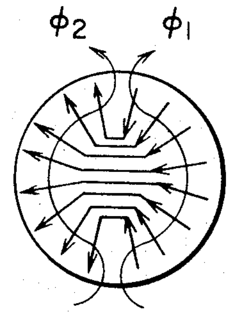
$+50^V$

FIG. 40F



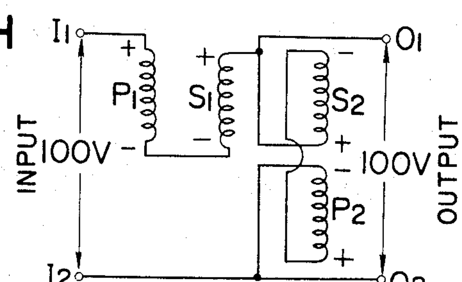
0^V

FIG. 40G



-50^V

FIG. 40H



0°

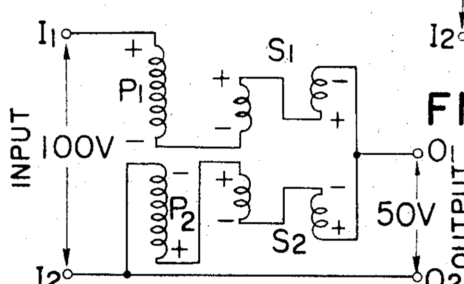
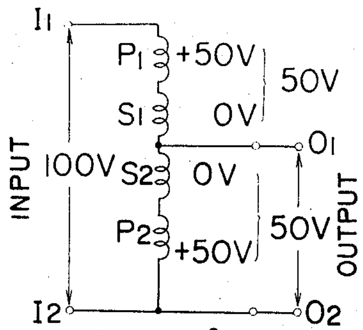


FIG. 40I

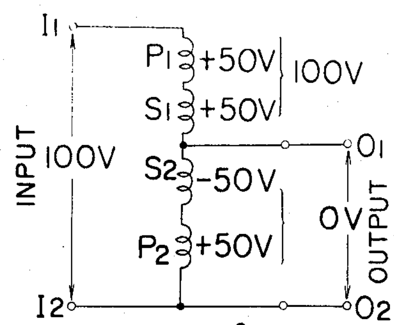
90°

FIG. 40L



90°

FIG. 40M



180°

FIG. 41

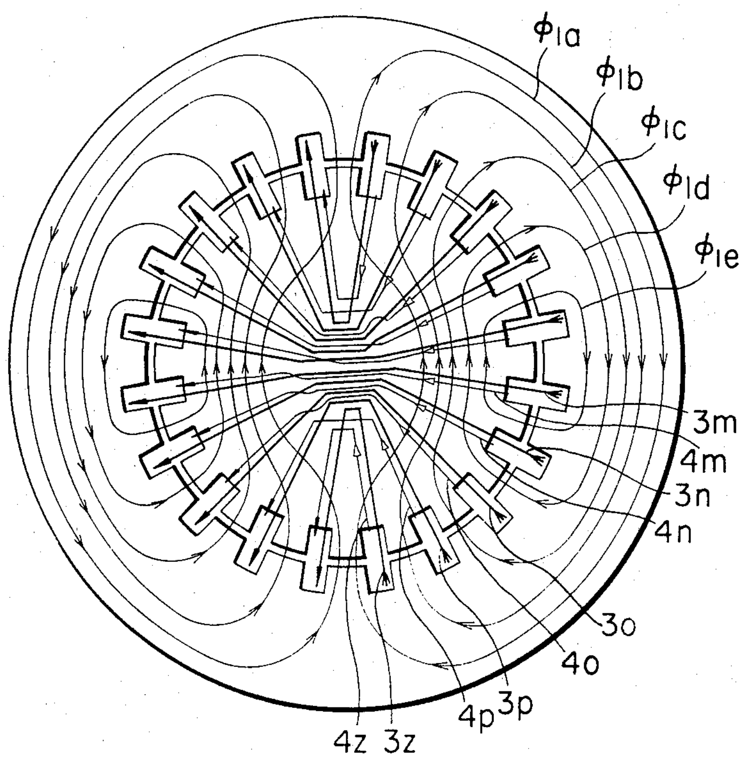


FIG. 42

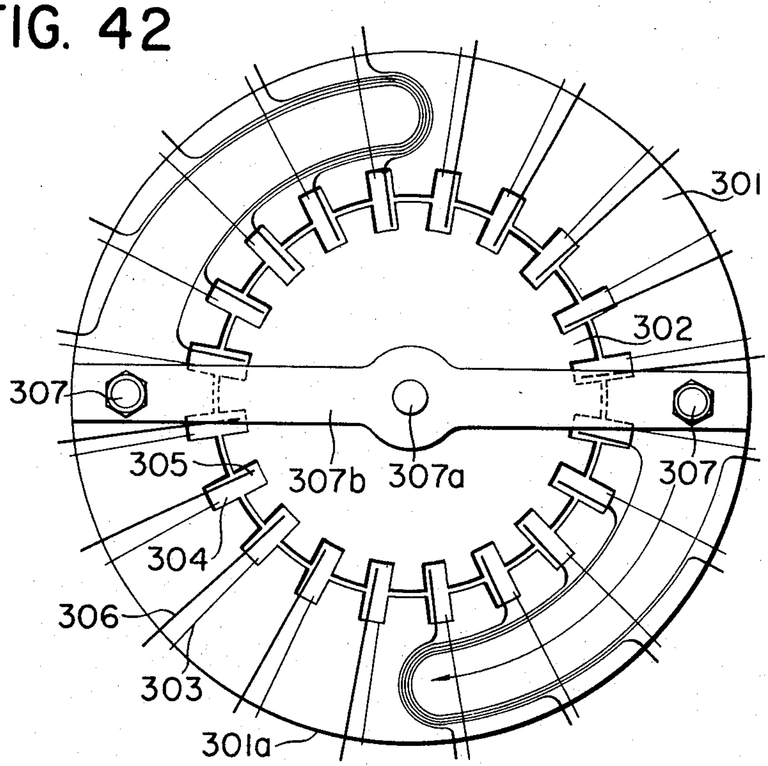

301
302
307
305
307b
307a
307
304
306
303
301a

FIG. 43

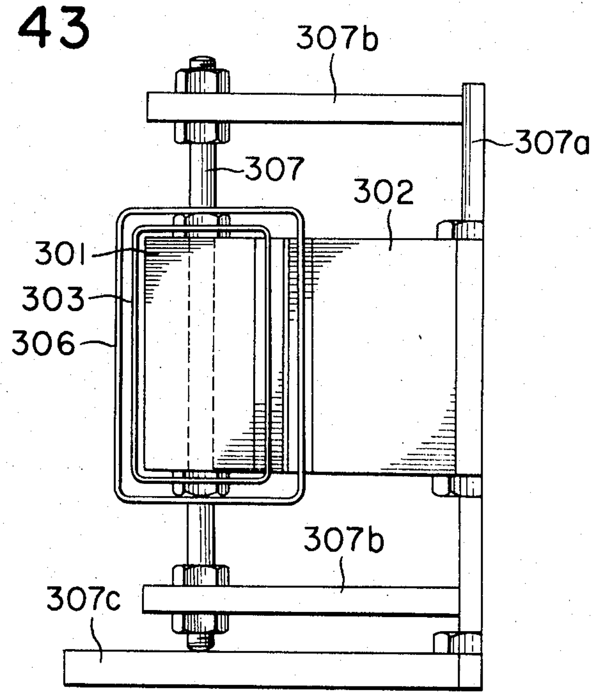

307b
307a
307
302
301
303
306
307b
307c

FIG. 46

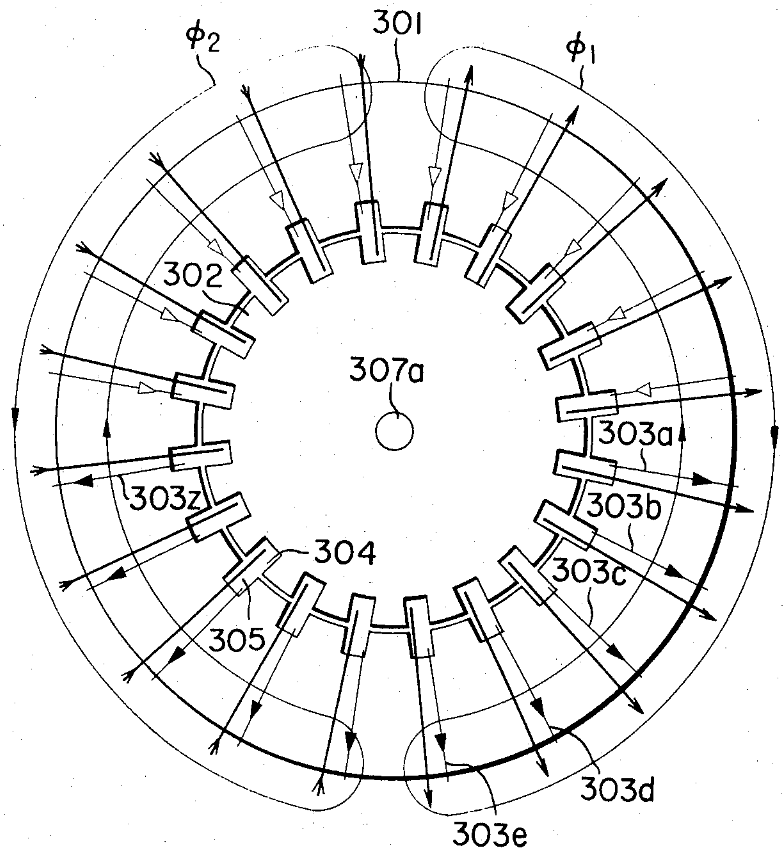


FIG. 40J

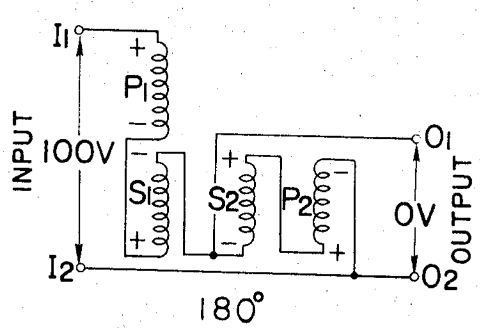


FIG. 40K

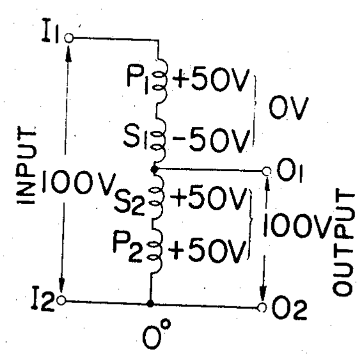


FIG. 47

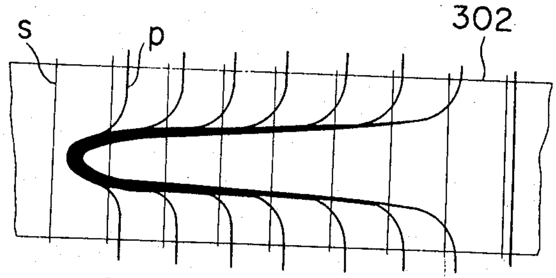

s
p
302

FIG. 48

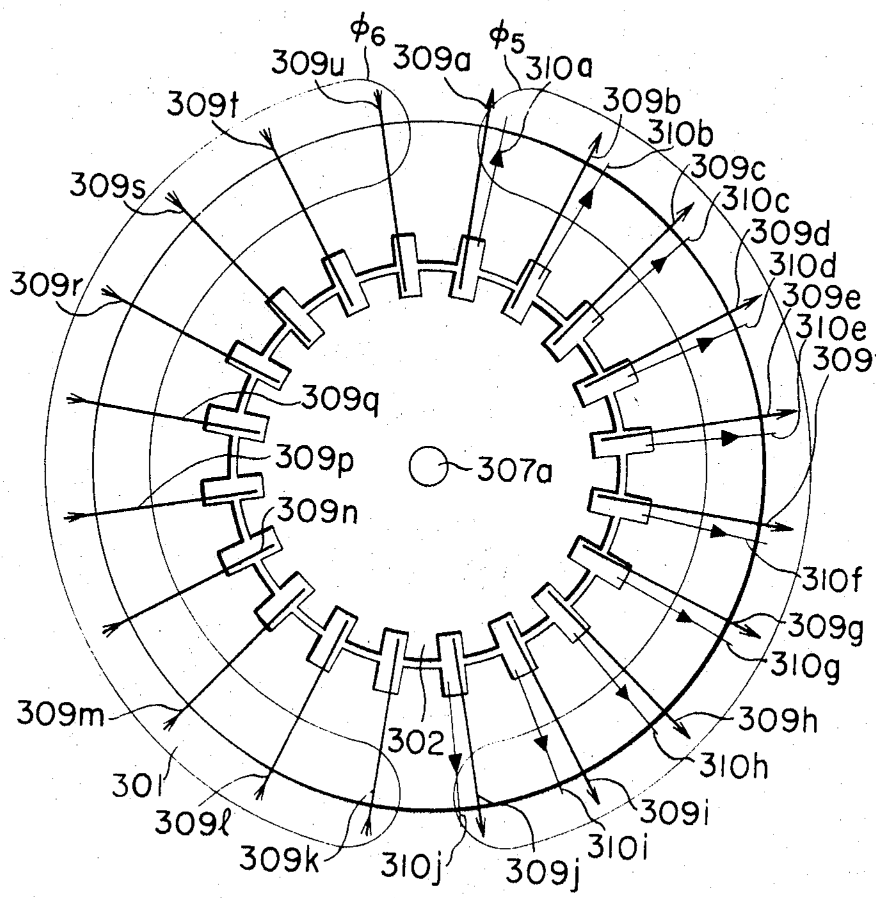
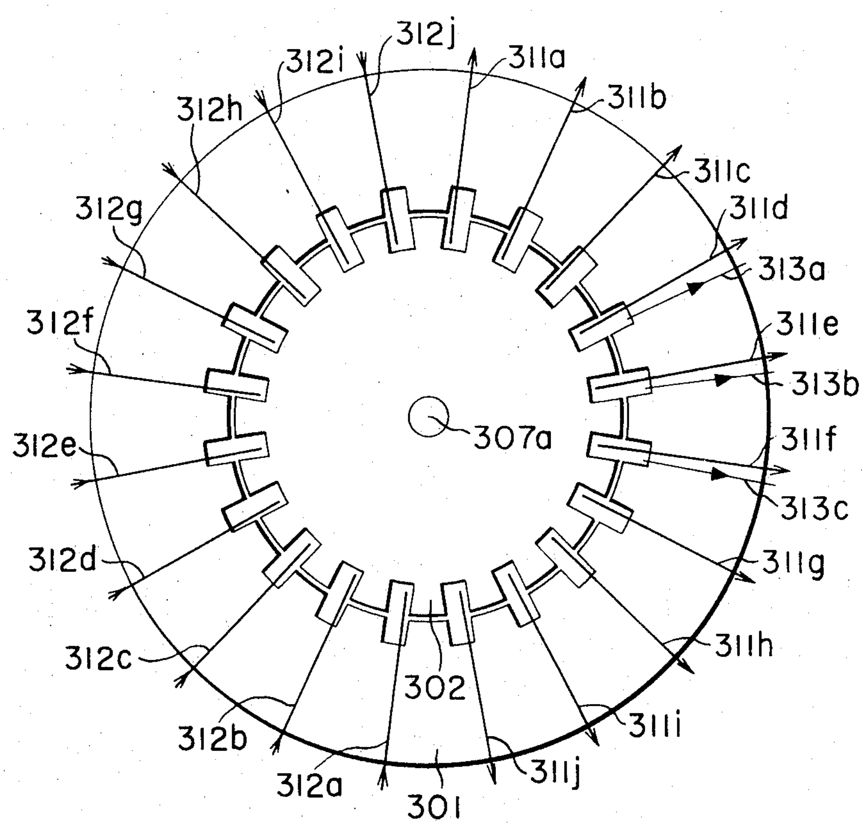

φ6
φ5
309u
309a
310a
309t
309b
310b
309c
310c
309s
309d
310d
309r
309e
310e
309f
309q
309p
307a
309n
310f
309g
310g
309m
309h
302
310h
301
309i
309ℓ
310i
309k
310j
309j

FIG. 49


312j
312i
311a
311b
312h
311c
312g
311d
313a
312f
311e
313b
307a
312e
311f
313c
312d
311g
312c
311h
302
311i
312b
311j
312a
301

ELECTROMAGNETIC INDUCTION APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to an electromagnetic induction apparatus.

In the conventional induction voltage regulators, when the primary winding is positioned at right angle to the secondary windings, no output voltage is induced across the secondary winding, but the secondary winding forms a magnetic path so that the self-inductance is incurred. Therefore, the short-circuited winding is used in order to cancel the magnetic flux produced by the load current. However, the shortcircuited winding has the following defects:

1. The copper loss is increased.
2. The copper wires large in diameter must be used in order to permit the flow of large short-circuited current because the effect of the short-circuited winding is increased as the larger short-circuited current flows.
3. An extra space must be provided in order to receive the short-circuited winding.

Furthermore, the conventional induction voltage regulators have generally the leakage impedance so that the problem of the voltage drop due to the leakage impedance is brought about.

SUMMARY OF THE INVENTION

Briefly stated, an electromagnetic induction apparatus in accordance with the present invention generally comprises an outer core, an inner core whose relative angular position relative to the outer core may be varied, a first group of windings on the outer core and a second group of windings on the inner core. The output voltage of the apparatus may be varied depending upon the relative angular position between the first and second windings. Even through the magnitudes of the magnetic fluxes produced by the first and second groups of windings remain unchanged, the direction of coupling and linking of the magnetic flux or fluxes produced by one group of winding to the other group of windings may be varied in response to the relative angular position between the first and second groups of windings so that the output voltage may be varied accordingly.

One of the objects of the present invention is therefore to provide an electromagnetic induction apparatus having less leakage impedance.

Another object of the present invention is to provide an electromagnetic induction apparatus which has less electrical losses.

A still another object of the present invention is to provide an electromagnetic induction apparatus compact in size and light in weight.

In this specification, the terms "inductively positively coupled" and "inductively negatively coupled" are used to refer to the fact that the primary and secondary windings are so coupled that the polarities of the voltage induced across the secondary winding are same with or opposite to those of the winding voltage across the primary winding.

The above and other objects, features and advantages of the present invention will become more apparent from the following description of some preferred embodiments thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of a first embodiment of the electromagnetic induction apparatus in accordance with the present invention illustrating the arrangement of an annular outer and inner cores and windings placed thereupon;

FIG. **2** is a fragmentary sectional view thereof illustrating the mechanical construction thereof;

FIGS. **3** – **5** are top views illustrating the relative angular position between the first and second windings of the apparatus shown in FIG. **1**;

FIGS. **6A** – **6C*a*** are views illustrating the connections of the windings and the relation between the angle of rotation of the rotor and the output voltage of the apparatus shown in FIG. **1**;

FIG. **6D** is a view illustrating the connection of the windings of a second embodiment shown in FIG. **7**;

FIG. **7** is a top view of a second embodiment of the electromagnetic induction apparatus in accordance with the present invention;

FIG. **8A** to FIG. **9C** are views used for explanation of the arrangements of slots formed in the outer and inner cores of the electromagnetic induction apparatus in accordance with the present invention;

FIG. **10** is a top view of a third embodiment of the electromagnetic induction apparatus in accordance with the present invention;

FIG. **11A** to FIG. **12B** illustrate the connections of the first and second windings of the third embodiment shown in FIG. **10**.

FIG. **13** is a circuit diagram used for explanation of the use of the apparatus of the present invention as a variable inductance;

FIGS. **14A** – **14G** illustrate the arrangements and connections of the first and second windings of still other embodiments of the present invention;

FIGS. **15A** – **15F** illustrate the arrangements and connections or couplings of the first and second windings of a still another embodiment of the present invention;

FIG. **16** is a top view of a still another embodiment of the present invention illustrating the arrangement of the windings placed upon the outer core;

FIG. **17** is a view used for explanation of the magnetic flux distribution in the electromagnetic induction apparatus in accordance with the present invention;

FIGS. **18** – **21** are top views illustrating still other embodiments of the present invention especially illustrating the shapes of the outer and inner cores and the arrangements of the first and second windings;

FIG. **22** is a fragmentary sectional view of a still another embodiment of the present invention;

FIGS. **23** – **25** are the top views thereof illustrating the relative angular relation between the first and secondary windings of the apparatus shown in FIG. **22**;

FIGS. **26**, **27** and **28** are top views which illustrate only two pairs of the first and second winding coils for the sake of simplicity to facilitate the explanation of the embodiment shown in FIGS. **22** – **25**;

FIGS. **29A** - **29O** illustrate the arrangements and connections of the first and second windings of still other embodiments of the present invention;

FIGS. **30A** – **30M** illustrate the arrangements and connections of still other embodiments of the present invention;

FIG. 31 is a top view used for explanation of the magnetic flux distribution in the apparatus in accordance with the present invention;

FIGS. 32, 33 and 34 are top views illustrating the relative angular positions between the first and second windings of the embodiment shown in FIG. 22;

FIGS. 35 and 36 are views illustrating the methods for centering the windings compact in size;

FIG. 37 illustrates the form of the coils of the windings of the apparatus of the embodiment shown in FIG. 22;

FIG. 38 is a fragmentary sectional view of a still another embodiment illustrating a recess formed in the inner core thereof for receiving the windings in compact;

FIG. 39A to FIG. 40M illustrate the arrangements and connections of the first and second windings of the embodiment shown in FIG. 38;

FIG. 41 is a view used for explanation of the magnetic flux distribution in the apparatus in accordance with the present invention;

FIG. 42 is a top view of a still another embodiment of the present invention;

FIG. 43 is a fragmentary sectional view thereof illustrating the mechanical construction;

FIGS. 44, 45 and 46 are top views of the embodiment shown in FIGS. 42 and 43 illustrating the relative angular positions between the first and second windings thereof;

FIG. 47 is a top view of an arrangement of the embodiment shown in FIG. 42;

FIG. 48 is a top view of the embodiment shown in FIG. 6D; and

FIG. 49 is a top view of a still another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, the first embodiment of the electromagnetic induction apparatus in accordance with the present invention generally comprises an annular outer core 1, an annular inner core 2 disposed coaxially of the outer core 1, a first group of windings 3 radially wound and placed in slots 4 formed along the inner peripheral surface of the outer core 1 and a center hole 5 axially formed at the center of the inner core 2, and a second winding group 7 wound between slots 6 formed along the outer peripheral surface of the annular inner core 2 and the center hole 5 thereof. It should be noted that both the first group 3 of windings and the second group of windings 7 pass through the center hole 5.

In the instant embodiment, first group of windings 3 may be used as primary windings whereas the second group of windings 7 may be used as secondary windings or vice versa. Similarly the annular outer core 1 may be the rotor whereas the annular inner core 2 may be the stator, or vice versa. The instant embodiment will be described in more detail with a further reference of FIG. 2. The annular outer core 1 has a plurality of slots 4 formed along the inner periphery thereof for mounting the first group of windings 3, and the annular inner core 2 has a plurality of slots 6 equal in number to the slots 4 for mounting the second group of windings 7 which may be radially converged toward the center hole 5. The second group of windings 7 is rotated in unison with the annular inner core 2. The first group of windings 3 pass through the slots 4 of the annular outer core 1 and the center hole 5 of the annular inner core 2. The portion 3*a* of the first group of windings extending from the slot 4 passes into the center hole 5 of the inner core 2 directly, but the windings 3*b*, 3*c*, . . . , and 3*z* are not straight, but are so arranged as to pass along the periphery of the center hole 5 and to converge toward common points 13 and 13*a* as best shown in FIG. 1. From these common points 13 and 13*a* the secondary windings 7*b*–7*z* start to pass through the center hole 5. The annular inner core 2 is carried for rotation by a center shaft 14 with brackets 15, bolts and nuts 16. The annular outer core 1 is supported between electrically insulating supporting members 18 extending from the center shaft 14 with bolts and nuts 17. If the supporting members 18 are not made of an electrically insulating material, the magnetic circuits are established among the center shaft 14, the brackets 15, the bolts and nuts 16 and 17, and the annular outer and inner cores 1 and 2 so that the magnetic fluxes pass through the circuit of a conductor to induce the voltage. Therefore, this conductor circuit is short-circuited, causing the abnormal operation of the apparatus.

As described above, according to the present invention, the secondary windings are once converged toward the common points 13 and 13*a* before they pass through the center hole 5 of the annular inner core 2 so that the angle of rotation of the annular inner core 2 may be increased. That is, the annular inner core 2 may be rotated in the direction indicated by the arrow in FIG. 1 about the axis of the center shaft 14 until the vertical portions 15*a* of the brackets 15 contact with the secondary windings 7 concentrated about the common points 13 and 13*a*.

In the first embodiment, the first group 3 consists of the primary windings whereas the second group 7, the secondary windings. The annular inner core 2 is rotatable whereas the annular outer core 1 is stationary. Thus, the group of the primary windings 3 are stationary whereas the group of the secondary windings 7 are rotatable in unison with the annular inner core 2.

Next referring to FIGS. 3, 4 and 5, the primary windings indicated by the bold lines and the secondary windings indicated by fine lines are wound in the directions indicated by the arrows. In FIGS. 3 – 5, the cores 1 and 2 are viewed from the top, so that the arrangements of the primary and secondary windings are opposite in direction to those shown in FIGS. 3 – 5 when viewed from the bottoms thereof.

In the embodiment illustrated in FIG. 3, the angle of rotation which is 360° is divided into two equal angles 180° so that a pair of windings produce the symmetrical fluxes ϕ_1 and ϕ_2 as shown in FIG. 3. Both the primary and secondary windings in each of the 180° sectors are wound in the same directions and are connected in series.

FIG. 5 shows that the annular inner core (rotor) is rotated through 180° from the position shown in FIG. 3 so that the directions of the secondary windings are opposite to those of the primary windings. It should be also noted that the directions of the secondary windings themselves are opposite to those shown in FIG. 3.

FIG. 4 shows that the inner core or rotor is located in a position substantially intermediate between the positions shown in FIG. 3 and FIG. 5 respectively. The directions of one half of the secondary windings in each 180° sector are opposite to those of the primary windings and to those of the secondary windings shown in FIGS. 3 and 5. In short, the secondary windings 7a – 7z shown in FIGS. 4 and 5 are rotated through 180° and 90° from the positions shown in FIG. 3, but since the primary windings are stationary, the two fluxes ϕ_1 and ϕ_2 produced by them remain unchanged in position.

As shown in FIGS. 8 and 9, the slots of the annular outer and inner cores may be formed in parallel with the axes thereof or inclined at angles in order to attain the uniform coupling between the primary and secondary windings. In general, the slots 4 of the annular outer core are located in line with the slots 6 of the annular inner core as shown in FIG. 1 or in positions intermediate the adjacent slots 6 as shown in FIGS. 8A and 8B. In the latter case, the coupling between the primary and secondary windings is rough as compared with the case the slots are aligned so that some leakage impedance occurs. When it is desired to eliminate this leakage impedance in order to obtain the desired characteristics, either of the slots 4 or 6 may be inclined as shown in FIG. 9B relative to the other so that the uniform coupling may be attained. In this case, the primary or secondary windings are always coupled to the secondary or primary windings so that the uniform coupling therebetween may be attained. In addition to the above described arrangements of the slots, various variations may be effected. For example, the slots may be so formed as to incline in the opposite directions or in the form of < or arc.

Furthermore, when the degree of the coupling between the primary and secondary windings changes because the slots are located in alignment with each other or displaced from each other as shown in FIGS. 8A and 8B, the number of the slots of the annular outer or inner core may be increased or decreased by one relative to the number of slots of the annular other core. For example, the annular inner core has a number of n slots whereas the annular outer core has a number of $(n \pm 1)$ slots. In this case, one of the n slots of the annular inner core will coincide with one of the $(n \pm 1)$ slots of the annular outer core when the annular inner core rotates through an angle of $1/n$ of the angle between the adjacent slots. In the instant embodiment, the number n is equal to 20 as shown in FIG. 1 so that the slots of the annular outer and inner cores coincide with each other when the latter rotates through the angle equal to (the angle between the adjacent slots)/20. When the annular outer core has a number of $(n \pm 2)$ slots, the slots of the annular outer and inner cores coincide with each other when the latter rotates through the angle equal to (the angle between the adjacent slots) $\times 2/n$. That is, when the number of slots is increased to $(n \pm 2)$, the angle of the rotation of the rotor or annular inner core must be increased twice as compared with the annular outer core having the number of $(n \pm 1)$ slots.

If the increase in exciting current presents no problem, the slots of the annular outer and inner cores may be eliminated.

Next the mode of operation will be described. FIG. 3 illustrates that the secondary voltage is in phase with the primary voltage and has the maximum magnitude; FIG. 5 illustrates that the secondary voltage is opposite in phase with respect to the primary voltage but has the maximum magnitude; and FIG. 4 illustrates that the secondary voltage is almost zero.

FIGS. 6A – 6D illustrate the connections of the primary and secondary windings and the relation between the output voltage and the relative position of the secondary winding with respect to the primary winding.

Referring back to FIG. 3, when the AC voltage is applied across the primary windings, the two fluxes ϕ_1 and ϕ_2 are produced in the directions indicated by the arrows in the annular outer core at, and pass through the annular inner core in the directions indicated by the arrows. Therefore the maximum output voltage is induced in the secondary windings because the latter are wound in the directions so that the maximum output voltage in phase with the primary voltage may be induced when the fluxes set up by the primary windings pass through the secondary windings.

When the annular inner core is rotated through 180° from the position shown in FIG. 3 to the position as shown in FIG. 5, the fluxes indicated by the arrows are generated and pass through the annular inner core in the directions indicated by the arrows. However, the directions of the primary and secondary windings are opposite to each other so that the secondary voltage induced is out of phase by 180° relative to the primary voltage.

When the rotor or the annular inner core 2 is rotated through 90° from the position shown in FIG. 3 to the position shown in FIG. 4, intermediate of the positions shown in FIGS. 3 and 5, one half of the secondary winding are opposite in direction to the primary winding whereas the remaining half of the secondary winding are in the same direction with the primary winding. As a result, the output voltages induced are in and out of phase with respect to the primary voltage, and are cancelled by each other, so that the resulting output voltage becomes zero. Same is true in the other secondary winding so that the overall output voltage is zero.

In the positions different from those shown in FIGS. 3, 4 and 5, the output voltage whose magnitude is dependent upon the angle of rotation of the rotor or the annular inner core is induced. That is, the output voltage changes depending upon the angle of rotation of the annular inner core or the rotor as shown below:

angle of rotation of rotor in deg.	Output voltage
0	Maximum and in phase
90	Zero
180	Maximum, but out of phase by 180°

This is more clearly illustrated in FIG. 6*Ca*.

In FIG. 6A, one end of the primary winding P is connected to one end of the secondary winding S so that the other ends of the primary and secondary windings may be used as the output terminals. The primary and secondary windings have the same turns.

In FIG. 3, it is assumed that the primary voltage be 100 volts. Then, the output voltage induced across the secondary winding is additive to the primary voltage applied across the primary winding. That is, the output voltage becomes the sum of the primary and scondary voltages given by $100\ (V) + 100\ (V) = 200\ (V)$.

When the annular inner core or the rotor is rotated through 90° to the position illustrated in FIG. 4, the secondary voltage becomes zero so that the output voltage becomes equal to the primary voltage, that is $100\ (V)$.

When the annular inner core or the rotor is rotated through 180° to the position shown in FIG. **5**, the secondary voltage is deductive relative to the primary voltage. Therefore the output voltage is given by 100 (V) − 100 (V) = 0 (V).

In the manner described above the output voltage may be adjusted between 200 (V) and 0 (V) when the rotor is rotated through an angle between 0° and 180°. This is illustrated in FIG. **6**A*a*, from which it is seen that the output voltage is about 130 (V) at the angle of rotation of 60° and about 70 (V) at the angle of rotation of 120°. Thus, the output voltage may be continuously and infinitesimally.

In FIG. **6**B, the primary winding is shown as being center-tapped so that the secondary voltage becomes one half of the primary voltage. That is, the secondary voltage becomes 50 (V) when the primary voltage is 100 (V). In this connection,

Angle of rotation of rotor in deg.	Output voltage in volt
0°	100
90°	50
180°	0

The relation between the angle of rotation of the rotor and the output voltage is shown in FIG. **6**B*a*.

In the circuit shown in FIG. **6**C, the turns of the secondary winding is equal to those of the primary winding so that the output voltage may be varied over the range from + 100 (V) to − 100 (V) as shown in FIG. **6**C*a*.

It is of course possible to effect various modifications and variations of the connections of the first embodiment described above. One variation shown in FIGS. **6** and **7** is substantially similar in construction to the first embodiment described above except that the coils **8***a* – **8***j* of the main winding P_1 (for example of 100 turns), the coils **8***k* – **8***u* of auxiliary winding P_2 (for example of 100 turns) wound around the annular outer core, and coils **9***a* – **9***j* of the winding S (for example of 50 turns) wound around the annular inner core are mounted in the directions indicated by the arrows respectively. That is, as shown in FIG. **7**, the coils **9***a* – **9***j* and **8***a* – **8***j* extend radially outwardly whereas the coils **8***k* – **8***u* extend radially inwardly so that the main winding P_1 on the annular outer core produces the flux ϕ_5 whereas the auxiliary winding P_2 produces the flux ϕ_6 in the directions indicated by the arrows. These three windings P_1, P_2 and S are connected in series as shown in FIG. **6**D.

When the supply voltage of 100 (V) is applied to the input terminals I_1 and I_2 in FIG. **6**D and when the rotor is located in the position shown in FIG. **7**, the voltage across the main winding P_1 is given by

$$100(V) \times \frac{\text{Turns of the main winding}}{\text{The sum of turns of the main, auxiliary and secondary windings}}$$

that is

$$\phi\ (V) \times 100/100 + 50 + 50 = 50\ (V).$$

In the position shown in FIG. **7**, the voltage per turn is given by 0.5 (V)/T. *Therefore, the voltage across the auxiliary winding P_2* is given by

$$0.5\ (V)/T \times 50\ T = 25\ (V), \text{ and}$$

similarly the voltage across the secondary winding S is given by

$$0.5\ (V)/T \times 50\ T = 25\ (V).$$

As a result, the output voltage between the output terminals O_1 and O_2 is 50 (V).

When the annular inner core is rotated through 180° so that the coils **9***a* – **9***j* are located in opposed relation with the coils **8***k* – **8***u* of the auxiliary winding, the coils **9***a* – **9***j* are directed radially outwardly whereas the coils **8***k* – **8***u* are directed radially inwardly. That is, the polarities of the voltages across the coils are opposite so that the coils 9*a*–9*j* and **8***k*–**8***u* have zero voltage. As a result, the voltage between the terminals I_2 and O_1 in FIG. **6**D becomes zero so that the output voltage between the output terminals O_1 and O_2 becomes zero, whereas the voltage between the terminals I_2 and O_1 is 100 volts. In summary when the annular inner core has rotated through 180°, the voltage between the terminals I_2 and O_1 drops from 50 volts to zero whereas the voltage between the terminals I_1 and O_1 rises from 50 volts to 100 volts. Thus, the voltages may be continuously and infinitesimally varied as the annular inner core rotates over the range between 0° and 180°. In the instant variation, the coils **8***a* – **8***u* are shown as being wound on the annular outer core, but the coils **9***a* – **9***j* may be wound on the annular outer core whereas the coils **8***a* – **8***u* may be wound on the annular inner core.

Next referring to FIGS. **10, 11** and **12**, another variation will be described. In FIG. **10**, the coils of the right winding mounted on the annular outer core or stator are designated by **10***a* – **10***j*; the coils of the left winding on the annular outer core, by **11***a* – **11***j*; and the coils of the winding on the annular inner core or rotor, by **12***a*–**12***j*, respectively.

In FIGS. **11**A and **11**B, one of the primary windings on the annular outer core is connected in series to the secondary winding on the annular inner core, and the output voltage is derived from the junction between the primary and secondary windings. The connection shown in FIG. **11**A illustrates that the rotor is rotated through 180° from the position shown in FIG. **10** for raising the voltage whereas the connection shown in FIG. **11**B is for lowering the voltage. It is of course possible to change the mountings of the primary and secondary windings.

In a still another variation shown in FIGS. **12**A and **12**B, both the primary windings are connected in parallel with the supply voltage source, and the secondary voltage obtained from the secondary winding may be adjusted. It is of course possible to change the mountings of the primary and secondary windings.

When the primary or input voltage of 100 (V) is applied in the connection shown in FIG. **11**B, the output voltage is lowered by the voltage drop across the winding **12.** When the windings **12, 10** and **11** have **30, 130** and **100** turns respectively, the output voltage is given by

$$\text{Output voltage} = 100(V) \times \frac{\text{Turns of winding 10}}{\text{The sum of turns of windings 10 and 12}}$$

$$= 100(V) \times \frac{130T}{130T + 30T} = 81\,(V).$$

Next when the rotor is rotated through 180° from the position shown in FIG. 11B to the position shown in FIG. 11A so that the secondary winding **12** is coupled to the primary winding **11.** In this case, the direction of the secondary winding **12** remains unchanged, but the direction of the primary winding **11** is opposite to that of the primary winding **10.** That is, the winding **11** is oriented radially inwardly whereas the secondary winding is oriented radially outwardly so that the polarity of the voltage induced across the secondary winding is opposite to that of the primary voltage across the primary winding **11.** Therefore, the output voltage is given by output voltage= (input or primary voltage)−(voltage induced across the secondary winding **12**)=voltage across the primary winding **10**, and the voltage across the secondary voltage is given by

$$\text{Voltage across the winding 12} = \frac{\text{Input or primary voltage}}{\text{Turns of winding 11}} \times \text{Turns of winding 12}$$

$$= \frac{100(V)}{100T} \times 30T = 30(V).$$

The polarity of the voltage induced across the secondary winding **12** is clearly opposite to that of the input or primary voltage so that the voltage is given by

$$\text{output voltage} = 100\ (V) - (-30\ V) = 100\ (V) + 30\ (V) = 130\ (V).$$

That is, the input or primary voltage is raised by 30 (V). Thus, in the variation shown in FIGS. **11A** and **11B**, the output voltage may be adjusted over the range from 81 (V) to 130 (V) infinitesimally when the input or primary voltage is 100 (V). Therefore, the variation shown in FIGS. **11A** and **11B** may be used when the constant output voltage of 100 (V) is desired even when the input voltage fluctuates between 130 (V) and 81 (V).

In another variation shown in FIGS. **12A** and **12B**, the connection shown in FIG. **12B** corresponds to the locations of the primary and secondary windings shown in FIG. **10.** Since the polarity of the secondary winding **12** is equal to that of the primary winding **10**, the output voltage is increased by the voltage across the secondary winding **12.** FIG. **12A** illustrates the connection when the annular inner core or rotor has been rotated through 180°. The polarity of the voltage induced in the secondary winding **12** is opposite to that of the voltage across the primary winding **11** so that the output voltage is decreased by the voltage across the secondary winding **12.**

In the variations shown in FIG. **11A** to FIG. **12B**, the primary windings are connected in parallel opposed to the connections shown in FIGS. **3** – **5** where the primary windings are connected in series.

In another variation shown in FIG. **6E**, the output voltage may be adjusted over the range from zero volt to 100 volts. Since the principle of this variation is clear from the description of the various embodiments described above, no detailed description will be made except that two variable induction circuits to be described in more detail with reference to FIG. **13** are coaxially connected in series in such a manner that when the upper circuit has a zero impedance the lower circuit has the maximum impedance; and the output terminal is the junction between these two circuits.

In a still another variation shown in FIG. **14A** to FIG. **14G**, the primary windings P_1 and P_2 are mounted on the annular outer core or stator whereas the secondary windings S_1, S_2, S_3 and S_4 are mounted on the annular inner core or rotor for rotation in unison. It is of course possible to reverse the mountings of the primary and secondary windings so long as the secondary windings $S_1 - S_4$ may rotate in unison. In the instant variation, the rotor rotates from 0° to 90°, but it is obvious to those skilled in the art from the description of the present invention to design the apparatus so that the rotor may rotate through 180°. The instant variation is generally characterized in that the polarities of the voltages induced across the secondary windings $S_1 - S_4$ are different depending upon the angle of rotation of the rotor so that the output voltage may be changed.

In FIGS. **14A** and **14C** the rotor is shown as being located at the initial position, that is the 0° position. The primary winding P_2 and the secondary winding S_4 are so oriented that they have the relation substantially similar to that between the coils **8***a* – **8***j* and the coils **9***a* – **9***j* shown in FIG. **7.** In a similar manner, the primary winding P_1 and the secondary winding S_3 are disposed. The secondary windings S_3 and S_4 on the rotor are in quadrature relation to the secondary windings S_3 and S_4 as shown in FIG. **14A.** When the primary voltage is applied, the fluxes ϕ_5 and ϕ_6 are generated as shown in FIG. **7,** and since the polarities of the primary windings P_1 and P_2 are same with those of the secondary windings S_3 and S_4 respectively, the output voltage is derived from the output terminals. However, as shown in FIG. **14A**, the secondary windings S_1 and S_2 are located in quadrature relation with respect to the primary windings P_1 and P_2, the voltages induced in the one halves of the windings are cancelled by those induced in the other halves. As a result, the voltages across the secondary windings S_1 and S_2 are zero, as shown in FIG. **14C.** Therefore, the output voltage is 100 volts.

FIG. **14B** and FIG. **14E** illustrate the relation among the primary windings and secondary windings when the rotor has been rotated through 90°. It is seen that the secondary windings S_1 and S_2 are inductively coupled to the primary windings P_1 and P_2 respectively so that the voltages are induced across them, whereas the windings S_3 and S_4 are coupled in quadrature relation with the primary windings P_1 and P_2 so that the voltages across the former are zero because of the reason described above. Thus, the output voltage becomes zero as shown in FIG. **14E.** FIG. **14E** shows the connections among the primary and secondary windings when the rotor has been rotated through 45°, and the output voltage becomes 50 volts, intermediate of those obtained in the 0° and 90° positions.

In order to adjust the output voltage between 0 volt and 130 volts, and additional secondary winding S_5 may be inserted as shown in FIG. **14F.**

When the output voltage drops due to the resistances of the windings, additional windings S_5 and S_6 may be inserted as shown in FIG. **14G** so that the voltage of 99 per-cent of the normal voltage may be obtained. Alternatively, the secondary windings are connected in series in the order of S_1, S_2, S_6, S_5, S_3 and S_4 in order to compensate the voltage drop due to the resistances of the windings. The primary windings P_1 and P_2 may be connected in parallel to the input voltage source.

An improvement of the variations shown in FIG. **14A** to FIG. **14G** are illustrated in FIG. **15A** to FIG. **15F** in which the secondary windings S_2 and S_3 are rotated relative to the stationary primary windings P_1 and P_2 in order to adjust the output voltage. The relation in position between the primary and secondary windings is illustrated in FIGS. **15A** and **15D** when the rotor is in the initial or 0° position; in FIGS. **15B** and **15E** when the rotor is rotated through 90°; and in FIGS. **15C** and **15F** when the rotor is rotated through 180°.

When the rotor or the annular inner core is in the initial position or 0° position as shown in FIGS. **15A** and **15D**, the polarity of the secondary winding S_1 is opposite to that of the primary winding P_1 while the polarity of the secondary winding S_2 is same with that of the primary winding P_2. As a result, output voltage is equal to the input voltage which is 100 volts in the instant embodiment. When the rotor is rotated through 90° from the position shown in FIG. **15A** to the position and connection shown in FIGS. **15B** and **15E**, the polarity of the left half of the secondary winding S_1 is opposite to that of the primary winding P_1 whereas the polarity of the right half is same with that of the primary winding P_2. However, polarities of the primary windings P_1 and P_2 are opposite as indicated by + and − signs so that the overall voltage across the secondary winding S_1 becomes zero. Similarly, the voltage across the secondary winding S_2 is also zero. In summary, when the rotor has been rotated through 90°, the voltages across the secondary windings S_1 and S_2 are zero, and the input or primary voltage is applied only across the primary windings P_1 and P_2 so that the output voltage becomes 50 volts.

When the rotor has been rotated through 180° as shown in FIGS. **15C** and **15F**, the relation in position and connection of the windings are reversed with respect to those shown in FIGS. **15A** and **15D**. That is, the polarity of the secondary winding S_2 is opposite to that of the primary winding P_2 whereas the polarity of the secondary winding S_1 is same with that of the primary winding P_1. As a result, that output voltage becomes zero.

In the instant embodiment, the two primary windings are used to generate two fluxes so that the output voltage may be adjusted as the rotor is rotated through 180°, but it is of course possible to use four primary windings so that the output voltage may be adjusted by the rotation of the rotor through 90°.

In the instant embodiment, in practice the load currents flow only through the primary and secondary windings P_1 and S_1 on the left side so that the balance between the left and right windings is lost. In order to overcome this problem, the arrangement of the primary and secondary windings may be appropriately adjusted. For example, one halves of the primary and secondary windings P_1 and S_1 may be located on the right side while one halves of the primary and secondary windings P_2 and S_2 may be located on the left side so that the loss of the balance due to the load current may be prevented.

Next referring to FIG. **16**, the second embodiment of the present invention which is different in construction from the first embodiment will be now described. In the second embodiment, the coils of the primary windings are concentrated together above the annular inner core **2** to form the passages through which the supporting members **19** of the annular inner core **2** may move in the directions indicated by the arrows. That is, the annular inner core **2** may rotate through an angle, indicated by the arrows, 180° in the instant embodiment. It will be obvious to those skilled in the art that the second embodiment may be so arranged that the rotor may rotate through 90°. Alaternatively, the primary windings may be concentrated along the side wall of the center hole **5** in such a manner that the annular inner core or the rotor **2** may rotate.

Next referring back to FIG. **13**, the use of the variable inductor will be described. The first and second windings which correspond to the windings on the annular outer and inner cores respectively are connected in series. When the first and second windings are located as shown in FIG. **3**, their polarities are same so that the maximum inductance may be obtained, but when the rotor is rotated through 180° from the position shown in FIG. **3**, their polarities are opposite as shown in FIG. **5** so that the reactance becomes zero. When the rotor is rotated through 90° as shown in FIG. **4**, the effective turns of the windings are decreased by one half so that the inductance is decreased about to one quater. In a similar manner, the inductance is varied depending upon the angle of rotation of the rotor. Thus, the variable inductor capable of infinitesimally varying its inductance may be provided.

In the above embodiments, the problem of leakage fluxes has not taken into consideration, but as shown in FIG. **17** the fluxes produced by the primary winding or windings and/or by the load current flowing through the secondary winding or windings are bypassed in practice. That is, so far only the flux ϕ_{1a} has been taken into consideration, but in practice various fluxes as indicated by $\phi_{1g}-\phi_{1g}$ are produced. Therefore the flux density is highest in the annular inner core at the portion where the coils **3***m* and **4***m* of the primary and secondary windings are placed, but is decreased gradually at the portions where the coils **3***n*, **4***n*, **3***o*, **4***o*, **3***p*, **4***p*, . . . and **3***z* and **4***z* are placed. To overcome this problem, that is to cause all fluxes to link or thread all windings (uniformly) the present invention provides three novel arrangements as shown in FIGS. **18, 19** and **20.**

Referring first to FIG. **18**, the side surface of the inner core is machined as shown so that the magnetic resistances in the bypaths may be increased in order to cause the maximum magnetic fluxes to pass through all windings. The recessed portions of the inner core are designated by reference numerals **141** and **142**, and the first windings (which may be the primary windings) indicated by the white triangles and the second windings (which may be the secondary windings) indicated by the white dots are placed in the right and left 180° sectors of the outer and inner cores respectively in a manner similar to that of the first embodiment described with reference to FIGS. **3, 4** and **5.** The principle and mode of operation and the connections of the windings are substantially similar to those of the first and second embodiments and variations thereof described hereinbefore. The dimensions of the recessed portions **141** and **142** of the annular inner core are determined in such a manner that the widths **143, 144** and **145** may equal each other. When the width **146** of the flux passage is greater, it is desired to form the deeper recessed portions **141** and **142.** In this arrangement, the electrical characteristics are much enhanced, and the cooling efficiency is increased. In order to minimize the leakage fluxes shown by $\phi_{1b}-\phi_{1z}$ in FIG. **17**, the shortcircuited windings or arcuate electrically conductive members **147** may be placed at the bottoms of the recessed portions **141** and **142.** When the apparatus shown in FIG. **18** is used as a variable voltage regulator, it is advantageous to mount the primary winding or windings on the annular inner core so that the magnetic fluxes ϕ_1 and ϕ_2 may rotate as the annular inner core rotates.

The arrangement shown in FIG. **19** is substantially similar to that shown in FIG. **18** except that the inner side wall of the annular outer core is recessed as indicated by reference numerals **141***a* and **142***a*. When the apparatus shown in FIG. **19** is used as a variable voltage regulator, it is preferable to mount the primary windings on the annular outer core as indicated by the white dots.

In the arrangement shown in FIG. **20**, the rectangular outer core is used. The arrangement is similar in construction to the conventional power transformer except that the leg of the inner core is so arranged as to rotate. The windings are placed in the positions indicated by the black and white dots, and the connections explained hereinbefore may be also used in this arrangement. In the arrangement shown in FIG. **20**, the white dots represent the primary winding whereas the black dots, the secondary winding, and no winding is placed along the axis connecting the poles N and S. This arrangement is most ideal because the number of dead or unnecessary coils may be minimized while the highest efficiency in operation may be attained. In the arrangements shown in FIGS. **18** and **19**, no coils are placed along the axes between the poles N and S.

Four variations are illustrated in the first, second, third and fourth quadrants of FIG. **21.** In the variation shown in the first quadrant, the slots are formed only in the outer core, and only the windings **104** are rotated. In the variation shown in the second quadrant, the outer and inner cores have no slot, and either of the windings **103** or **104** may be rotated. In the variation shown in the third quadrant, only the inner core is provided with slots, and only the windings **103** are rotated. In the variation shown in the fourth quadrant, either or both of the windings **103** and **104** are embedded in the magnetic member, and either of the windings **103** or **104** may be so arranged as to rotate with respect to the other. In this case, not only the torque for rotating the windings may be decreased, but also the starting and stopping of the windings may be made easier. Furthermore, the variation shown in the fourth quadrant has an advantage that the exciting current may be reduced as compared with the variation shown in the second quadrant and provided with no magnetic members.

Next referring to FIGS. **22 – 28,** another embodiment of the present invention will be described. The coil of the windings of the first group **103** is placed in the slots which are diametrically opposed, and then placed in the next slot to be placed in the diametrically opposed slot, and so on. In a similar manner to that described above, the coils **104** of the windings of the second group are placed on the inner core **102.** The first group of windings **103** may be used as the primary windings and the second group of windings **104** may be used as the secondary windings, and vice versa. The outer core **101** may be stationary whereas the inner core **102** may be rotatable, and vice versa. In the instant embodiment, the first windings **103** are the primary windings whereas the second windings **104** are the secondary windings. The inner core **102** is rotatable whereas the outer core **101** is stationary. Therefore, the primary windings **103** on the outer core **101** are stationary whereas the secondary windings **104** on the inner core **102** are rotatable. Reference numeral **105** designates a rotary shaft; and **106** and **107,** slots of the outer and inner cores **101** and **102,** respectively. In FIGS. **23 – 28,** the primary windings **103** are indicated by the bolt lines whereas the secondary windings **104** are designated by the fine lines. FIGS. **23 – 28** are the top views so that the windings **103** and **104** are reversed in direction when viewed from the bottoms of the outer and inner cores **101** and **102.**

In FIGS. **23 – 25,** the outer and inner cores are shown as having **20** slots, but the number of the slots is not limited to **20,** and may be increased or decreased as the needs demand. Moreover, the slots in any shape such as square, rectangular, triangular or circular in cross section may be used as in the case of the embodiments described hereinbefore.

In the embodiment shown in FIGS. **23 – 28,** the inner core or the rotor is so arranged as to rotate through an angle of 180°, and two primary and secondary windings **103** and **104** are placed on the semi-circular sectors of the outer and inner cores respectively. In the instant embodiment of primary and secondary windings **103** and **104** are connected in series, but may be connected in parallel when so required. Furthermore, the number of the primary and secondary windings is not limited to two.

FIGS. **25** and **28** illustrate the positions of the rotor or the inner core having the secondary windings **104** when the rotor is rotated through 180° from the positions shown in FIGS. **23** and **26.** It is seen that the polarities of the secondary windings **104** are opposite to those of the primary windings **103.**

FIGS. **24** and **27** show the positions of the rotor when it is rotated through about 90° from the positions shown in FIGS. **23** and **28** so that the rotors are located in the positions intermediate the positions shown in FIGS. **23** and **28** and the positions shown in FIGS. **25** and **26.** It is seen that the polarities of one halves of the secondary windings are opposite to those of the primary windings.

The instant embodiment will be described with reference to FIGS. **26, 27** and **28** hereinafter because the arrangements of the windings shown in FIGS. **23, 24** and **25** are rather complex. Now referring to FIG. **26,** when the primary AC voltage is applied to the primary windings **104,** two fluxes ϕ_1 and ϕ_2 are produced at some instant in the directions indicated by the arrows in the outer core **101.** The two fluxes link the secondary windings **104***a* and **104***b* so that the secondary voltage in phase with the primary voltage is induced in each of the secondary windings **104***a* and **104***b*. That is, the primary windings **103***a* and **103***b* coincide with the secondary windings **104***a* and **104***b* with the same polarity so that the secondary voltages in phase with the primary voltage are induced in the secondary windings **104***a* and **104***b*. Next when the inner core or the rotor **102** having the secondary windings **104***a* and **104***b* is rotated from the position shown in FIG. **26** through 90° to the position shown in FIG. **27,** the directions of the fluxes ϕ_1 and ϕ_2 remain unchanged because the primary windings **103***a* and **103***b* placed on the outer core **101** remain unchanged in position. Since the rotor **102** has been rotated through 90° with respect to the stator or the outer core **101,** the secondary winding **104***a* coincides with the primary winding **103***b* with the same polarity whereas the secondary winding **104***b* coincides with the primary winding **103***a* with the opposite polarity. Therefore, the secondary voltage in phase with the primary voltage is induced in the secondary winding **104***a* whereas the secondary voltage out of phase by 180° with the primary voltage is induced in the secondary winding **104***b*. As a result, these induced secondary voltages cancel each other so that the output voltage becomes zero.

When the rotor or the inner core **102** is rotated through 180° to the position shown in FIG. **28,** the secondary windings **104***a* and **104***b* coincide with the primary windings **103***a* and **103***b* respectively but with the opposite polarity. Therefore, the voltages out of phase by 180° with the primary voltage are induced in the secondary windings **104***a* and **104***b*. That is, the output voltage is out of phase by 180° with respect to the primary or input voltage. The relation between the angle of rotation of the rotor and the induced output voltage may be summarized as follows:

	Angle of rotation of rotor in deg.	Output voltage
FIG. 26	0	positive voltage in phase with primary or input voltage
FIG. 27	90	zero voltage
FIG. 28	180	negative voltage out of phase by 180° with the input voltage

The arrangements of the slots described hereinbefore with reference to FIGS. **8** and **9** may be also applied to the embodiment described with reference to FIGS. **22 – 28.**

In FIGS. **23, 24** and **25,** the positions of the secondary windings **104** denoted by the fine lines with the black and white arrows with respect to the primary windings **103** placed on the outer core **101** are illustrated. As the rotor **102** rotates, the output voltage can be regulated in a manner similar to that described with reference to FIGS. **26, 27** and **18.** The relation between the angle of rotation of the rotor and the output voltage may be summarized as follows:

	Angle of rotation of rotor in deg.	Output voltage
FIG. 23	0	positive voltage in phase with the input voltage
FIG. 24	90	zero voltage
FIG. 25	180	negative voltage out of phase by 180° with the input voltage

The above relation may be clearly seen from the graph shown in FIG. **6C***a*, and the connection is shown in FIG. **6C**. That is, the primary windings and the secondary windings are all connected in series, and have the same turns so that the output voltage may be varied over the range from + 100 (*V*) to – 100 (*V*) as shown in FIG. **6C***a*. According to the present embodiment only one apparatus is used to derive the secondary voltage from the circuit electrically isolated from the supply circuit so that the advantages hitherto unobtainable by the conventional slide voltage regulators may be provided.

In order to provide an economical type, the connection of the autotransformer as shown in FIG. **6B** may be used. One end of the secondary winding S is connected to the center tap of the primary winding P, and the output is derived from the other end of the secondary winding S. When the arrangement is made in such a manner that the secondary voltage equal to one half of the input voltage having the maximum voltage of for example 100 volts may be induced, the relation between the angle of rotation of the rotor and the output voltage may be summarized as follows:

Angle of rotation of rotor in deg.	Output voltage
0	100 volts
90	50 volts
180	0 volt

The above relation is illustrated in FIG. **6B***a*.

When the connection of the autotransformer is used to raise the input voltage, the connection shown in FIG. **6A** may be used. One end of the secondary winding S is connected to one end of the primary winding P, and the other ends of the primary and secondary windings P and S are used as the output terminals. The primary and secondary windings P and S are shown as having the same turns. When the rotor is at 0° position or initial position and when the input voltage is 100 volts, the secondary voltage induced across the secondary winding S is additive to the input voltage applied across the primary winding P so that the output voltage becomes the sum of the voltages across the primary and secondary windings. That is, the output voltage is given by

$$\text{output voltage} = 100\ (V) + 100\ (V) = 200\ (V).$$

When the rotor is rotated through 90° as shown in FIG. **24,** the voltage induced across the secondary winding becomes zero so that the output voltage equals the input voltage. That is, the output voltage is 100 volts.

When the rotor is rotated through 180° as shown in FIG. **25,** the polarity of the voltage induced across the secondary winding is opposite to that of the input voltage applied across the primary winding so that the output voltage is given by

$$\text{output voltage} = 100\ (V) - 100\ (V) = 0\ (V)$$

Thus, as the rotor rotates through the range between 0° and 180°, the output voltage may be regulated between 200 volts and zero volt as shown in FIG. **6A**a. From this figure, it is seen that the output voltages are 130 and 70 volts respectively when the angles of rotation of the rotor are 60° and 120°. Thus, the output voltage may be continuously and infinitesimally regulated.

In principle, the output voltage varies linearly as shown in FIGS. **6A***a*, **6B***a* and **6C***a*. Referring back to FIG. **23,** when the rotor and hence the secondary windings are rotated through the angle given by

(Angle of rotation of rotor)/(a number of slots located within the angle of rotation) = 180°/10 = 18°, the polarities of a pair of coils of the secondary winding are opposite to those of the corresponding coils of the primary winding. That is, when there are ten pairs of coils and when the input voltage is 100 volts, the output voltage changes by 100 (*V*)/10 = 10 (*V*) when the rotor rotates through 18°. In other words, the angle of rotation of the rotor is in proportion to the lowered voltage.

Next referring to FIG. **29A** to FIG. **29O**, variations of the embodiment described above with reference to FIGS. **22 – 28** will be described. The variations to be described are similar in construction of the outer and inner cores to the embodiment described with reference to FIG. **22** so that only the arrangements of the windings will be described. So far the inner core has been shown as being disposed within the outer core in FIGS. **23 – 28,** but for the sake of simplicity in the description of the variations the arrangements of the inner core and the secondary windings are illustrated in FIGS. 29B – 29G separately from the arrangement of the outer core and its windings shown in FIG. 29A. It should be also noted that in FIGS. 29B – 29G the inner core is designated by the dot at the center and that the outer core is stationary whereas the inner core is rotatable. However, the present invention will not be limited to this arrangement, but the outer core may be so arranged as to rotate with respect to the inner core. Alternatively both the outer and inner cores may be so arranged as to rotate with respect to each other. In summary, any arrangement which permits the relative rotation between the outer and inner cores may be employed. In FIG. 29A to FIG. 29G, the windings on the outer core are shown as the primary windings, but the windings on the inner core may be used as the primary windings. In this case, it should be noted that the magnetic fluxes ϕ_1 and ϕ_2 rotate as the inner core rotate. In the instant variations the windings placed in the slots of the outer core or stator are the primary windings so that the magnetic fluxes will not rotate even when the inner core rotates.

FIGS. 29B, 29C and 29D are views used for explanation of the arrangement of the secondary winding S_1 and the positions thereof when the rotor is rotated, and FIGS. 29E, 29F, and 29G are the views used for explanation of the arrangement of the secondary winding S_2 and the positions thereof when the rotor is rotated. That is, FIGS. 29B and 29E illustrate the secondary windings in the initial or 0° positions; FIGS. 29C and 29F, the secondary windings in the positions rotated through 45° from the positions shown in FIGS. 29B and 29E; and FIGS. 29D and 29G, the secondary windings in the positions rotated through 90° from the positions shown in FIGS. 29B and 29E. It should be noted that in practice both secondary windings S_1 and S_2 are placed in the same slots of the rotor as shown in FIGS. 29B – 29G, but for the sake of simplicity they are separately shown as described above. More particularly the secondary windings S_1 and S_2 are placed in quadrature relation with respect to each other, and have the same turns in the instant variation.

The connections of and voltages across the primary and secondary windings when the rotor is in the initial or 0°, 45° and 90° positions are illustrated in FIGS. 29H, 29I, and 29J, respectively. The primary windings is connected to the supply circuit, and the secondary windings are connected in series. The output voltage is derived from the junction between the secondary windings. It is of course possible to connect the coils of the primary winding placed in the slots in parallel to the supply circuit.

Next the mode of operation of the variation with the above construction will be explained. It is assumed that the primary and secondary windings have 100 turns. In the initial position or 0° position the polarities of the secondary winding S_1 are same with those of the primary winding P so that the induced voltage is 100 volts. However, the fluxes ϕ_1 and ϕ_2 link the secondary winding S_2 in the opposite directions as shown in FIG. 29E so that the induced voltages are cancelled by each other. As a result, the voltage induced across the secondary winding S_2 is zero. This condition is similar to those shown in FIGS. 24 and 27. In summary, as shown in FIG. 29H, the voltage across the secondary winding S_1 is 100 volts, that across the secondary winding S_2, 0 volt; and the output voltage is 100 volts.

When the secondary windings are rotated as shown in FIGS. 29C and 29F through 45°, the fluxes ϕ_1 and ϕ_2 link the coils S_{1a} and S_{1b} and the coils S_{1c} and S_{1d} in the opposite directions so that the voltages induced are cancelled. That is, the voltage induced in these four coils is zero. Therefore, the voltage induced in the coils $S_{1e}-S_{1h}$ becomes 50 volts. In a similar manner the voltage induced across the secondary winding S_2 shown in FIG. 29F becomes 50 volts. Therefore, the output voltage becomes 50 volts as shown in FIG. 29I.

When the rotor has been rotated through 90°, the fluxes ϕ_1 and ϕ_2 link the halves of the secondary winding S_1 in opposite directions respectively as shown in FIG. 29D so that the voltage induced across the secondary winding S_1 becomes zero. On the other hand, the fluxes ϕ_1 and ϕ_2 link the secondary winding S_2 in the same direction as shown in FIG. 29G, the secondary voltage induced across the secondary winding S_2 becomes in phase of the input voltage and is 100 volts. Therefore the output voltage becomes zero as shown in FIG. 29J.

So far the mode of operation at the three positions, 0°, 45° and 90° positions have been described, but it is seen that the output voltage depending upon the angle of rotation of the rotor may be obtained. The variation in output voltage in response to the rotation of the rotor is linear, which is very advantageous in practice.

In another variation, the slots of the rotor are so divided that the secondary windings S_1 and S_2 may be placed as shown in FIG. 29K. This arrangement serves to simplify the manufacturing process, and can attain the same effects.

Next referring to FIGS. 29L – 29O, the variations in the connections of the windings will be described. In the connection shown in FIG. 29L, the series-connected secondary windings S_1 and S_2 are connected to suitable points of the primary winding P. This connection is economically advantageous in that only the secondary windings S_1 S_2 for obtaining a desired voltage-variation range are required. For example, when the series-connected secondary windings S_1 and S_2 are connected to the 70 (*V*) and 30 (*V*) taps of the primary winding P, the precise voltage regulation over the range from 70 volts and 30 volts may be attained in a very economical way.

In the connection shown in FIG. 29M, the series-connected secondary windings S_1 and S_2 are connected to the 130 volt tap and 70 volt tap of the primary winding P so that the voltage regulation over the range from 130 to 70 volts may be attained with a higher degree of accuracy. This connection is also advantageous in that even when the supply circuit voltage drops to 77 volts, the output of 100 volts may be secured, and even when the supply circuit voltage is raised to 143 volts, the output voltage of 100 volts may be securely obtained. The supply circuit may be connected to the input terminals so that the constant output voltage of 100 volts may be obtained even when the input voltage varies over the range between 70 volts and 130 volts.

In the autotransformer connection shown in FIG. 29N, the output voltage may be varied over the range between 100 volts and 150 volts.

In many cases, it is desired to obtain the output voltage of 100 volts from the input voltage of 100 volts, but due to the voltage drop across the secondary winding S_2, the output voltage of 100 volts cannot be obtained in practice. To overcome this problem, the connection shown in FIG. 29O is provided in which an additional winding S_3 is disposed together with the secondary winding S_1 in order to compensate the voltage drop. Since the additional winding S_3 is so coupled to the winding S_1 as shown in FIG. 29O, when the voltage is lowered, the voltage across the winding S_3 becomes zero when the secondary voltage across the secondary winding S_1 is zero as in the case of the connection shown in FIG. 29J. Thus, the voltage may be compensated over the range from 100 volts to zero volt when loaded.

So far the voltages are induced across both the secondary windings S_1 and S_2, but either of them may be eliminated. However, the use of the two secondary windings has the advantage over the use of the single secondary winding in that the output voltage is well stabilized by the voltages induced across the two secondary windings.

Next referring to FIGS. 30A to 30N, some further variations will be described. In FIGS. 30A to 30G, the outer and inner cores and their associated windings are separately illustrated as in FIGS. 29A to 29K. These variations to be described are similar in construction to the embodiment described with reference to FIGS. 22 and 23.

FIGS. 30A and 30N illustrate the outer cores, and FIG. 30A illustrates the primary winding P_1 whereas FIG. 30N, the primary winding P_2 which are oriented in the direction same with that of the primary winding P_1. However, they may be wound in the opposite direction when the connections shown in FIGS. 30H, 30I and 30J are changed accordingly. The secondary winding S_1 is illustrated in FIGS. 30B, 30C and 30D while the secondary winding S_2, in FIGS. 30E, 30F and 30G. As shown in FIGS. 30B and 30E, the directions of the secondary windings S_1 and S_2 are opposite, but they may be wound in the same direction.

The connections of the windings are shown in FIGS. 30H to 30M. In FIGS. 30H, 30I and 30J, the polarities of the voltages across the windings are denoted by + and − signs so that the polarity relation between the coupled windings may be clearly understood. In the connections shown in FIGS. 30K, 30L and 30M, the voltages across the windings when the input voltage is 100 volts are shown.

The mode of operation will be described under the assumption that the winding P_1, P_2, S_1 and S_2 have substantially the same impedance, but they may have different impedances when required. The primary windings P_1 and P_2 are stationary whereas the secondary windings S_1 and S_2 are rotated. The intitial positions of the secondary windings S_1 and S_2 are shown in FIGS. 30B and 30E, and in FIGS. 30H and 30K. The positions of the secondary windings when rotated through 90° are shown in FIGS. 30C and 30F and in FIGS. 30I and 30L. The positions when they rotated through 180° are shown in FIGS. 30D and 30G and in FIGS. 30J and 30M.

When the windings are arranged as shown in FIGS. 30B and 30E and are connected as shown in FIGS. 30H and 30K, the polarities of the voltage induced across the secondary winding S_1 are opposite to those of the voltage applied across the primary winding P_1 whereas the polarities of the voltage induced across the secondary winding S_2 are same with those of the voltage across the primary winding P_2 so that the output voltage becomes 100 volts. When the windings are rotated through 90° as shown in FIGS. 30C and 30F and are connected as shown in FIGS. 30I and 30L, the voltage induced in the right half of the secondary winding S_1 is in phase with the voltage across the primary windings P_1 and P_2 whereas the voltage induced across the left half is in phase opposite to the voltage across the primary windings P_1 and P_2. Accordingly as indicated by the + and − signs, the overall voltage induced across the secondary winding S_1 becomes zero. In a similar manner, the voltage induced across the secondary winding S_2 becomes zero. In short, when the rotor rotates through 90°, the voltage induced in both secondary windings S_1 and S_2 are zero. As a result, the supply circuit voltage is applied across the primary windings P_1 and P_2 at that the output voltage or the voltage derived from the center tap of the series connected windings become 50 volts.

When the windings are rotated through 180° as shown in FIGS. 30D and 30G and are connected as shown in FIGS. 30J and 30M, the condition is opposite to that when the rotor is in the initial position (See FIGS. 30B, 30E, 30H and 30K). That is, the voltage induced across the secondary winding S_2 has the polarities opposite to that of the voltage across the primary winding P_2 whereas the polarities of the voltage induced across the secondary winding S_1 are same with those of the voltage across the primary winding P_1. As a result, the sum of the voltages across the secondary and primary windings S_2 and P_2 becomes zero so that the output voltage becomes zero.

in the variation described so far, the two primary windings are used to produce two fluxes, and the output voltage is controlled by the rotation of the rotor through 180°, but it is obvious to those skilled in the art from the above description that four primary windings may be used to produce four fluxes so that the voltage regulation may be effected by the rotation of the rotor through 90°.

Next the use of the apparatus in accordance with the present invention as a variable inductor will be described. Referring back to FIGS. 6A, 23, 24 and 25, the input terminal I_2 and the output terminal O_1 are used. When the rotor is in the initial position or 0° position, the polarities of the primary windings are same with those of the secondary winding S as shown in FIGS. 23 so that the maximum inductance may be obtained. When the rotor is rotated through 90° as shown in FIG. 24, the impedances of the halves of the secondary winding 104 are cancelled by each other so that the impedance of the winding 104 need not be taken into consideration. As a result, only the impedance of the winding 103 may be taken into consideration. That is, the number of turns of the windings may be considered to be one half of that of the windings shown in FIG. 28 so that the inductance drops to about one quarter. When the rotor is rotated through 180° as shown in FIG. 25, the polarities of the windings 103 and 104 are opposite so that the sum of the turns of the windings when viewed into the circuit from the terminals I_2 and O_1 in FIG. 6A becomes zero. As a result, the inductance becomes zero. Thus, the impedance may be varied from the maximum to the minimum or vice versa by rotating the rotor of the apparatus of the present invention.

Next some variations of the outer and inner cores of the apparatus of the present invention will be described. Referring to FIG. 31 illustrating again the construction of the apparatus described so far, the fluxes produced by the primary windings and by the load currents flowing through the secondary windings will not pass through all of the coils of the windings in practice and will tend to produce the shortest magnetic paths. That is, so far the magnetic flux has been limited to one denoted by ϕ_{1a}, but in practice other fluxes such as ϕ_{1b}, ϕ_{1c}, . . . , and ϕ_{1z} are produced so that the magnetic flux density becomes greatest in the inner core **2** in the proximity of the primary coil *3m* and the secondary coil *4m* and is gradually decreased in the proximity of the primary and secondary winding coils *3n*, *4n*, *3o*, *4o*, *3p*, *4p*, . . . and *3z* and *4z*. Therefore, the present invention has provided some countermeasures which were described in reference to FIGS. **18 – 21** in order to cause as much fluxes as possible to pass through all the coils of the windings.

Next a still another embodiment of the present invention will be described with reference to FIGS. **32, 33, 34, 35, 36** and **22.** As shown in FIG. 32.

A first group of windings **203** is placed in the slots of an annular outer core **201** symmetrically about a line (the chain line in FIG. 32) passing through the center of the outer core and also about a line passing through the center at a right angle relative to the chain line. It is seen that in the upper and lower sector of the top of the outer core the coils of the first group of windings **203** are disposed to diverge from an converge toward the portions in the proximity of the center of the outer core at the same angles relative to the vertical center line (the chain line). A second group of windings **204** is also placed in the slots of an annular inner core **202** in a manner substantially similar to that of the first group of windings **203** on the outer core **201.**

The first group of the windings **203** may be used as the primary windings whereas the second group of windings **204** may be used as the secondary windings, or vice versa. The outer core **201** may be so arranged as to be stationary whereas the inner core **202** may be rotatable, or vice versa. In the instant embodiment, the first windings **203** are used as the primary windings whereas the second windings **204** are used as the secondary windings. The inner core **202** is rotated with respect to the outer core **201** which is stationary. Therefore, the primary windings **203** are stationary whereas the secondary windings **204** are rotated in unison with the inner core **202.** In the figure, reference numeral **205** designates a rotary shaft; and **206** and **207**, the slots of the outer and inner cores **201** and **202** respectively.

In FIGS. **32** to **36,** the windings are wound in the directions indicated by the arrows, and the primary windings are denoted by the bold lines whereas the secondary lines, by fine lines. FIGS. **32** to **36** are top views so that when viewed from the bottom, the directions of the windings are opposite to those shown in FIGS. **32** to **36.**

In FIGS. **32** to **36,** the outer and inner cores are shown as having **20** slots, but the present invention is not limited to the number of **20** slots. The number of slots may be increased or decreased as the needs demand, and the slots of any shape such as square, triangular or circular in shape may be used as in the case of the preceding embodiments.

In the embodiments shown in FIGS. **32** to **36,** the rotor may rotate through an angle of 180°, and two pairs of windings are so disposed that two fluxes ϕ_1 and ϕ_2 are produced symmetrically about a diameter of the outer core. That is, as described above, the pairs of the primary and secondary windings are placed symmetrically about the two center lines at right angles relative to each other, and are wound in the same directions in the semicircular sectors of the annular outer and inner cores. More particularly, the coil **203***a* placed in the slot of the annular outer core **201** is symmetrical about the vertical center line (the chain line in FIG. 32) with respect to the coil **203***j* placed also in the slot of the annular outer core. Similarly the coil **204**a placed in the slot of the annular inner core **202** is symmetrical about the vertical center line with respect to the coil **204***j* placed in the slot of the inner core.

In FIGS. **32, 33** and **34,** the portions in the proximity of the shaft **205** of the inner core **202** are not shown because these portions are very complex, but the windings may be centered around the shaft as shown in FIGS. **35** and **36.** That is, in the embodiment shown in FIG. **35,** the portions of the windings in the proximity of the rotary shaft **205** are so arranged not to extend through the shaft. In the figure the primary windings are not shown, and only the secondary windings are shown, but the primary windings may e placed around the secondary windings in a similar manner. In FIG. **36,** only the upper halves of the secondary windings are shown, but the lower halves may be located in a similar manner.

In order to prevent the height of the groups of the windings centered around the rotary shaft from becoming too high, the inner core is provided with upper and lower recesses formed in the proximity of the rotary shaft as shown in FIG. 38 so that the windings may be disposed within these recesses. Alternatively the diameter of the center hole of the inner core may be increased so that the windings centered around the shaft may be disposed in the enlarged center hole.

FIG. **37** shows the formed coil of the winding, and reference numerals **204***e*, **204***f*, **204***b* and **204***i* correspond to those used in FIGS. 32 to **36.** The arrows indicate the direction of the coil.

Next the principle of operation of the apparatus in accordance with the present invention will be described with refenece to FIGS. **32, 33, 34** and FIGS. **6C** and **6C***a*. FIG. **32** shows the initial position or 0° position; FIG. **33,** the position rotated through 90°; FIG. **34,** the position rotated through 180°; and FIG. **6** shows the connections of the windings and the relations between the angle of rotation of the rotor and the output voltage. In the instant embodiment, both the primary and secondary windings are connected in parallel but in practice they may be partly connected in series as in the preceding embodiments.

FIG. **32** shows the initial position or 0° position, and the primary windings denoted by the large arrows and the secondary windings denoted by the small arrows are all oriented in the same direction. Therefore, the voltages induced across the secondary windings are in phase with the supply circuit voltage or input voltage. That is, the maximum output voltage in phase with the input voltage is obtained as shown in FIG. **6C***a*.

When the inner core or rotor is rotated through 90° to the position shown in FIG. 33, the magnetic fluxes ϕ_1 and ϕ_2 produced by the primary windings remain unchanged as in the case of FIG. 32 because the primary windings are stationary, but the directions of one halves of the coils of the secondary windings indicated by the small arrows are opposite to those of the primary windings indicated by the large arrows. This means that one half of each of the secondary windings is inductively positively coupled to the primary winding whereas the other half, inductively negatively coupled. As a result, the voltage induced across the secondary winding becomes zero. Similarly, the voltage induced across the other secondary winding is also zero. Therefore, when the rotor is rotated through 90°, the overall secondary voltage becomes zero as shown in FIG. **6C***a*.

When the rotor is rotated through 180° from the initial position to the position shown in FIG. **34**, the directions of the seondary windings indicated by the small arrows are opposite to those of the primary windings indicated by the large arrows so that the voltages induced across the secondary windings are out of phase by 180° with respect to the input voltage and are maximum as shown in FIG. **6C***a*. Thus, when the rotor is rotated through the angle 0°, 90° and 180°, the output voltage becomes maximum in phase with the input voltage, zero, and maximum out of phase by 180° with the input voltage. So far the output voltages at three positions have been described, but depending upon the angle of rotation of the rotor, the output voltage may be suitably regulated.

In the connection of the windings described above, the secondary voltage may be derived by one apparatus in which the secondary windings are electrically isolated from the supply circuit so that the features hitherto unattainable by the conventional step voltage regulators may be attained.

In order to provide an economical type, the autotransformer type connection shown in FIG. **6B** may be used. That is, the one end of the secondary winding is connected to the center tap or 50 volt tap of the primary winding P so that when the input voltage of 100 volts is applied to the latter, the secondary windings S may have the voltage of 50 volts. The other end of the secondary winding S is used to derive the output voltage. When the rotor is in the initial or 0° position, the output voltage becomes the sum of the voltage across the secondary winding S and 50 volts of the primary winding, that is 100 volts. When the rotor is rotated through 90°, the output voltage is 50 volts because the voltage across the secondary winding S is zero because of the reasons explained above. When the rotor is rotated through 180°, the voltage across the secondary winding S is 50 volts but is out of phase by 180°. Therefore, the voltages of the primary and secondary windings are cancelled by each other so that the output voltage becomes zero. Thus the output voltage may be varied infinitesimally from 100 volts to zero volt.

When the autotransformer type connection is used to raise the voltage, the connection shown in FIG. **6** may be used. As shown in FIG. **6A***a*, the output voltage may be controlled over the range from 200 volts to zero volt. The variation in output voltage is similar to that described with reference to FIGS. **23, 24** and **25** so that no detailed description will be made.

In the instant embodiment which has been described with reference to FIGS. **32, 33** and **34**, the arrangements of the slots of the outer and inner cores described with reference to FIGS. **8** and **9** may be applied.

So far the fundamental connections of the windings in accordance with the present embodiment have been described, but various modifications and variations may be effected by those skilled in the art based upon the underlying principle of the present invention.

Next a still another variation will be described with reference to FIGS. **39A** to **39O** and **22** (the latter illustrating the construction of the apparatus). Since the outer and inner cores of the instant variation are similar in construction to those described with reference to FIG. **22,** only the arrangement of the windings will be described. In FIG. **39A** to **39Q**, for the sake of simplicity the windings associated with the outer and inner cores are illustrated separately, and the rotary shaft of the inner core is denoted by the dot at the center of the inner core. The outer core is stationary while the inner core rotates with respect to the outer core, but the outer core may be rotatable while the inner core may be stationary when so required. That is, any arrangement may be employed so long as the outer and inner cores are rotated relative to each other. In the instant variation, the windings placed on the outer core and used as the primary windings, but the windings on the inner core may be used also as the primary windings when so required. In the latter case, the magnetic fluxes ϕ_1 and ϕ_2 rotate as the inner core rotates. In FIGS. **39A** – **39G**, the primary windings placed in the slots of the outer core produce the fluxes ϕ_1 and ϕ_2 which will not rotate even when the inner core rotates, so that the directions of the fluxes ϕ_1 and ϕ_2 remain unchanged as shown in FIG. **39A** even when the secondary windings on the rotor rotate relative to the primary indings as shown in FIGS. **39B** – **39G**. FIGS. **39B, 39C** and **39D** are the views used for explanation of the secondary winding S_2 and the positions thereof when rotated. FIGS. **39E, 39F** and **39G** are the views used for explanation of the secondary winding S_1 and the positions thereof when rotated. That is, FIGS. **39B** and **39E** show the initial or 0° positions of the secondary windings S_1 and S_2; FIGS. **39C** and **39F**, the 45° positions; and FIGS. **39D** and **39G**, the 90° positions. In practice the secondary windings S_1 and S_2 are placed in the same slots, but for the sake of simplicity they are separately illustrated in FIG. **39.** The secondary windings S_1 and S_2 are disposed in quadrature relation with each other and have the same turns. The connection of the windings and the voltages across the windings when the rotor is at the 0°, 45° and 90° positions are illustrated in FIGS. **39H, 39I** and **39J** respectively. The primary winding P is connected to the supply circuit, and the secondary windings S_1 and S_2 are connected in series and the output voltage is derived from the junction between the secondary windings S_1 and S_2. The coils of the primary winding P placed in the slots may be connected in parallel to the supply circuit.

In the instant variation, the primary and secondary windings P, S_1 and S_2 have 100 turns respectively.

In the position shown in FIG. **39E**, the voltage induced across the secondary winding S_1 has the same polarities with those of the primary winding P so that the voltage across the secondary winding S_1 is 100 volts. In the position shown in FIG. **39B**, the voltages induced across one half of the coils of the secondary winding S_2 have the polarities opposite to those of the voltage induces across the other half of the coils of the secondary winding S_2. Therefore, these voltages having the opposite polarities cancel each other so that the induced voltage across the secondary winding S_2 becomes zero as in the case of the winding shown in FIG. **33.** Thereofre, the voltage across the winding S_2

is zero; that across the winding S_1 is 100 volts; and the output voltage is 100 volts as shown in FIG. **39H**.

When the rotor has been rotated through 45°, the secondary windings S_1 and S_2 are brought to the positions shown in FIGS. **39C** and **39F**. As shown in FIG. **39C**, the voltages induced across the coils S_{2c} and S_{2d} have the polarities opposite to those of the voltages induced across the coils S_{2e} and S_{2f} so that these voltages cancel each other. As a result, the overall voltage induced across these four coils becomes zero. On the other hand, the voltage induced across the coils S_{2a}, S_{2b}, S_{2g} and S_{2h} is 50 volts as shown in FIG. **39I**. Therefore, the output voltage is 50 volts.

When the rotor has been rotated through 90° so that the secondary windings S_1 and S_2 are brought to the positions shown in FIGS. **39G** and **39D**, the voltage induced across the secondary winding S_1 becomes zero because the fluxes ϕ_1 and ϕ_2 link the secondary winding as shown in FIG. **39G** whereas the voltage induced across the secondary winding S_2 becomes 100 volts because the fluxes ϕ_1 and ϕ_2 link the secondary winding as shown in FIG. **39D**. The voltage across the secondary winding S_2 is in phase with the supply circuit voltage or input voltage. As a result, the output voltage becomes zero as shown in FIG. **39J**. So far the output voltages when the rotor rotates through 0°, 45° and 90° have been described, but the output voltage may be varied depending upon the angle of rotation of the rotor based upon the principle described hereinbefore. The variation in output voltage is linear, which is very advantageous in practice.

When the secondary windings S_1 and S_2 are placed in the slots of the inner core as shown in FIGS. **39K**, **39P** and **39Q** manufacturing process may be much simplified as compared with the arrangement shown in FIGS. **39A** – **39G**. FIG. **39K** illustrating the 0° position of the secondary windings corresponds to FIG. **39H**; FIG. **39P** illustrating the 45° position, to FIG. **39I**; and FIG. **39Q** illustrating the 90° position, to FIG. **39J**.

Next a still another connection will be described with reference to FIG. **39L**. The ends of the series-connected secondary windings S_1 and S_2 are connected to for example the 70 volt and 30 volt taps of the primary winding P. This arrangement is advantageous because only the secondary windings S_1 and S_2 for obtaining a desired voltage variation are required. That is, the output voltage variation over the range between 70 volts and 30 volts may be attained by the rotation of the rotor with a greater degree of accuracy.

In the connection shown in FIG. **39M**, the ends of the series connected secondary windings S_1 and S_2 are connected to for example the 130 volt and 70 volt taps of the primary winding P so that the output voltage may be varied over the range from 130 volts to 70 volts. Furthermore, by a suitable change in design, the constant output voltage of 100 volts may be secured even when the input voltage drops to 77 volts. Moreover, even when the input voltage rises to 143 volts, the output voltage may be secured at 100 volts. It is also possible to connect the output terminals to the supply circuit so that the constant output voltage of 100 volts may be derived across the primary winding even when the supply circuit voltage varies over the range between 70 volts and 130 volts.

In case of the autotransformer connection shown in FIG. **39N**, the output voltage may be controlled over the range from 100 volts to 150 volts.

In many cases in practice it is desired to obtain the output of 100 volts from the input voltage of 100 volts, but due to the voltage drop across the secondary winding S_2, it is difficult to obtain the output voltage of 100 volts. The greater the load current, the greater the voltage drop across the secondary winding S_2. As a result, the output voltage drops. In order to overcome this problem, in the connection shown in FIG. **39O**, an additional winding S_3 is provided and coupled to the secondary winding S_1 so that the voltage drop may be compensated. Since the additional winding S_3 is coupled to the secondary winding S_1, when the voltage across the winding S_1 becomes zero, the voltage across the winding S_3 becomes also zero as shown in FIG. 39J. Thus, the output voltage variation over the range from 100 volts to zero volt may be well compensated when loaded.

In the above variations, the two secondary windings S_1 and S_2 are used, but it is also possible to obtain a variable output voltage from only one secondary winding. However, the use of the two secondary windings is advantageous because the output voltage may be well stabilized by the voltages induced across the two secondary windings.

A still another embodiment of the present invention will be described wtih reference to FIG. **40** in which the outer and inner cores and their ssociated windings are separately illustrated for the sake of simplicity. The instant embodiment is substantially similar in construction of the outer and inner cores to that shown in FIG. **22**.

The polarities of the winding voltage of the primary winding P_1 placed upon the outer core shown in FIG. **40A** are opposite to those of the winding voltage of the primary winding P_2 shown in FIG. **40N**. However, if required, they may be wound in the opposite direction, and the connections shown in FIGS. **40H**, **40I** and **40J** are modified. Moreover, it is possible to wind the primary windings P_1 and P_2 in the upper and lower sectors of the outer core respectively. The two secondary windings S_1 and S_2 are illustrated in FIGS. **40B**, **40C** and **40D** and FIGS. **40E**, **40F** and **40G** respectively. The secondary windings S_1 and S_2 are so arranged that the polarities of the voltages induced across the secondary windings are opposite to each other, but the secondary windings S_1 and S_2 may be wound in the same direction, and the connection may be modifed accordingly.

The connections of the windings are illustrated in FIGS. **40H**, **40I** and **40J** and in FIGS. **40K**, **40L** and **40M** respectively. In FIGS. **40H**, **40I** and **40J**, the polarities of the winding voltages are indicated by + and – signs in order to clearly illustrate the couplings between the primary and secondary windings. In FIGS. **40K**, **40L** and **40M** the windings voltages are given when the input voltage is 100 volts. In the instant embodiment, the windings P_1, P_2, S_1 and S_2 have the same impedance, but may have different impedances when so required. The primary windings P_1 and P_2 are stationary whereas the secondary windings S_1 and S_2 are rotatable. The positions and connections of the secondary windings when they are in the initial positions are illustrated in FIGS. **40B**, **40E**, **40H** and **40K**; the positions and connections when they are rotated through 90° are illustrated in FIGS. **40C**, **40F**, **40I** and **40L**; and the positions and connections when they are rotated through 180° are illustrated in FIGS. **40D**, **40G**, **40J** and **40M**.

When the secondary windings are located in the positions shown in FIGS. 40B and 40E and are connected as shown in FIGS. 40H and 40K, the polarities of the voltage induced across the secondary winding S_1 are opposite to those of the winding voltage of the primary windings P_1 and P_2 whereas the polarities of the voltage induced across the secondary winding S_2 are same with those of the winding voltage of the primary windings P_1 and P_2. Therefore, the output voltage derived form the junction between the secondary windings S_1 and S_2 is equal to the input voltage, and is 100 volts.

When the secondary windings S_1 and S_2 are rotated through 90° to the positions shown in FIGS. 40C and 40F and are coupled to the primary windings P_1 and P_2 as shown in FIGS. 40I and 40L, the voltage induced across the secondary winding S_1 is zero because as shown in FIG. 40C, the flux ϕ_1 link the right half coils of the secondary winding S_1 so that the voltages induced in the coils denoted by the black arrows have the polarities opposite to those of the voltages induced in the coils indicated by the white arrows. As a result, the induced voltages cancel each other. This condition is same with that of the secondary winding shown in FIG. 33. Similarly in the left sector the induced voltage is zero, so that the overall voltage across the secondary winding S_1 becomes zero. Similarly the voltage induced across the secondary winding S_2 is zero in the position shown in FIG. 40F. Thus, the voltage induced across the series-connected secondary indings S_1 and S_2 becomes zero. Consequently, the output voltage comes 50 volts as shown in FIGS. 40I and 40L.

Next when the secondary windings S_1 and S_2 are rotated to the positions shown in FIGS. 40D and 40G and coupled to the primary windings P_1 and P_2, the conditions are opposite to those described with reference to FIGS. 40B, 40E, 40H and 40K. That is, the polarities of the voltage induced across the secondary winding S_2 are opposite to those of the winding voltage of the primary winding P_2 whereas the polarities of the voltage induced across the secondary winding S_1 are same with those of the voltage across the primary winding P_1. As a result, the output voltage becomes zero as shown in FIGS. 40J and 40I.

In the instant embodiment, the two primary windings are used to produce two fluxes, and the output voltage is controlled by the rotation of the rotor through 180°. However, when four primary windings are used to produce four fluxes as shown in FIG. 39R, the output voltage may be regulated by the rotation of the rotor through 90°. Although the voltage regulation only in three angular positions, 0°, 90° and 180° positions has been described so far, the output voltage may be linearly varied depending upon the angle of rotation of the rotor intermediate the above three angular positions.

Next the use of the apparatus of the present invention as a variable inductance is substantially similar to that described with reference to FIGS. 6A, 23, 24 and 25.

The embodiments of the present invention described hereinbefore has generally the construction shown in FIG. 41. In practice, the magnetic fluxes produced by the primary windings and by the load currents flowing through the secondary windings will not pass through all the coils of the windings and tend to pass through the shortest magnetic paths. So far the description of the fluxes in the above embodiments has been limited to those indicated by ϕ_{1a} in FIG. 41, but in practice the magnetic fluxes indicated by ϕ_{1b}, ϕ_{1c} . . . , and ϕ_{1z} are produced. Therefore, in the inner core, the magnetic flux density becomes maximum in the proximity of the coil 3_m of the primary winding and the coil 4_m of the secondary winding, and is gradually decreased as they approach to the coils 3_n, 4_n, 3_o, 4_o, 3_p, 4_p, . . . , and 3_z and 4_z. To overcome this problem, the arrangements described with reference to FIGS. 18, 19, 20 and 21 may be also applied to the above embodiment.

In the above embodiments described, the inner core has been described as constituting the inner leg of the core whereas the outer core, as constituting the outer legs of the core. However, in the embodiment to be described hereinafter, the inner core forms the magnetic paths in the outer legs whereas the outer core forms the mganetic paths in the inner leg. The embodiment to be described hereinafeter corresponds to the embodiment described with reference to FIGS. 1, 2, 3, 4 and 5 so that it may be also applied to the variations shown in FIGS. 17, 18 and 19.

Referring to FIG. 42, the apparatus in accordance with the present invention comprises an annular outer core 301 and an annular inner core 302. First windings 203 radially extend from slots 304 formed on the inner side wall of the annular outer core 301 to the outer side wall 301*a* thereof. Second windings 306 extend from slots 305 formed on the outer wall of the annular inner core 302 to the outer surface 301a of the annular outer core 301. In summary, the first and second windings are placed upon the outer peripheral surface 301*a* of the annular outer core 301.

The first windings 303 may be used as the primary windings while the second windings 304 may be used as the secondary windings, or vice versa. The annular outer core 301 may be stationary whereas the annular inner core 302 may be rotatable, or vice versa. However, in the instant embodiment the first windings 303 arre used as the secondary windings whereas the secondary windings 306 are used as the primary windings, and the annular outer core 301 is rotated wtih respect to the stationary annular inner core 302. Hence the secondary windings 303 rotate in unison with the annular outer core 301 whereas the primary windings 306 are stationary on the annular inner core 302.

As shown in FIGS. 42 and 43, the secondary windings 303 placed in the slots 304 of the annular outer core 301 extend radially toward the outer peripheral surface 301*a* thereof, and rotate in unison with the annular outer core 301. The primary windings 303 placed in the slots 305 of the annular inner core 302 extend toward the outer peripheral surface of the outer peripheral surface of the annular outer core 301. Each half of the primary windings 306 is centered at one position above the annular outer core 301 as shown in FIG. 42 so that shafts 307 of the annular outer core 301 may move over a distance indicated by the arrow in FIG. 42 without being interrupted by the primary windings 306. Hence the annular outer core 301 may rotate over the range indicated by the arrow. As a variation, the primary windings may be concentrated at one portion of the outer peripheral surface of the annular inner core 302. In FIG. 43, reference numeral 307*a* designates a rotary shaft; 307*b*, arms for connecting the center shaft 307*a* to the shafts 307; and 307*c*, a support of the apparatus. If the center shaft 307*a*, the arms 307*b*, and the shafts 307 are made of an electrically conductive material, an electric circuit will be established so that some of them must be made of an electrically insulating material or suitable insulating means must be employed as described elsewhere hereinbefore.

In FIGS. **44, 45** and **46**, the coils of the windings are wound in the directions indicated by the arrows. The secondary windings are denoted by the bolt lines whereas the primary windings, by fine lines. FIGS. **44** to **46** are the top views so that when the bottom of the apparatus is viewed, the arrangement of the windings becomes opposite to those shown in FIGS. **44** to **46.**

The two primary windings are so arranged that two fluxes ϕ_1 and ϕ_2 are produced symmetrically of a diameter of the annular outer core **301** as shown in FIG. **46.** That is, in each 180° sector of the apparatus the primary and secondary windings are wound in the same direction and the primary and secondary windings are connected all in series respectively. However, if required, they may be connected in parallel.

FIG. **45** illustrates the positions of the secondary windings **303** placed upon the annular outer core **301** when the latter is rotated through 180° from the position shown in FIG. **44.** The directions of the secondary windings **303** are opposite to those of the primary windings, that is the voltages induced across the secondary windings have the polarities opposite to those of the voltages across the primary windings.

FIG. **46** illustrates the positions of the secondary windings **303** on the annular outer core **301** when the latter is rotated through about 90° from the position shown in FIG. **44.** That is, the positions of the secondary windings shown in FIG. **46** are intermediate the positions shown in FIGS. **44** and **45.** It is seen that one half of the coils of the secondary windings **303** are oriented in the directions opposite to those of the primary windings.

It is also seen that the coils **303***a*, **303***b*, **303***c*, . . . and **303***z* of the secondary winding have been rotated through 180° in the positions shown in FIG. **45** and through 90° in the positions shown in FIG. **46** from the positions shown in FIG. **44.** However, the two fluxes ϕ_1 and ϕ_2 produced by the primary windings **306** remain in the same positions because the latter will not rotate. The arrangements of the slots **304** and **305** of the outer and annular inner cores described with reference to FIGS. **8** and **9** may be also applied to the instant embodiment. The number of the slots may be increased or decreased as described with reference to FIG. **8C.** If the increase in exciting current presents no problem in applications, the slots of the outer and inner annular cores may be eliminated.

Next the mode of operation will be described. In FIG. **44,** the secondary voltage induced is in phase with the primary voltage and has the maximum magnitude. In FIG. **45,** the secondary voltage is out of phase relative to the primary voltage and has the maximum value. In FIG. **46,** the secondary voltage is almost zero.

The connections and couplings of the windings and the winding voltages are shown in FIGS. **6A** – **6D.**

When the AC voltage is applied to the primary windings **306,** the two fluxes ϕ_1 and ϕ_2 are produced in the directions shown in FIG. **44.** Since the two secondary windings linked with the fluxes ϕ_1 and ϕ_2 are so wound that the voltages induced across the secondary windings **303** have the same polarities with those of the voltages across the primary windings. Hence, the voltage induced across the secondary windings have the maximum magnitude.

When the annular outer core **301** has been rotated through 180° to the position shown in FIG. **45** from the position shown in FIG. **44,** the two fluxes ϕ_1 and ϕ_2 are produced and link the secondary windings **303** so that the voltages are induced across the secondary windings. However, the secondary windings **303** are oriented in the direction opposite to that of the primary windings **306** so that the secondary voltages are opposite to those induced under the conditions shown in FIG. **44.**

Next when the annular outer core has been rotated through 90° to the position shown in FIG. **46,** the intermediate positions shown in FIGS. **44** and **46,** one halves of the secondary windings are oriented in the directions opposite to those of the primary windings **306** whereas the other halves are oriented in the same directions with those of the primary windings. As a result, the voltages both in phase and out of phase by 180° with the primary voltage are induced in the secondary windings, but they cancel each other. As a consequence the overall secondary voltages induced across the secondary windings become zero. In a similar manner, the output voltage may be varied depending upon the angle of rotation of the annular outer core. The relation between the angle of rotation of the annular outer core and the induced secondary voltage may be summarized as follows:

Angle of rotation of annular outer core	Induced voltage
0°	maximum and in phase with primary voltage
90°	zero
180°	maximum but out of phase

The above relation is illustrated in FIG. **6C***a*.

As in the case of the connection shown in FIG. **6A,** one end of the secondary winding S is connected to one end of the primary winding P, and the other ends of the primary and secondary windings are used as the output terminals. The primary and secondary windings have the same turns.

When the input voltage 100 volts is applied, under the conditions shown in FIG. **52,** the voltage induced across the secondary winding S has the same polarities with those of the primary voltage across the primary winding P. Therefore, the voltage across the output terminals becomes the sum of the primary and secondary voltages. That is, the output voltage is given by

$$\text{output voltage} = 100\ (V) + 100\ (V) = 200\ (V).$$

When the rotor has been rotated through 90° to the position shown in FIG. **46,** the secondary voltage is zero and the output voltage equals the input voltage, that is 100 volts.

When the rotor has been rotated through 180° to the position shown in FIG. **45,** the secondary voltage induced across the secondary winding has the polarities opposite to those of the primary voltage. As a result, the output voltage is given by

$$100\ (V) - 100\ (V) = 0\ (V).$$

Hence, the output voltage may be varied over the range between 200 volts and 0 volt when the rotor and hence the secondary winding is rotated through the range from 0° to 180° as shown in FIG. **6A***a*. So far the output voltage variation at three angular positions, that is 0°, 90° and 180° positions of the rotor has been described, but from FIG. 6A*a* it is seen that the output voltage becomes about 130 volts and about 70 volts when the rotor rotates through 60° and 120° respectively.

When one end of the secondary winding S is connected to the center tap of the primary winding P and the other end is used as the input terminal, the connection similar to that shown in FIG. **6B** is obtained. The maximum voltage induced across the secondary winding equals one half of the primary or input voltage. For example when the input voltage is 100 volts, the voltage induced across the secondary winding S is 50 volts, and the relation between the angle of rotation of the rotor and the induced voltage may be summarized as follows:

Angle of rotation of rotor in deg.	Output voltage in volt
0	100
90	50
180	0

The above relation is illustrated in the graph shown in FIG. **6B***a*.

When the primary and secondary windings having the same turns are coupled as shown in FIG. **6C**, the output voltage may be varied over the range from + 100 volts to − 100 volts as shown in FIG. **6C***a*.

It will be understood that various variations and modifications may be effected based upon the description of the instant embodiment. In one variation in accordance with the present embodiment, the primary and secondary windings are connected as shown in FIG. **6D** and are arranged as shown in FIG. **48.** The instant variation is similar in construction of the outer and inner cores to the embodiment described with reference to FIG. **46** so that only the connection and arrangement of the primary and secondary windings will be described. In the instant variation, the following windings are used:

Main winding P_1 on the annular inner core whose coils are denoted by **309***k*–**309***u* and which has for example 50 turns; and

Auxiliary winding P_2 on the annular inner core whose coils are denoted by **309***h* - **309***u* and which has for example 50 turns; and

Secondary winding on the outer core whose coils are denoted by **310***a* - **310***j* and which has for example 50 turns.

These windings P_1, P_2 and S are wound in the directions indicated by the arrows. That is, the coils **309***k*–**309***j* and coils **310***a* - **310***j* are radially outerwardly oriented whereas the coils **309***a* - **309***j* are oriented radially inwardly. The main winding P_1 on the annular inner core produces the flux ϕ_5 whereas the auxiliary winding P_2 on the annular inner core, the flux ϕ_6 in the directions indicated in FIG. **48.** The above three windings are connected in series as shown in FIG. **6D.**

When the input voltage of 100 volts is applied across the input terminals I_1 and I_2 shown in FIG. **6D**, and when the rotor is in the position shown in FIG. **48**, the voltage induced across the main winding P_1 on the annular inner core is given by:

$$\text{Induced voltage} = 100(V) \times \frac{\text{Number of turns of the main winding}}{\text{Sum of turns of main, auxiliary and secondary windings}}$$

$$= 100(V) \times \frac{100T}{100T + 50T + 50T} = 50(V).$$

Hence, under the conditions shown in FIG. **46,** the winding voltage is given by 0.5 $(V)/T$. Therefore, it follows that winding voltage of the auxiliary winding P_2=

$0.5\ (V)/T \times 50T = 25\ (V)$; and

winding voltage of the secondary winding S = 0.5 $(V)/T \times 50T = 25\ (V)$.

Therefore, the output voltage across the terminals O_1 and O_2 is 50 volts.

When the annular outer core has rotated through 180° so that the coils **310***a* - **310***j* have moved toward the side of the coils **309***k*–**309***u* of the auxiliary winding on the annular inner core, the coils **310***k*–**310***u* are oriented radially outwardly whereas the coils **309***k*–**309***u*, radially inwardly so that the coil voltages in the coils **309***a* - **310***j* have the polarities opposite to those of the voltages induced in the coils **310***a* - **310***j*. As a result, the winding voltages across the auxiliary winding and the secondary winding cancel each other. In other words, there is no voltage between the terminals I_2 and O_1 in FIG. **6D.** Therefore, the voltage between the terminals I_2 and O_1 is zero and that between the terminals I_1 and O_1 is 100 volts when the input voltage of 100 volts is applied across the input terminals I_1 and I_2. Hence, when the annular outer core is rotated through 180°, the voltage between the terminals I_2 and O_1 may be varied from 50 volts to zero volt whereas the voltage between the terminals I_1 and O_1 may be varied from 50 volts to 100 volts. Of course in other angular positions of the annular outer core, the voltages in response to the angle of rotation of the annular outer core may be derived. Thus, the voltage may be regulated continuously and infinitesimally by the rotation of the annular outer core. In the above embodiment, the coils **309***a* - **309***u* have been described as being placed in the slots of the annular inner core, but the coils **310***a* - **310***j* may be placed in the slots of the annular inner core whereas the coils **309***a* - **309***u* may be placed in the slots of the annular outer core.

A further variation will be described with reference to FIGS. **49, 11A, 11B, 12**A and **12B**. First referring to FIG. **49,** the coils of the winding placed on the right side of the annular inner core are designated by **311***a* - **311***j*; the coils on the left side of the annular inner core, by **312***a* - **312***j*; and the coils of the winding on the annular outer core, by **313***a* - **313***c*.

Referring back to FIGS. **11A** and **11B**, the secondary winding on the annular outer core is connected in series to one of the primary windings on the annular inner core. FIG. **11A** illustrates the coupling between the primary and secondary winding when the rotor (See FIG. **49**) has been rotated through 180° for raising the voltage. FIG. **11B** illustrates the coupling for lowering the voltage. Opposed to the instant variation, the winding on the annular outer core may be placed on the annular inner core whereas the windings on the latter may be placed on the former.

The connections and couplings shown in FIG. **12** may be applied to the instant variation. The right and left primary windings are connected in parallel to the supply circuit, and the secondary winding across which is derived a variable voltage is placed on the outer core. The secondary winding may be placed on the annular inner core whereas the primary windings, on the annular outer core.

As shown in FIG. 11B, if the windings **311** (**10** in FIG. **11B**) and **313** (**12** in FIG. **11B**) are oriented in the same direction and the input voltage of **100** volts is applied across them, the output voltage becomes equal to the input voltage minus the voltage drop across the winding **313** since the output is derived from the junction. When the winding **313** has 30 turns, the winding **311,** 130 turns, and the winding **312** (**11** in FIG. **11B**), 100 turns, the output voltage is given by:

$$\text{Output voltage} = 100(V) \times \frac{\text{Number of turns of winding } 11}{\text{Sum of turns of windings } 11 \text{ and } 13}$$

$$= 100(V) \times \frac{130T}{130T + 30T} = 81(V).$$

When the annular outer core has been rotated through 180° from the position shown in FIG. **11B** to the position shown in FIG. **11A**, the winding **312** is inductively coupled with the winding **311** so that the polarities of the voltage across the winding **312** are opposite to those of the winding voltage across the winding **311.** That is, the winding **313** is oriented radially outwardly even when it is brought to the magnetic path formed by the winding **312** whereas the winding **312** is oriented radially inwardly. The voltage induced across the winding **313** is opposite (in sign) to that induced when the winding **313** is in the magnetic path formed by the winding **311.** The output voltage is given by:

output voltage = (input voltage) − (voltage across the winding **313**).

$$\text{Voltage across the winding 311}$$

$$= \frac{\text{(input voltage)}}{\text{turns of the winding } 312} \times \text{turns of the winding } 313$$

$$= 100(V) \times \frac{100T}{100T} \times 30T = 30(V).$$

This voltage has the opposite polarities. Hence, the output voltage is

output voltage = 100 (V) − (− 30 (V)) = 100 (V) + 30 (V) = 130 (V). This means that the output voltage is raised by 30 volts. Therefore, by the connection and couplings shown in FIGS. **11A** and **11B**, the output voltage may be regulated infinitesimally over the range from 81 volts to 130 volts depending upon the angle of rotation of the annular outer core when the input voltage is 100 volts. This means that even when the supply circuit voltage varies over the range between 130 volts and 81 volts, the constant output voltage of 100 volts may be secured.

Next the connection and couplings will be described same as in FIGS. **12A** and **12B**. The winding **313** (**12** in FIGS. **12A** and **12B**) is inductively positively coupled to the winding **311** (**10** in FIGS. **12A** and **12B**) so that the output voltage is raised by the winding voltage across the winding **313.** FIG. **12A** shows the position of the annular outer core when rotated through 180°. As the winding **313** is brought into the magnetic path formed by the winding **312** (**11** in FIGS. **12A** and **12B**), it is inductively negatively coupled to the winding **312** so that the voltage is lowered. That is, the output voltage is lowered by the voltage corresponding to the voltage drop induced by the winding **313.**

In the connections and couplings shown in FIGS. **11A, 11B, 12A** and **12B**, the primary windings are connected not in series but in parallel opposed to the connection shown in FIGS. **44 – 46.**

The connection shown in FIGS. **14A** to **14G** may be also applied to the instant embodiment, and FIGS. **14A** and **14B** schematically show the arrangement of the primary and secondary windings on the cores similar to those shown in FIGS. **48** and **49.** The first windings P_1 and P_2 are placed on the annular inner core whereas the second windings S_1, S_2, S_3 and S_4 are placed on the annular outer core. Of course it is possible to reverse the above arrangement as long as the second windings $S_1 - S_4$ may rotate in unison. In the instant embodiment, the rotor rotates through from 0° to 90°, but it is obvious to those skilled in the art to change the design so that the rotor may rotate through 180° from the description of the instant embodiment. The feature of the instant embodiment is that the output voltage may be varied because the voltages induced across the second windings $S_1 - S_4$ have the opposite polarities depending upon the angle of rotation thereof.

The initial position of the rotor when not rotated is shown in FIGS. **14A** and **14C**. The relation between the windings P_2 and S_4 is similar to that between the coils **309*a* – 309*j*** and the coils **310*a* – 310*j*.** In a similar relation, the windings P_1 and S_3 are arranged. The windings S_1 and S_2 are arranged in quadrature relation with respect to each other as shown in FIG. **14A.** When the input voltage is applied to the primary windings, the fluxes ϕ_5 and ϕ_6 are produced as shown in FIG. **48.** Since the primary windings P_1 and P_2 are inductively positively coupled to the secondary windings S_2 and S_4, the voltages are induced across the secondary windings. Since the secondary windings S_1 and S_2 are located in quadrature relation relative to the primary windings P_1 and P_2, the voltages induced in the respective halves of the winding S_1 cancel each other so that the voltage across the winding S_1 is zero. In a similar manner, the voltage across the secondary winding S_2 is zero. Hence as shown in FIG. **14C**, the output voltage is 100 volts.

Next when the rotor is rotated through 90° as shown in FIGS. **14B** and **14E**, the secondary windings S_1 and S_2 are inductively positively coupled to the primary windings P_1 and P_2 so that the voltages are induced across the secondary windings S_1 and S_2. However, the voltages across the windings S_3 and S_4 are zero as they are located in quadrature relation with respect to the primary windings P_1 and P_2. Hence, the output voltage is zero as shown in FIG. **14E.**

Next when the rotor is rotated through 45° as shown in FIG. **13D**, the output of **50** volts is obtained. In FIG. **14F**, an additional winding S_5 which is capable of inductively generating 30 volts across the winding is located in the same position with those of the secondary windings S_3 and S_4 in order to vary the output voltage over the range between zero volt and 130 volts. The connection shown in FIG. **14G** is for compensating the voltage drop due to the resistance of the winding. The compensating windings S_5 and S_6 are arranged for 10 percent compensation. In this arrangement the output voltage is compensated to become 99 per-cent. Alternatively, the secondary and compensating windings may be connected in series in the order of S_1, S_2, S_6, S_5, S_3 and S_4.

Next referring to FIG. **15**, a still another embodiment of the present invention will be described. The instant embodiment is an improvement over the embodiment described above with reference to FIG. **14.** The primary windings P_1 and P_2 are held stationary while the secondary windings S_1 and S_2 are rotated with respect to the primary windings P_1 and P_2, the output voltage being derived from the junction between the secondary windings S_1 and S_2. The initial positions of the primary and secondary windings are shown in FIGS. **15A** and **15D**; the positions when rotated through 90° are shown in FIGS. **15B** and **15E**; and the positions when rotated through 180° are shown in FIGS. **15C** and **15F**.

In the positions shown in FIG. **15A** and when connected as shown in FIG. **15D**, the secondary winding S_1 is inductively negatively coupled to the primary winding P_1 whereas the secondary windings S_2 is inductively positively coupled to the primary winding P_2. Hence the voltage at the junction is equal to the input voltage, that is 100 volts.

Next when the rotor is rotated through 90° to the position shown in FIGS. **15B** and **15E**, the left half of the winding S_2 is inductively negatively coupled to the primary winding P_1, and the right half is inductively positively coupled to the primary winding P_2. Accordingly as denoted by + and − signs, the overall voltage induced across the secondary winding S_1 is zero. Similarly the voltage induced across the secondary winding S_2 is zero. Thus, the supply circuit voltage is applied only across the primary windings P_1 and P_2, so that the output voltage becomes 50 volts, one half of the input voltage of 100 volts.

When the rotor is rotated through 180° to the position shown in FIGS. **15C** and **15F**, the conditions are opposite to those shown in FIGS. **15A** and **15D**. The winding S_2 is inductively negatively coupled to the primary winding P_1 whereas the secondary winding S_1 is inductively positively coupled to the primary winding P_1. Hence the voltage across the windings S_2 and P_2 becomes zero so that the output voltage becomes zero.

In the above embodiment, two fluxes are produced by the two primary windings, but when four primary windings are used to produce four magnetic fluxes, the output voltage regulation may be effected by the rotation of the rotor through 90°.

In FIG. **15**, the windings P_1 and S_1 are located on the left whereas the windings P_2 and P_1 on the right. However, in practice, the load current flows only through the windings P_1 and S_1 so that the windings on the left side is more heavily loaded than the windings on the right side. To overcome this problem, the halves of the primary and secondary windings P_1 and S_1 may be located on the right side whereas one halves of the primary and secondary windings P_2 and S_2, on the left side.

Next the variable inductance will be described. As shown in FIG. **13**, the primary and secondary windings on the annular inner and outer cores are connected in series. When the primary and secondary windings are located in the positions shown in FIG. **44**, they are inductively positively coupled in series so that the maximum inductance may be obtained. When the rotor is rotated through 180° from the position shown in FIG. **44** to the position shown in FIG. **45**, the windings are inductively negatively coupled to each other so that the inductance becomes zero. Next when the rotor is rotated through 90° from the position shown in FIG. **44** to the position shown in FIG. **46**, the inductance equal to one quarter of the maximum may be obtained. Hence, in response to the angle of rotation of the rotor, the inductance may be varied continuously and infinitesimally.

In summary, the electromagnetic induction apparatus in accordance with the present invention has the following advantages:

1. The primary and secondary leakage impedances are substantially constant and almost equal to those of the conventional transformers at any position of the rotor, and are less than those of the conventional induction voltage regulators;

2. The self-inductance remains unchanged opposed to the conventional induction voltage regulator depending upon the angle of rotation of the rotor, and will not be excessively increased even when the primary or secondary windings are rotated through 90° relative to the other:

3. No short-circuited winding is required. The usefullness of the short-circuited winding is to cancel all ampere-turns (AT) generated by the load current flowing through the secondary winding. However the higher the load current, the greater the ampere-turn becomes and must be cancelled. In other words, as the load current is increased, the secondary winding is doubled. This means that the copper loss is doubled so that more copper wires are required, thus resulting in the high cost of the apparatus. Furthermore, the problem for providing the space for disposing the copper wires presents, thus further increasing the cost of the apparatus. However, according to the present invention, the short-circuited winding may be eliminates so that the apparatus is excellent in operation characteristics, low in cost, compact in size and light in weight.

4. The variation in output voltage in response to the angle of rotation of the regulator rotor is linear. In the conventional induction voltage regulator, the variation is sinusoidal so that the voltage variation ratio is low on the high and low voltage sides whereas the ratio is rapidly increased. However according to the present invention, the variation in output voltage is basically linear. The apparatus of the present invention may be said to be the refinement of the step voltage regulator in which the number of taps is infinitively increased. In the conventional step voltage regulators, the output voltage is adjusted by sliding the carbon brush or contractor so as to contact with one of the voltage regulation taps, but in the apparatus of the present invention, the annular outer or inner core is rotated with respect to the inner or outer core as to change the inductive coupling between the primary and secondary windings. Because of the linear variation in output voltage in accordance with the present invention, the operation becomes very advantageous, and the scales may be graduated with ease especially in case of the small-sized apparatus.

5. When the core is recessed as shown in FIGS. **18, 19** and **20**, the passage of the cooling air or oil may be much facilitated.

6. Since the windings are radially distributed, the local temperature rise may be prevented.

7. The apparatus may be used as a variable inductance. As described hereinbefore, the short-circuited winding may be eliminated in accordance with the

present invention so that there are no problems of the use of much copper wires, of the copper loss and of the space for disposing the copper wires. Therefore, the apparatus of the present invention is inexpensive in cost, light in weight and compact in size.

In addition to the advantages of the present invention described above, the present invention has many other novel features and advantages. The electromagnetic induction apparatus in accordance with the present invention is used not only as a voltage regulator but also a rotary transducer in which the secondary voltage varies in response to the angle of rotation of the rotor so that the angle of rotation of the rotor may be detected as the variation in the secondary voltage.

The apparatus of the present invention may be also used as a frequency modulator because when the inner core is rotated at a predetermined speed, the supply circuit voltage or input voltage may be modulated by the frequency of the rotation of the inner core.

What is claimed is:

1. An electromagnetic induction apparatus comprising

an outer core,

an inner core which has a center hole and is disposed coaxially of said outer core,

a first group of windings wound along the inner peripheral surface of said outer core and through said center hole of said inner core, and

a second group of windings wound along the outer peripheral surface of and through said center hole of said inner core and inwardly of said first group of windings in a similar manner thereto,

at least one of said first and second groups of windings being rotatable with respect to each other so that the relative angular position therebetween may be varied and that in response to said angular relative position the degree of the inductive coupling between said first and second groups of windings may be varied.

2. An electromagnetic induction apparatus as set forth in claim **1** wherein at least one of said outer and inner cores is annular in shape.

3. An electromagnetic induction appratus as set forth in claim **1** wherein at least one portion of each of the inner peripheral surface of said outer core and of the outer peripheral surface of said inner core is provided with slots for at least one portion of said first and second groups of windings.

4. An electromagnetic induction apparatus as set forth in claim **1** wherein at least one of said outer and inner cores and said first and second groups of windings is provided with leakage flux preventive means.

5. An electromagnetic induction apparatus as set forth in claim **1** wherein one of said first and second groups of windings which is connected to a supply circuit is electrically insulated against the other group of windings connected to a load circuit.

6. An electromagnetic induction apparatus as set forth in claim **1** wherein one end of one of said first and second groups of windings which is connected to a load circuit is connected to a tap of the other group of windings which is connected to a supply circuit.

7. An electromagentic induction apparatus as set forth in claim **3** wherein said slots are formed in parallel with the axis of said inner core.

8. An electromagnetic induction apparatus as set forth in claim **3** wherein said slots are formed at angles relative to the axis of said inner core.

9. An electromagnetic induction apparatus as set forth in claim **3** wherein said slots are bent at any point intermediate the ends thereof.

10. An electromagnetic induction apparatus as set forth in claim **4** wherein said leakage flux preventive means comprises at least one recess formed at least on one of the inner peripheral surface of said outer core and the outer peripheral surface of said inner core.

11. An electromagnetic induction apparatus as set forth in claim **4** wherein said leakage flux preventive means comprises an electrically conductive plate disposed along at least one of said inner peripheral surface of said outer core and the outer peripheral surface of said inner core.

12. An electromagnetic induction apparatus as set forth in claim **6** wherein said first and second groups of windings are connected in series, and a load is connected between one of the terminals of said first and second groups of windings and a point of said series-connected circuit of said first and second groups of windings.

13. An electromagnetic induction apparatus as set forth in claim **6** wherein said first or second group of windings is further divided into two subgroups the junction of which is connected to a supply circuit, and

said first or second group of windings has its both ends connected to a load circuit in parallel with said second or first groups of windings connected to said load circuit.

14. An electromagnetic induction apparatus as set forth in claim **6** wherein said first group of windings connected to said supply circuit is further divided into two subgroups the junction of which is connected to one terminal of said supply circuit together with one end of said second circuit connected to said load circuit; and

one of the terminals of said first group of windings connected to said supply circuit and the other terminal of said first group of windings connected to said load circuit; and

the other terminal of said second group of windings connected to said supply circuit and said load circuit.

15. An electromagnetic induction apparatus as set forth in claim **6** wherein

one half of said second group of windings connected to said load circuit is inductively positively coupled to said first group of windings connected to said supply circuit;

the other half is further divided into two subgroups one of which is inductively positively coupled to and the other of which is inductively negatively coupled to said first group connected to said supply circuit;

said winings connected to said load circuit are all connected in series and then connected in parallel to said group connected to said supply circuit; and

said group of windings connected to said load circuit has its center tap connected to said load circuit.

16. An electromagnetic induction apparatus comprising

an outer core,

an inner core disposed coaxially of said inner core, a first group of windings which are wound around said inner core so as to pass in the proximity of the axis of said inner core and extend across the points along the outer periphery thereof and in diametrially opposed relation,

a second group of windings wound inwardly of said outer core but outwardly of said first group of windings in a manner similar thereto,

either of or both of said outer and inner cores being rotatable relative to each other so that the relative angular position therebetween may be varied and that in response to said angular relative position the effects of the fluxes produced by said first and second groups of windings on the other may be varied. (The degree of the inductive coupling between said first and second groups of windings may be varied.)

17. An electromagnetic induction apparatus comprising

an outer core,

an inner core disposed coaxially of said outer core,

a first group of windings which are wound around said inner core in such a manner that said windings may pass through the points along the outer periphery of said inner core and symmetrical about the line passing through the center thereof and may also pass in the proximity of said center,

a second group of windings wound inwardly of said outer core but outwardly of said first group of windings in a manner similar thereto,

at least one of said inner and outer cores being rotatable with respect to the other so that the relative angular position therebetween may be varied and that in response to said angular relative position. The degree of inductive coupling between said first and second groups of windings may be varied.

18. An electromagnetic induction apparatus comprising

an outer core,

an inner core disposed coaxially of said outer core,

a first group of windings wound around the inner and outer peripheral surfaces of said outer core,

a second group of windings wound around the outer peripheral surfaces of said inner and outer cores,

at least one of said outer and inner core being rotatable with respect to each other so that the relative angular position therebetween may be varied and that in response to said relative angular position. The degree of induction coupling between said first and second groups of windings may be varied.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,777,296 Dated December 4, 1973

Inventor(s) Masayuki Ohyama and Takefumi Nakamizo

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 7, line 64: the formula should be:

$$100\ (v) \times \frac{100}{100+50+50} = 50\ (v)$$

Column 12, line 4 : "Alaternatively" should be --Alternatively--

line 21: "quater" should be --quarter--

line 32: "$\emptyset_{1g} - \emptyset_{1g}$" should be --Ø 1b - Ø1z--

Column 14, line 6 : "bolt" should be --bold--

Column 20, line 16: "at" should be --so--

line 18: "become" should be --becomes--

line 34: "in" should be --In--

Column 21, line 29: "an" should be --or--

Column 22, line 25: "e" should be --be--

line 45: "refenece" should be --reference--

Column 24, line 62: "induces" should be --induced--

line 67: "Thereofre" should be --Therefore--

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,777,296 Dated December 4, 1973

Inventor(s) Masayuki Ohyama and Takefumi Nakamizo

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 26, line 27: "ssociated" should be --associated--

Column 28, line 38: "arre" should be --are--

IN THE CLAIMS:

Claim 16, line 4 : inner" (second occurrence) should be --outer--

line 9 : "ally" should be --cally--

line 11: "but" should be -- and passing in the proximity of said axis and extend across points along the inner periphery thereof in symetrically opposed relation--

line 12: "in a similar manner thereto" should be --whereby each of the windings of each group of windings are radially arranged,--

line 13: "either of or both" should be --at least one--

line 14: "each" should be --the--

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,777,296 Dated December 4, 1973

Inventor(s) Masayuki Ohyama and Takefumi Nakamizo

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 16, line 18: cancel the period

line 19: "(The" should be --, whereof the degree of the--

line 20: cancel the close-parenthesis mark.

Claim 17, line 9 : cancel "may"

line 12: cancel "but"

line 13: cancel "in a manner similar thereto"; after the comma insert --said second windings passing through point along the inner periphery of the outer core symmetrical about said line and also passing in the proximity of said center, whereby each of the windings of each group of windings are radially arranged,--

line 17: cancel the period

line 18: cancel "(The" and insert --, the--

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,777,296 Dated December 4, 1973

Inventor(s) Masayuki Ohyama and Takefumi Nakamizo

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 18, line 5 : after "wound" insert --to extend--

line 7 : after "wound" insert --to extend--

line 12: cancel the period and insert a comma

line 13: cancel "The" and insert --, the--

Signed and sealed this 29th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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