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(54) **Stirring of molten metal.**

(57) To stir the molten metal in an open-topped mould (10) of a continuous casting process an electromagnetic stirrer (20) is placed adjacent the lower end of the mould and around the strand (12) emerging from the mould.

The magnetic field produced by the stirrer (20) rotates about a vertical axis and promotes movement of the molten metal above and below the stirrer into the mould and into the strand.

The stirrer is formed as separable parts for fitting to existing moulds and the stirrer is adapted for use with moulds of different shapes and sizes.

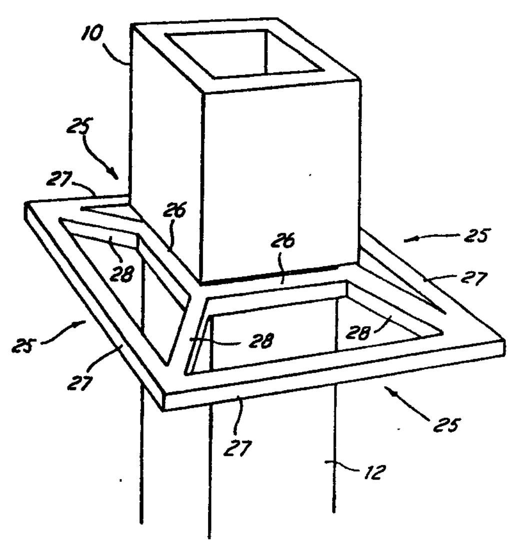

FIG.3

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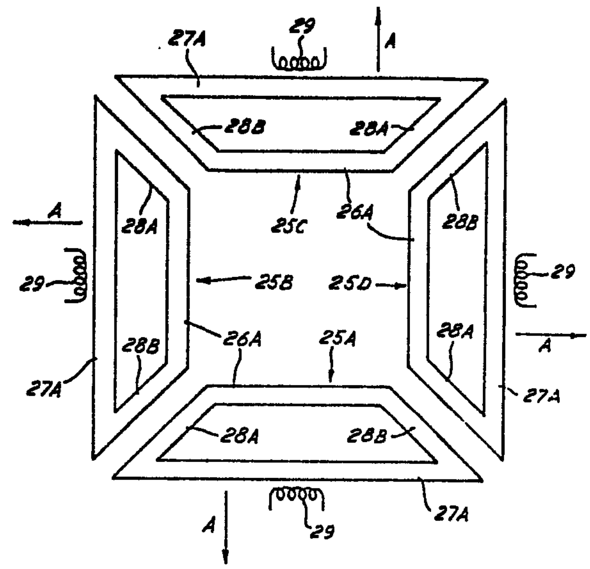
27A
29
A
28B
28A
25C
26A
28B
A
28A
29
25B
25D
29
26A
25A
28A
A
28B
27A
27A
28A
28B
A
29
27A

FIG. 4

Stirring of Molten Metal

This invention relates to the stirring of molten metal.

When casting metal, for example steel, by a continuous casting process the molten metal is poured into the open top of a cooled copper mould and the metal emerges from the bottom of the mould as a continuous strand. A solidified skin is formed on the metal which contains the still molten core as it emerges from the mould.

Without stirring of the metal as it solidifies the metal forms an inhomogeneous structure. Accordingly it has been proposed to stir the metal and one way in which stirring has been effected is to generate electromagnetically induced movement of the molten metal.

In British Patents Nos. 2077161, 2079195 and 2079196 there is described a method and apparatus for electromagnetic stirring of molten metal in which a multi phase alternating current is supplied to closed loops of electrically conductive material spaced around the axis of the mould and spaced above the upper end of the mould. In this way a magnetic field is produced which rotates about the vertical axis of the mould. Such a stirring action is intended to break up dendritic formations in the metal and provide a clear skin to the solidifying metal.

It has also been proposed to provide a below mould electromagnetic stirrer which produces an up and down or linear movement of the molten metal in the strand as it emerges from the mould.

Such previous stirrers have suffered from disadvantages. In the case of the above mould, rotary stirring arrangement the apparatus needs to be built according to the individual dimensions of the respective mould to which it is to be fitted and it is difficult to fit the apparatus after the mould has been installed. In addition, being above the mould, the apparatus can obstruct the pouring of metal and be a hazard in the event of leakages.

Previous below mould stirrers have given inadequate stirring in the upper part of the mould.

According to one aspect the invention provides a method of stirring molten metal in an open-topped mould characterised by the steps of pouring molten metal into the top of the mould, cooling the metal as it passes through the mould so that a skin of solidified metal is formed at the walls of the mould and contains the molten metal as it passes downwardly out of the lower end of the mould as a strand containing molten metal, and electromagnetically inducing a magnetic field in the molten metal by placing induction apparatus about the strand adjacent the lower end of the mould, the induction apparatus being arranged to produce a magnetic field which rotates about a vertical axis in said strand and the rotary stirring of the molten metal being arranged to induce motion of the molten metal upwards and downwards from the level of the apparatus.

According to a second aspect of the invention there is provided apparatus for stirring molten metal, characterised by comprising an electromagnetic transducer formed of three or more closed loops of electrically conductive material located around the vertical axis of the mould, the loops being coupled to the phases of a multi-phase alternating current supply so that the currents passing through the loops will produce a magnetic field which rotates about the vertical axis of the mould, the loops being positioned below the lower end of the mould to locate around the strand of metal emerging from the mould.

Preferably the loops are constructed as individual units separable from one another, each loop including an inner portion carrying an electric current derived from a transformer portion including an energising coil radially outwardly located relative to the inner portion and to the vertical axis of the mould.

Conveniently each loop has a transformer portion which carries at least one energising coil, different loops having an energising coil connected to different phases of the multi-phase supply.

In one arrangement the loops are of non-ferromagnetic material and the loops are associated with ferromagnetic pole piece means, the pole piece means including a common pole piece member for providing a continuous flux path around the strand, and individual pole members associated with each loop.

The common pole piece member may be formed as elements one associated with each loop and separable from each other.

Further features of the invention will appear from the following description of an embodiment of the invention given by way of example only and with reference to the drawings, in which:

Fig. 1 is a diagrammatic vertical section through a prior art stirring arrangement,

Fig. 2 is a diagrammatic vertical section through a stirring arrangement according to the invention,

Fig. 3 is a diagrammatic perspective view of one version of the stirring arrangement of Fig. 2,

Fig. 4 is a diagrammatic plan view of another version of the stirring arrangement of Fig. 2,

Fig. 5 is a diagrammatic perspective view of a pole piece arrangement for the stirring arrangement of Figs. 3 and 4,

Fig. 6 is a diagrammatic perspective view of another pole piece arrangement,

Fig. 7 is a diagrammatic perspective view of a further pole piece arrangement,

Fig. 8 is a diagrammatic plan view of a further stirring arrangement,

Figs. 9 and 10 are diagrammatic plan views showing two alternative phase connections for the stirrers of Fig. 4 and Fig. 8,

Fig. 11 is a diagrammatic plan view of a stirrer for a circular-section mould, and

Fig. 12 is a diagrammatic plan view of a stirrer for a slab mould.

Referring to the drawings, Fig. 1 shows a known stirrer for stirring molten metal in a mould. The mould 10 is of a known kind having an open top into which molten metal is poured from a pourer 11. The mould is of copper and is of rectangular, round or of other suitable cross-section. The mould is cooled and the molten metal solidifies at the walls of the mould as it moves downwardly in the mould so as to form a thin skin of solidified metal which surrounds and contains the still molten metal as it emerges from the lower end of the mould as a strand 12.

After emergence of the strand 12 it is further cooled so that the molten metal solidifies until the whole of the strand consists of solidified metal. In the absence of any stirring of the molten metal as it solidifies an inhomogeneous structure of the solidified metal is formed. Accordingly it has been proposed to stir the molten metal by generating an electro-magnetically-induced magnetic field in the metal. It has hitherto been found necessary to induce magnetic fields at the upper end of the mould and below the lower end of the mould as shown at 13 and 14 in Fig. 1. Conventionally the induction means 13 at the upper end of the mould induces a rotary stirring action about the vertical axis of the mould and the induction means 14 below the lower end of the mould induces a linear stirring action in the up and down direction, as indicated by arrows 15 and 16 respectively in Fig. 1.

Not only has it been found necessary to provide two spaced stirring means to obtain adequate stirring but the means 13 at the upper end of the mould must be constructed to fit a specific mould configuration. Accordingly each stirrer is adapted for a specific mould and a standard construction of stirrer which is more widely usable is difficult to achieve. Moreover the stirrer is located relative to the mould in a position in which it is more likely to interfere with operation of the mould.

It has been proposed that the upper stirring means be located above the mould in order to achieve adequate stirring in the upper region and to overcome problems due to the presence of the copper mould with its high electrical conductivity. In the above-mentioned stirrer a magnetic field rotating about a vertical axis has been produced whereby a magnetic field which penetrates down into the mould is provided. However such a magnetic field penetrates down into the molten metal to a limited extent and a below mould stirrer is still necessary if adequate stirring of the molten metal is to be achieved.

It has now been established that if a stirrer producing a magnetic field rotating about a vertical axis is located about the strand below the mould, surprisingly a stirring action can be achieved which stirs the body of molten metal in a manner which obviates the previous requirement for a stirrer at a higher level.

Referring to Fig. 2 a stirrer 20 is provided at the lower end of the mould 10 and around the strand 12 emerging from the mould. When the stirrer 20 is of the kind generating a magnetic field rotating about the vertical axis of the mould movement of the molten metal is generated up into the mould and down into the strand below the stirrer 20. Such movement is indicated by the arrows in Fig. 2. Thus a rotary movement 21 is induced adjacent the stirrer which is directed about the vertical axis of the mould. This movement induces up and down movement above and below the stirrer as indicated at 22 and 23. Such up and down movement in turn induces rotary movements about the vertical axis towards the upper end of the mould at 24 and at a lower part of the strand 12 at 25a. It has been found that by this means stirring movement of the molten metal at a distance from the stirrer of the order of ten times the width of the strand can be induced.

Means for inducing a rotary stirring motion of the molten metal about a vertical axis has already been taught in, for example, British Patent No. 2079195, and this teaching can be applied in the present invention, but other means can also be used.

It is preferred that three or more loops of electrically-conductive material are located around the strand 12 and a portion of each loop forms a conductive element which lies adjacent the strand. Each of the loops is associated with a transformer or energising coil and the transformers are coupled to a multi-phase alternating current supply such that a magnetic field is produced rotating about an axis passing between the conductive elements.

Referring to Fig. 3 loops 25 can be arranged, as shown, immediately below the end of the mould 10 and around the strand 12. The loops 25 are, in this case, four in number and are associated with a square cross-section mould 10. Each loop is made of non-ferromagnetic material with an inner loop element 26, and an outer loop element 27. The inner and outer elements are interconnected with one another by intermediate elements 28 which are common to two loops 25. In Fig. 3

the energising coils are omitted but, in this arrangement, they would normally be associated with the intermediate elements 28.

The inner and outer elements 26 and 27 are formed as continuous members and the inner elements 26 are normally associated with ferromagnetic pole pieces, to be described, to provide a low reluctance flux path, in known manner.

Referring now to Fig. 4 an alternative form of stirrer is shown which, unlike that of Fig. 3, is capable of being withdrawn from a position adjacent the strand (not shown).

The stirrer includes four loops 25A, 25B, 25C and 25D formed as separate units, each having an inner loop element 26A and an outer loop element 27A, the loop elements 26A and 27A being joined at their ends by intermediate loop elements 28A and 28B to form individual closed loops.

In this case energising or transformer coils 29 are associated with the outer loop elements 27A. When in an operative position the stirrer is arranged with the intermediate loop elements 28A and 28B of adjacent loops closely adjacent one another but due to the loops being formed as individual units they may each be withdrawn outwardly in the directions of arrows A in the event of, for example, a break out from the strand 12 and for installation and maintenance purposes.

Fig. 5 shows an arrangement of pole pieces which may be used with the stirrer parts of Figs. 3 and 4. The pole piece arrangement includes a continuous pole piece member 30 usually of laminated ferromagnetic material and, in plan view, the strand cross-section is, in this case, of square shape. Along each side of the member 30 is located a discrete pole piece element 31, the elements 31 concentrating the magnetic field to cause it to penetrate into the strand.

Fig. 6 shows an alternative pole piece arrangement in which a continuous pole piece member 30 is provided which is conveniently attached directly to the lower end of the mould 10 (not shown). The pole piece elements 31 are, in this case, attached to the inner elements 26A of separable loops 32 (only two of which are shown) similar to those of Fig. 4 whereby the loops 32, together with the elements 31, are movable towards and away from the strand (not shown).

As a further alternative to the pole piece arrangement of Figs. 5 and 6 the continuous pole piece member 30 may be replaced by four separable members 34 one associated with and connected to each associated loop member 32, as shown in Fig. 7. The members 34 are obliquely angled at their ends so that when the loops 32 and, hence, the members 34 are moved to an operational position adjacent the strand, i.e. in the direction of arrows X, the ends come into close proximity to one another to provide a substantially continuous flux path. Each of the members 34 carries a discrete pole piece element 35.

As a still further pole piece arrangement (Fig. 8) bridging pole piece members 37, one at each corner of the strand 12, can be used. Each of the loops 32 carries a pole piece element 38 which together with the bridging members 37 define a substantially continuous flux path around the strand when in an operative position. In this way by selecting different sizes for the bridging members 37 the loops 32 can be adapted to different sizes of strand 12. Alternatively the bridging members 37 can overlap the loops 32 to accommodate different sizes.

In the arrangement of separable loops 25A, 25B, 25C and 25D of Fig. 4 and the loops 32 of Figs. 6, 7 and 8 the loops are each associated with energising coils or transformers 29 to generate a magnetic field which rotates about the vertical axis of the strand 12. To achieve this the coils 29 are connected to a multi-phase alternating current supply and different coils are associated with different phases. In this way the magnetic field induced by the currents is made to rotate about the vertical axis perpendicular to the plane of the loops.

Fig. 9 shows one arrangement of the phases in the loops. A two phase supply is used for the four loops 32A, 32B, 32C and 32D. The phases of opposite loops 32A, 32C and 32B, 32D are equal and opposite at any one instant and one pair of opposite loops is of different phase to the other pair of opposite loops.

This arrangement is electrically simple but the secondary current in the loops is not shared so well between the loops and relatively large-section copper bars are required.

In the Fig. 10 arrangement the loops each have two energising coils 29, 29A associated with the loops so that the current is more equally shared. Thus coils of adjacent loops carry part of the current of one phase of the supply and the coils of opposite pairs of loops are of opposite phase. The cross-section of the loops can be reduced compared with the Fig. 9 arrangement for the same magnetic field strength.

The arrangements described can be used for round moulds producing a round strand 12', as shown in Fig. 11. Slab moulds producing a strand 12" having an elongate rectangular shape, as shown in Fig. 12, can also use an arrangement of separable loops, in this case arranged along opposite sides of the strand 12". As illustrated three loops 40, 41 are arranged along each side of the strand 12" and a three phase supply is advantageously employed in the manner indicated.

The stirrers described have the advantage of effecting stirring without the need for an additional stirrer and, especially when separable frames defining the loops are used, the stirrer need not be individually constructed for each mould configuration. Moreover the stirrer may be fitted to an existing mould without significant modification of the mould.

Being situated below the mould the stirrer is not subjected to the same problems as above-mould stirrers and, if necessary the stirrer can be withdrawn from adjacent the strand in the event of, for example, a break out of molten metal from the strand.

The strand as it emerges from the mould has a thin solidified skin which has a high electrical resistance and a low permeability at the temperatures involved, so that the magnetic field is easily able to penetrate the skin into the molten metal in this region. Moreover the field penetrates directly into the molten metal and does not have to fringe down into the metal as with above-mould stirrers. Thus the current required in the conducting loops may be reduced compared with above-mould stirrers or stirrers in which the flux has to penetrate the copper wall of the mould.

The loops require to be cooled during use and water or oil coolant is passed through channels in the loops or through pipes secured to the loops (neither of which is shown).

The coils may be housed in stainless steel boxes (not shown) insulated from the loops and coolant may be passed through the boxes to cool the coils.

CLAIMS

1. A method of stirring molten metal in an open-topped mould (10), characterised by the steps of pouring molten metal into the top of the mould (10), cooling the metal as it passes through the mould (10) so that a skin of solidified metal is formed at the walls of the mould (10) and contains the molten metal as it passes downwardly out of the lower end of the mould as a strand (12) containing molten metal, and electromagnetically inducing a magnetic field in the molten metal by placing induction apparatus (20, 25) about the strand (12) adjacent the lower end of the mould (10), the induction apparatus (20,25) being arranged to produce a magnetic field (21,25a) which rotates about a vertical axis in said strand and the rotary stirring of the molten metal being arranged to induce motion (23) of the molten metal upwards and downwards from the level of the apparatus.

2. Apparatus for stirring molten metal according to the method of claim 1, characterised by comprising an electromagnetic transducer formed of three or more closed loops (25,32,40,41) of electrically conductive material located around the vertical axis of the mould (10), the loops (25,32,40,41) being coupled to the phases of a multi-phase alternating current supply so that the currents passing through the loops (25,32,40.41) will produce a magnetic field which rotates about the vertical axis of the mould (10), the loops (25,32,40,41) being positioned below the lower end of the mould (10) to locate around the strand (12) of metal emerging from the mould (10).

3. Apparatus according to claim 2, wherein the loops (25A, 25B, 25C, 25D) are constructed as individual units separable from one another, each loop (25A, 25B, 25C, 25D) including an inner portion (26A) carrying an electric current derived from a transformer portion including and energising coil (29) radially outwardly located relative to the inner portion (26A) and to the vertical axis of the mould (10).

4. Apparatus according to claim 3, wherein each loop (25A, 25B, 25C, 25D) has a transformer portion which carries at least one energising coil (29), different loops having an energising coil connected to different phases of the multi-phase supply.

5. Apparatus according to any one of claims 2, 3 and 4 wherein the loops (25, 32, 40, 41) are of non-ferromagnetic material and the loops are associated with ferromagnetic pole piece means (30), the pole piece means including a common pole piece member (30) for providing a continuous flux path around the strand and individual pole members (31) associated with each loop.

6. Apparatus according to claim 5, wherein the common pole piece member (30) is formed as elements (34) one associated with each loop (32) and separable from each other.

7. Apparatus according to claim 6, wherein the common pole piece member (30) includes separable elements (38) associated with bridging pole piece elements (37) between the separable elements (38) whereby a substantially continuous flux path is provided through the separable elements (38) and the bridging elements (37).

8. Apparatus according to claim 6 or claim 7, wherein each separable element (38) is associated with a separable loop unit (32).

9. Apparatus according to any one of claims 2 to 8, wherein each loop (32A, 32B, 32C, 32D) has a transformer portion with two energising coils (29, 29A) each connected to a different phase of alternating current, the phase of one coil of one loop being the same as the phase of one coil of an adjacent loop.

10. Apparatus according to any one of claims 2 to 9, wherein the mould (10) is of elongate rectangular section and the closed loops (40, 41) are arranged along the longer sides of the mould (10) and at opposite sides thereof.

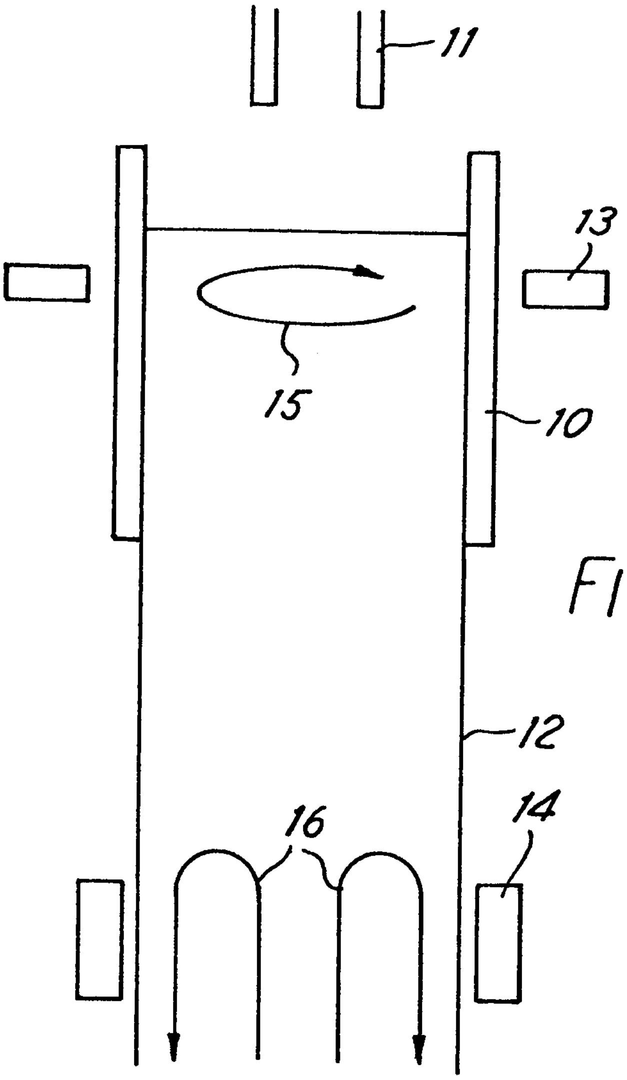

FIG.1

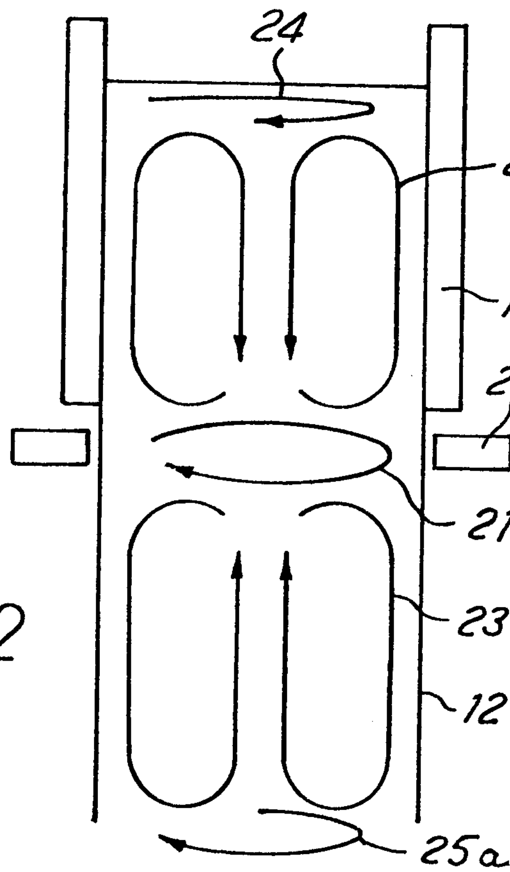

FIG.2

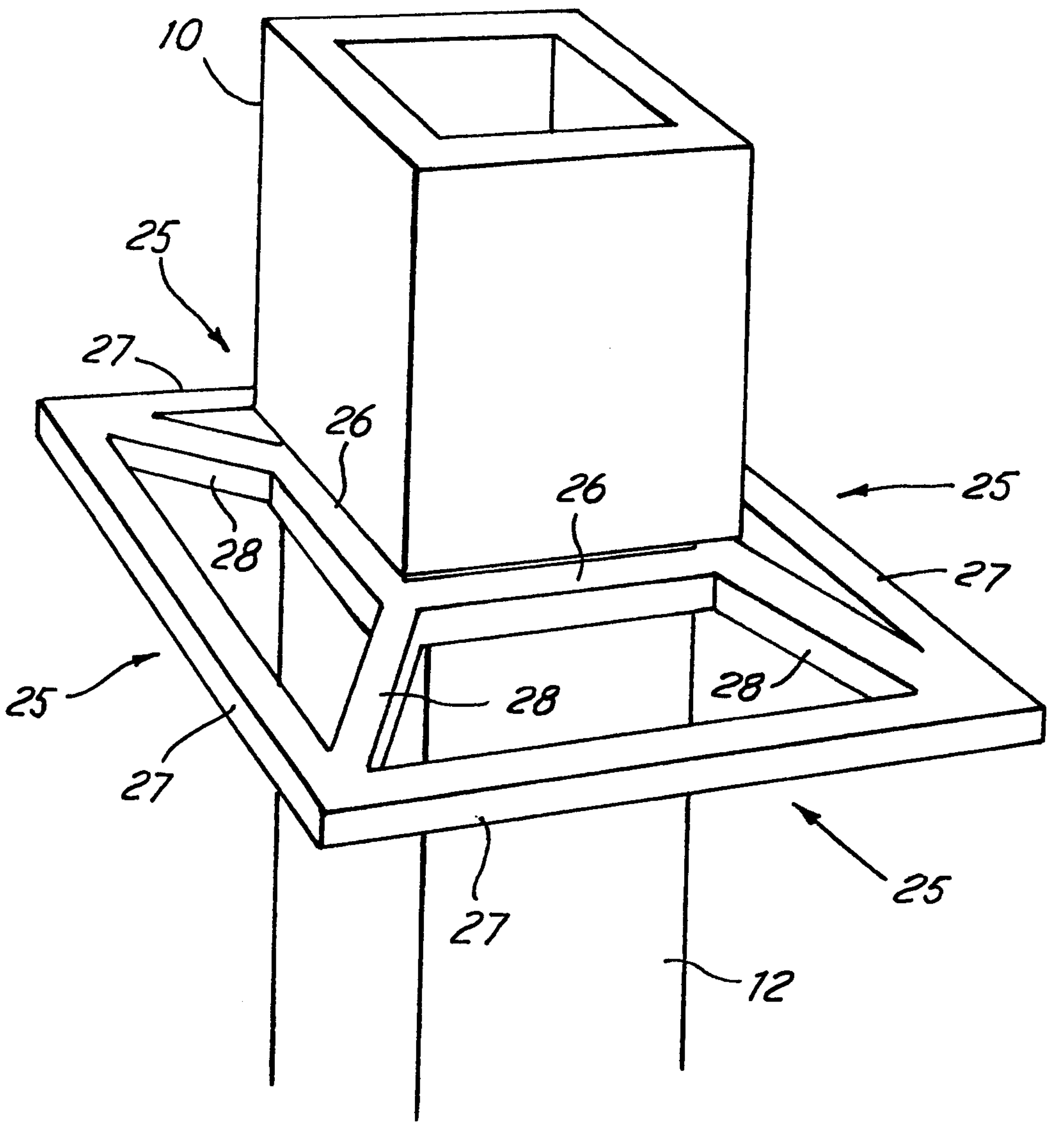

FIG. 3

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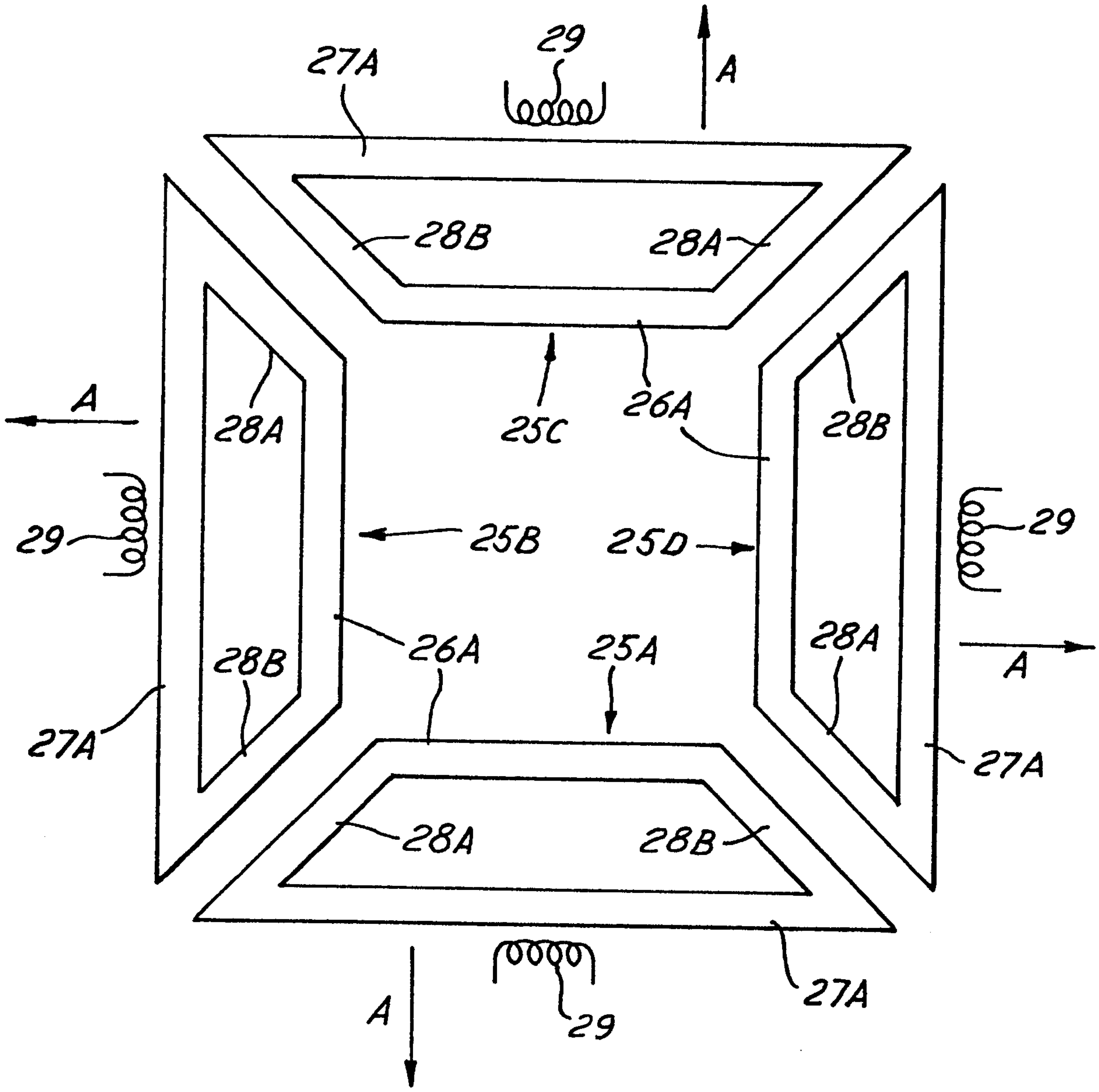


FIG. 4

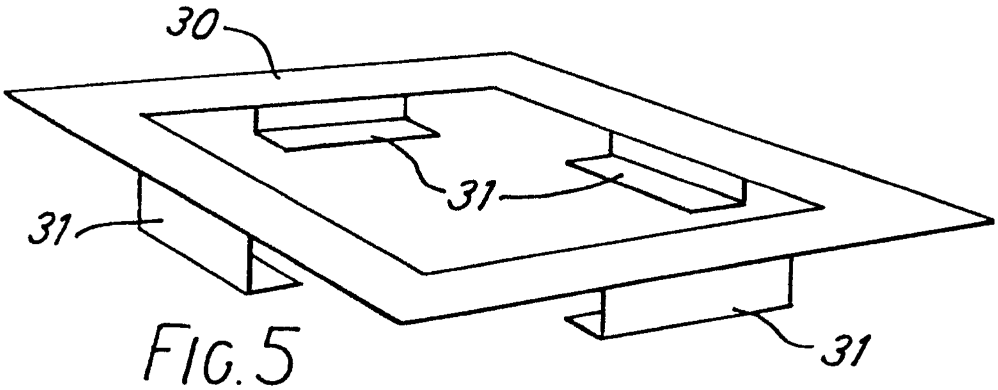


FIG. 5

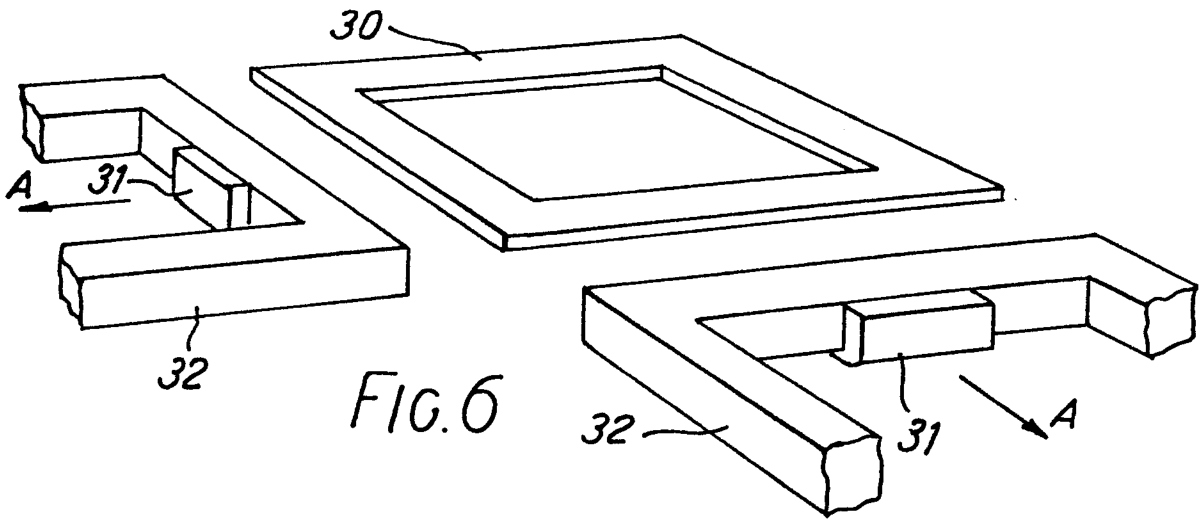


FIG. 6

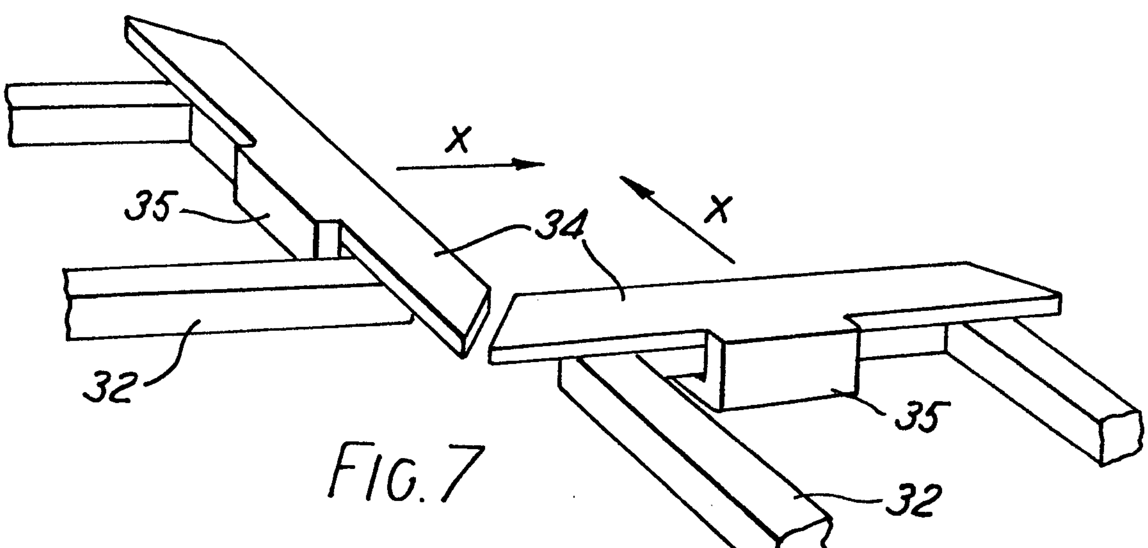


FIG. 7

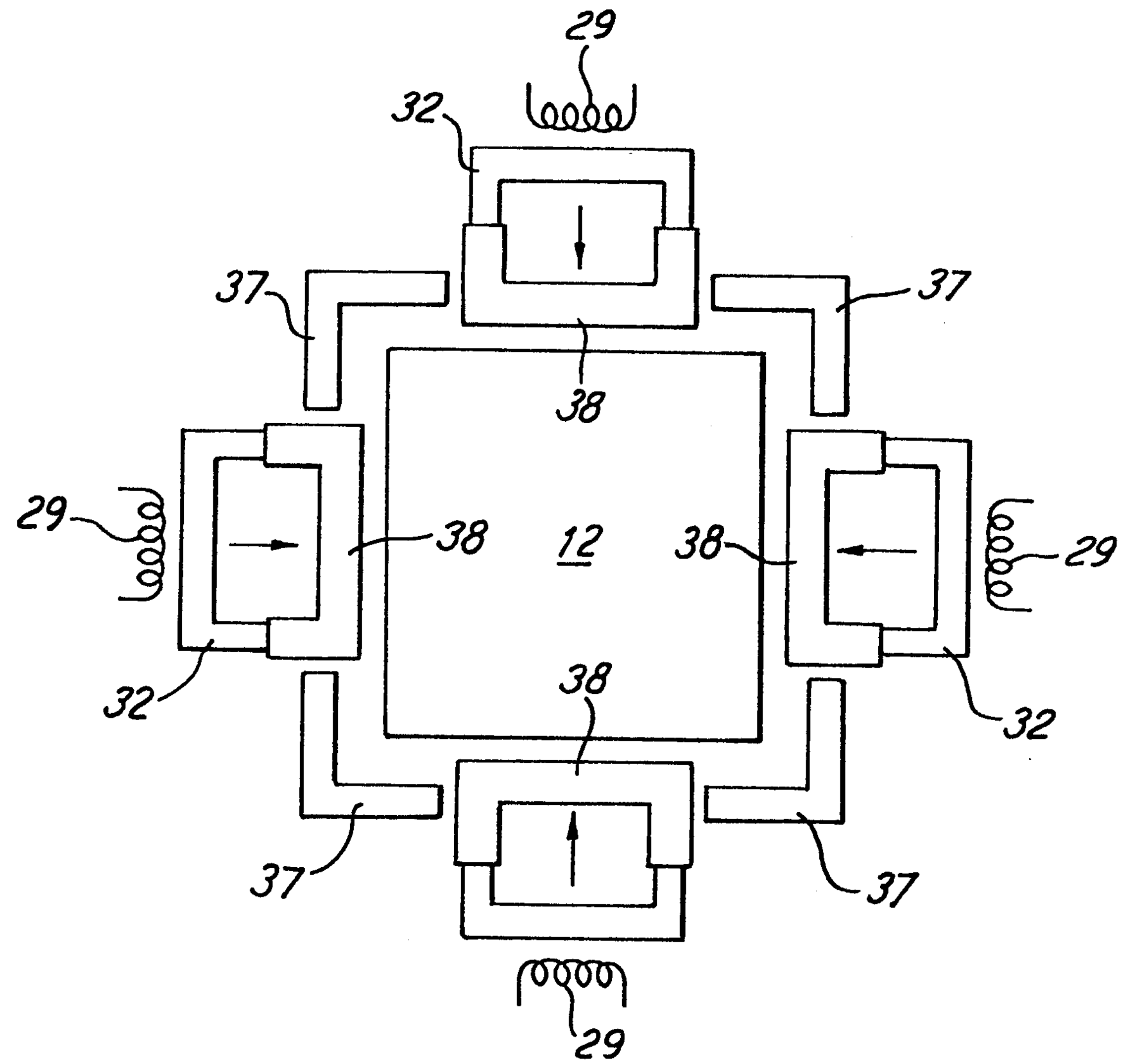
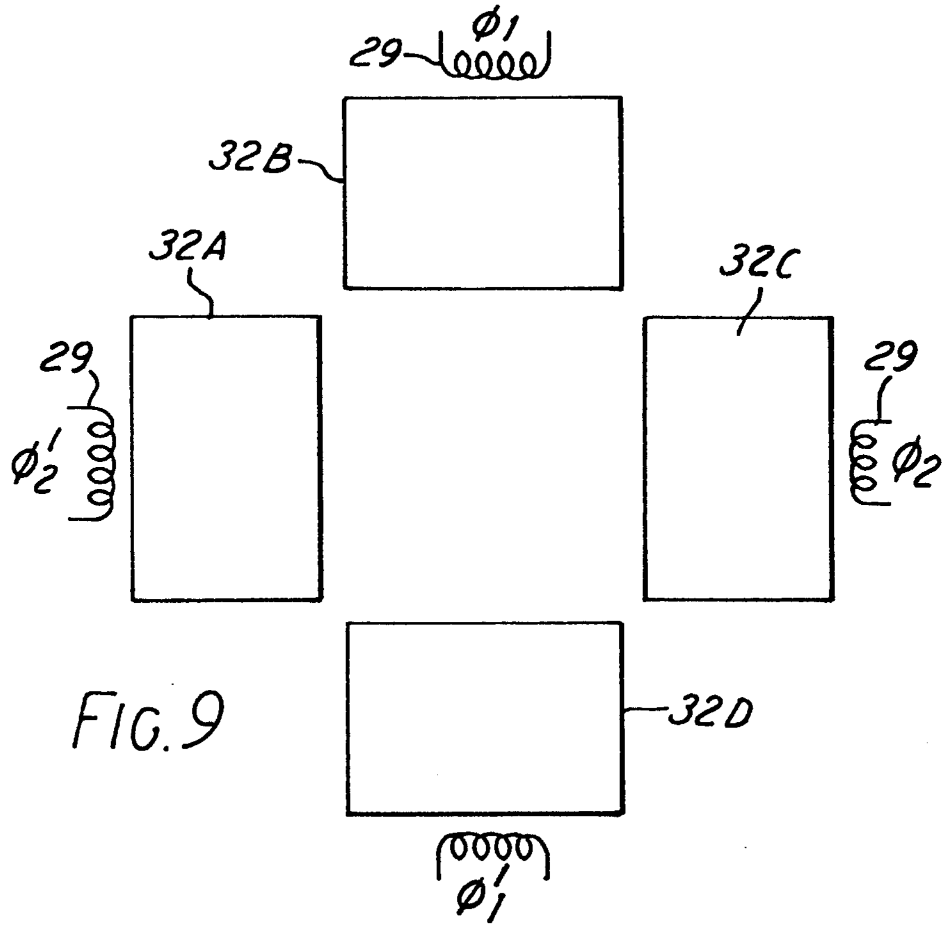
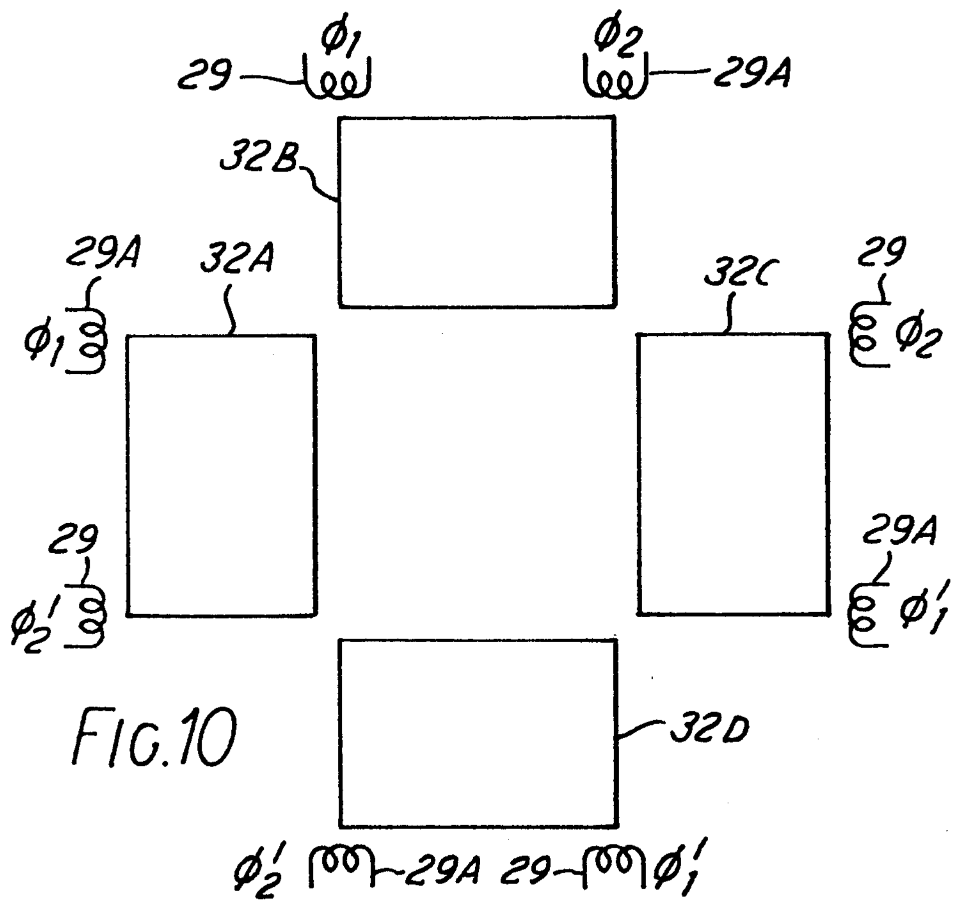


FIG. 8



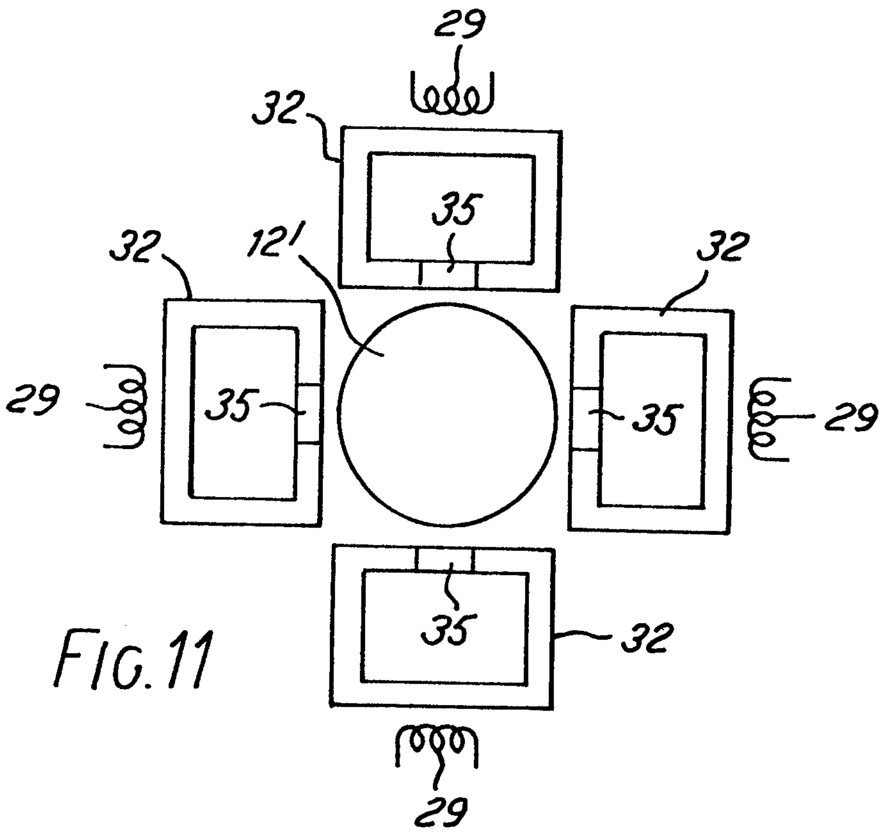
φ1
29
32B
32A
32C
29
φ'2
29
φ2
32D
φ'1

FIG. 9



φ1
29
φ2
29A
32B
29A
32A
32C
29
φ1
φ2
29
29A
φ'2
φ'1
32D
φ'2
29A
29
φ'1

FIG. 10


29
32
35
12'
32
32
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35
35
29
35
32
29

FIG. 11

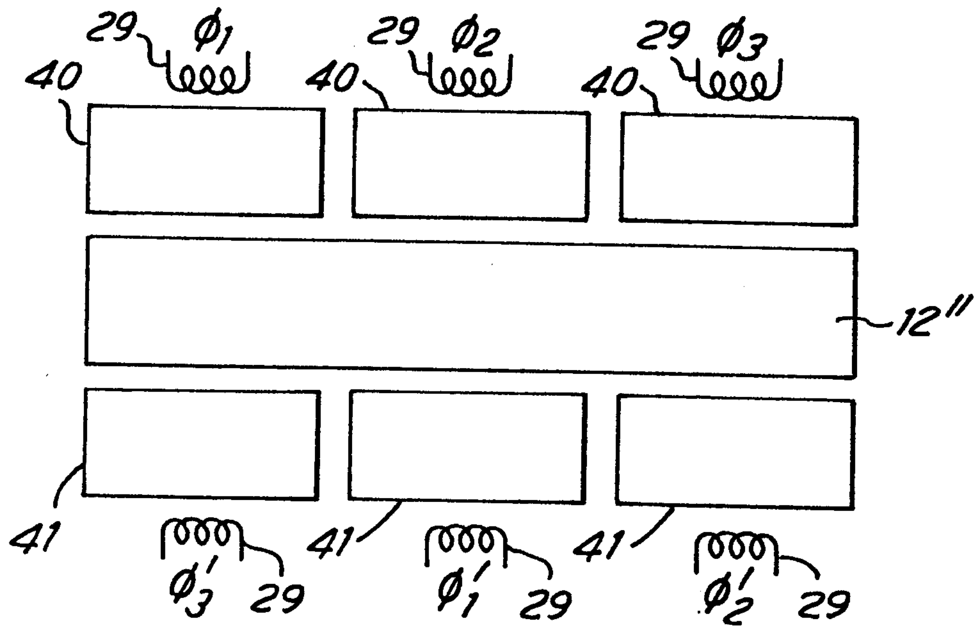
29 ϕ_1
40
29 ϕ_2
40
29 ϕ_3
40
12''
41
41
41
ϕ_3' 29
ϕ_1' 29
ϕ_2' 29

FIG. 12

European Patent Office

0228827

Application number

EUROPEAN SEARCH REPORT

EP 86 30 9455

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
X	GB-A-2 061 783 (ASEA AKTIEBOLAG) * Figure 1; page 1, lines 35-40 * ---	1	B 22 D 11/10
Y	US-A-4 183 395 (STEN KOLLBERG) * Claims 1,3; figures 2,6; column 2, lines 2-6 * ---	1-4	
Y,D	GB-A-2 077 161 (TI(GROUP SERVICES)LTD) * Figure 1; claims 1,5; page 3, lines 7-12 * -----	1-4	
			TECHNICAL FIELDS SEARCHED (Int Cl.4)
			B 22 D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10-03-1987	DOUGLAS K.P.R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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