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(12) # EUROPEAN PATENT APPLICATION

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(54) **Electromagnetic stirring apparatus.**

(57) Windings 16 of electromagnetic stirring apparatus surround a longitudinal chamber and are so connected and energised in use as to create a magnetic field rotating about the axis of the chamber. The windings 16 are arranged around a magnetic core 15 with portions extending outside of the core and portions extending inside the core, the windings being arranged in pairs cyclically, disposed about the chamber 10. The windings of a pair are located opposite each other across the chamber with the extents of the windings inside the core carrying simultaneous current in the opposite sense on opposite sides of the chamber. The core 15 and the winding 16 preferably have a long extent parallel to the axis of the chamber and a short extent radial thereto. The core 15 preferably extends in a complete magnetic circuit around the chamber. The chamber 10 may be a mould for continous casting of steel, the steel being stirred in the molten state as it passes longitudinally along the mould.

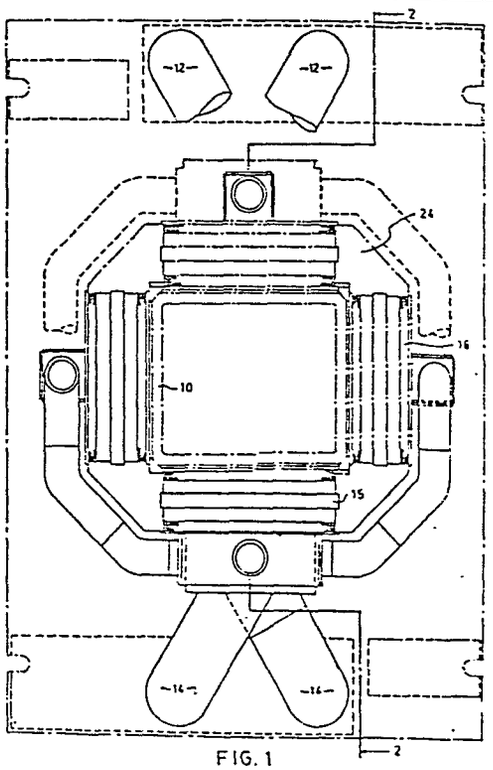

FIG. 1

EP 0 058 048 A1

ELECTROMAGNETIC STIRRING APPARATUS

This invention relates to electromagnetic stirring apparatus for the provision of a magnetic field rotating about the path of steel through a continuous casting mould, the purpose of such field being to cause rotation of the steel, which is still liquid, in the mould.

By the term 'axis of the mould' herein is meant the line extending in the direction of flow through the mould at the approximate centre of such flow.

In European patent publication 00 36 302, there is described a electromagnetic stirring apparatus which eliminates the use of radially (relative to the mould axis) directed pole pieces associated with the magnetic field rotation apparatus surrounding the core. Omitting such pieces, the prior publication provided coils (corresponding to each phase of the exciting A.C. current) which were made up of turns extending down one side of the mould, half-way about the mould, up the opposite side, half-way about the mould down the one side and so on. Such windings produced a magnetic field extending across the mould and together with similar windings cyclically disposed about the mould and subject

to multi-phase energization produce a rotating magnetic field in the mould. Although such arrangement has been successful and the elimination of the pole pieces an advantage, such arrangement has had the disadvantage that for each coil, each turn extent running axially of the mould (which is the portion of the turn affecting the production of the rotating magnetic field) has required a connecting extent running half-way about the mould to a corresponding turn extent on the other side. Such connecting extents corresponding in number to each half turn in the winding have been cumbersome and have interfered with and caused undesirable modification to the design of the moulding apparatus as a whole.

It is the object of this application to provide a design for providing a rotating electromagnetic field for a continuous casting mould which eliminates the need for pole pieces but also provides the vertical turn extents for the desired magnetic field without the necessity of large numbers of connecting extents.

According to one aspect of the invention there is provided apparatus for causing electromagnetic stirring in a continuous casting mould be characterised by comprising;

a magnetic circuit formed of magnetic material extending substantially continuously about said mould and spaced therefrom,

at least two pairs of windings,

each winding comprising extents arranged to carry current in one direction on the inside of the magnetic material and extents arranged to carry such current in the other direction on the outside of the magnetic material,

the windings in a pair being located opposite each other across the flow axis of said mould whereby they may be energized by the same phase of alternating current to produce in the respective inside extents of such opposed pair of windings simultaneous current in the opposite sense on opposite sides of said mould,

wherein the number of winding pairs is integrally related to the number of phases of a multiphase electrical supply and windings corresponding to such phases are arranged cyclically around the mould.

According to another aspect of the invention there is provided apparatus for causing electromagnetic stirring in a continuous casting mould characterised by comprising;

at least one pair of windings corresponding to each phase of a multiphase alternating current supply,

the windings in a pair being located opposite each other across said mould,

windings corresponding to said respective phases being arranged cyclically about said mould.

each said windings being composed of turns having long dimension extents parallel to the flow axis of said mould and short dimension extents transverse to such axis,

said windings being wound about cores of magnetic material.

By 'cyclically' is meant that, (for example with two phases) the windings will be arranged Phase 1+, Phase 2+, Phase 1- and so on about the mould and with three phases the windings are arranged: Phase 1+, Phase 2+, Phase 3+, Phase 1- and so on about the mould. Preferably, each of the windings comprises a plurality of turns wound on a core arranged to have a long extent of a turn on the mould-adjacent and on the mould-remote sides of the core, and short connecting extents connecting the long extents which thus alternate inside and outside the core. Such a winding provides the plurality of nearly vertical turn extents adjacent the mould. The combination of such winding having such mould adjacent turn extents carrying current in one of the upward or downward directions with its counterpart coil of the same phase with its mould-adjacent extents carrying current in the opposite direction to the first, is to provide flux across the mould in a sense determined by the mould-adjacent current directions and perpendicular thereto.

Coupled with the effects of the pairs of coils of other phases there is produced the desired rotating field in the mould which will rotate the molten steel being continuously cast therein. A core can be provided for each coil. Magnetic material is preferably provided substantially joining the ends of the cores of adjacent coils as encountered moving about the mould. With such joining magnetic material there is provided a magnetic circuit extending about the mould.

Tests have indicated that the magnetic field effects inside the mould are at their maximum in the vertical extent opposite the core and drop off rapidly at locations along the axis beyond the core. Accordingly, it is preferred that the core shall have the shape of the coil cross section, having in radial cross section relative to the axis of the mould a long dimension axially of the mould (for the approximate extent desired for the effective operation of the rotating field) and a short dimension measured in a radial direction.

The long turn extents of each winding on the side of the core remote from the mould do not contribute to the desired field in the mould. However due partially to the presence of the core such mould-remote extents do not materially detract from such field. It is noted that with such arrangement of paired coils on sides of

the mould, these paired coils may be connected in series to the phase supply, requiring only a single connection between the one end of a paired coil and one end of the other paired coil. Thus the cumbersome multiple connections of the apparatus shown in the earlier publication are avoided. Connecting the paired coils in parallel may further reduce the connections between the coils. However, the series connection between the coils is preferred since the use of a single type of current capacity conductor renders fabrication simpler.

In drawings which illustrate preferred embodiments of the invention:

Figure 1 is a horizontal cross-section of the inventive electromagnetic stirring apparatus for a continuous casting mould,

Figure 2 is a partial vertical cross-section along the lines 2-2 of Figure 1,

Figure 3 is a schematic indication of the winding connections for a mould,

Figure 4 is a plan view of a form of the electromagnetic stirring apparatus which is an alternative to that shown in Figure 1,

Figure 5 is a vertical cross section along the lines 5-5 of Figure 4,

Figure 6 schematically indicates the application of the invention to three phase wiring.

Figure 6A shows the three phase connection of the windings in Figure 6.

In Figure 1 is shown a rectangular continuous casting mould defined by mould wall 10. A cooling pipe network is provided for cooling the mould along with water inlet and outlet conduits 12 and 14. These are not described in detail since they are well known and conventional in the continuous casting arts. As indicated in Figure 2 the mould walls to the left and right of the Figure are slightly curved to be concave to the right. Such curvature in one of the four directions is provided in modern moulds to allow the billet direction to be gradually altered from one direction (here vertical) to another (here horizontal). Older moulds have straight wall sides and both types are within the scope of the invention.

Corresponding to each side of the mould is provided a coil comprising a core 15 and a multi-turned winding 16 wound thereon. Figure 1 is a horizontal section. As Figure 3 indicates the winding segments shown on each side of the core are joined over the top and bottom of the core.

Core 15 as shown extends, in plan view, approximately

the length of the mould side. It is relatively thin in vertical cross-section. It is shown as constructed of three laminations of suitable magnetic core material rivetted together. However the lamination arrangent is merely for ease of fabrication and desired dimensions of core 15 of suitable magnetic material may be achieved in any desired way. As indicated, the core 15 is provided with a long dimension in its axial direction relative to its thickness and to the axial height of the core. The axial height and axial location of the core defines effectively the effective axial height of the rotating electromagnetic field in the mould.

As indicated in Figures 1 and 2 a winding is formed by turns having a long axial dimension extent down one side of the core, a short radial transverse extent about the lower edge, a long axial extent up the other side of the core, about the upper edge again, down the mould and so on. The core, wound in this way, may be provided with the number of layers and of turns desired. Such a winding is provided with leads 18 and 20 which are connected, (and the winding is wound) so that the current flows in one direction (up or down) one one side of the core and in the opposite direction on the other. The windings are paired on opposite sides of the mould and are connected in series which series connection, together

with the winding direction, is used to provide that the mould-adjacent extents (i.e. the parts of the winding turns between the core and the mould) carry (at an instant in the A.C. energization) current down in the winding on mould-adjacent long extents on one side of the mould and current up in the mould adjacent long extents of the paired coil on the other side of the mould. Such currents will produce a field across the mould having its main component transverse to both the mould axis and to the diameter extending between the centre of the paired windings. When the magnetic effects of such paired coils are combined with the field produced by the other two paired coils, and the two pairs of coils are respectively excited by the two phases of a two phase relationship, a rotating magnetic field is produced in the mould which causes rotation of that steel in the mould which is in its liquid state.

Figure 3 represents schematically the two sets of paired windings 16 in relation to input leads and the mould wall 10. Thus one pair of windings 16 is connected in series between the phase 1 power input P and neutral connection N while the other pair of coils 16 is connected by two connections 22 in series between the phase 2 power input Q and the neutral connection N. It will be noted that, in distinction from prior art arrangements, that only one connection is required between paired coils.

(It will also be noted that there would be no greater number of connections if the paired coils were connected in parallel). It will also be noted that when the two sets of paired coils are energized with two phase power, with a phase angle of 90° between the phases, that there is created desired rotating electromagnetic field and having a rotational frequency equal to the exciting frequency of each phase. (It is within the scope of the invention to provide multiple pairs of coils per phase cyclically arranged about the mould). As indicated in Figure 3, the series connection of the paired opposite windings 16 only requires a single conductor 22 between the series connected windings which conductor 22 extends half-way about the mould and (if input leads P, Q and N are all on the same side of the assembly) a conductor from the non-series connected end of one of the coils which is remote from the input leads P, Q and N round to the side of the input leads. Thus with this arrangement cumbersome multiple leads are avoided. As explained in the introduction, the opposed paired windings 16 may be connected in parallel across the relevant phase of the two phase supply and with such parallel connection no more and possibly less leads are required about the mould.

To complete the magnetic circuit about the mould,

which is desirable, magnetic core material is provided in the corner members 24 which are triangular in plan view and extend for the approximate height of the core. The members 24 about the ends of core members 15 on each side of a respective corner to provide with such core members a substantially continual magnetic circuit about the mould.

Figures 4 and 5 show an arrangement where the magnetic circuit is, in effect, a unitary core member 28, formed of magnetic material, extending about the core, although it may be formed of separate connected members if desired. On each of the four sides of the core, two peripherally designed recesses 30 are provided so that the windings 32 on each side of the mould may be wound in two sections for convenience of winding. The two sections on each side of a core are connected in series and the paired windings 32 on opposite sides of the mould are connected in series by a single conductor as in the alternative of Figure 1. As in the Figure 1 alternative the winding sense and the connections are such that the turn extents of mould-adjacent sides of opposed coils carry current down on one side of the mould and up on the other at any instant of the A.C. energization. The two divisions shown on one side of a coil are designed for more convenient winding. The connection of the opposed

pairs of coils is in series and the relationship is the same as with the embodiment of Figure 1. With pairs of coils connected in series a single half turn is needed to connect ends of paired coils.

When, in relation to the embodiments of Figures 1-3 or Figures 4 and 5 the term "single conductor" is used referring to the connections to or between windings, this is not intended to be limiting. The invention requires only a single connection to or between windings about the mould. This connection may for current carrying capacity or ease of winding be embodied in two or more conductors which together establish the connection.

Figure 6 shows the same elements as shown in Figures 1 and 2 adapted for three phase operation. Thus the windings of the alternative of Figure 6 have, collectively, the same extent as those shown in Figures 1 and 2. However the windings of Figure 6 comprise three pairs, for example each winding 31 forming part of the phase 1 pair extents along 2/3 of a side as does each winding 33 corresponding to the phase 3 pair. The phase 2 windings 32 each have adjacent extents 32A and 32B connected about a corner. The windings in a pair are located in opposing positions across the mould and the phases of the windings are cyclically distributed about the mould. The windings for a phase, connected

as indicated in Figure 6A, are wound so that, in the extents between the core and the mould, current runs down on one side of the mould and up on the other. Thus the portions of the winding pairs inside the core produce 3 fields whose combined effect, with the three phase energization, is to produce a magnetic field across the mould rotating in accord with the three phase energization.

CLAIMS:

1. Apparatus for causing electromagnetic stirring in a continuous casting mould 10 characterised by comprising;

a magnetic circuit 15, 24 formed of magnetic material extending substantially continuously about said mould and spaced therefrom,

at least two pairs of windings 16,

each winding comprising extents arranged to carry current in one direction on the inside of the magnetic material and extents arranged to carry such current in other direction on the outside of the magnetic material,

the windings in a pair being located opposite each other across the flow axis of said mould whereby they may be energized by the same phase of alternating current to produce in respective inside extents of such opposed pair of windings simultaneous current in the opposite sense on opposite sides of said mould,

wherein the number of winding pairs is integrally related to the number of phases of a multiphase electrical supply and windings corresponding to such phases are arranged cyclically around the mould.

2. Apparatus for causing electromagnetic stirring in a continuous casting mould 10 characterised by comprising;

at least one pair of windings 16 corresponding to phase of a multiphase alternating current supply,

the windings in a pair being located opposite each other across said mould,

windings corresponding to said respective phases being arranged cyclically about said mould,

each said windings being composed of turns having long dimension extents parallel to the flow axis of said mould and short dimension extents transverse to such axis,

said windings being wound about cores 15 of magnetic material.

3. Apparatus as claimed in claim 2 wherein each said core 15 is formed, in cross-section radial with respect to the axis of said mould to, having a long dimension parallel to such axis and a short dimension extending radially with respect therto.

4. Apparatus as claimed in claim 2or claim 3 wherein magnetic core material 24 is provided extending substantially between the ends of adjacent cores 15 whereby a magnetic circuit formed of said cores and said extending core material extends substantially continuously about said mould.

5. Apparatus as claimed in claim 1 wherein said turns are arranged to have a long extent parallel to the axis of said mould and a short extent transverse thereto.

6. Apparatus as claimed in claim 1 or claim 5 wherein said magnetic material is formed in cross-section radial relative to said mould having a long dimension parallel to the axis of said mould and a short dimension radial with respect to said axis.

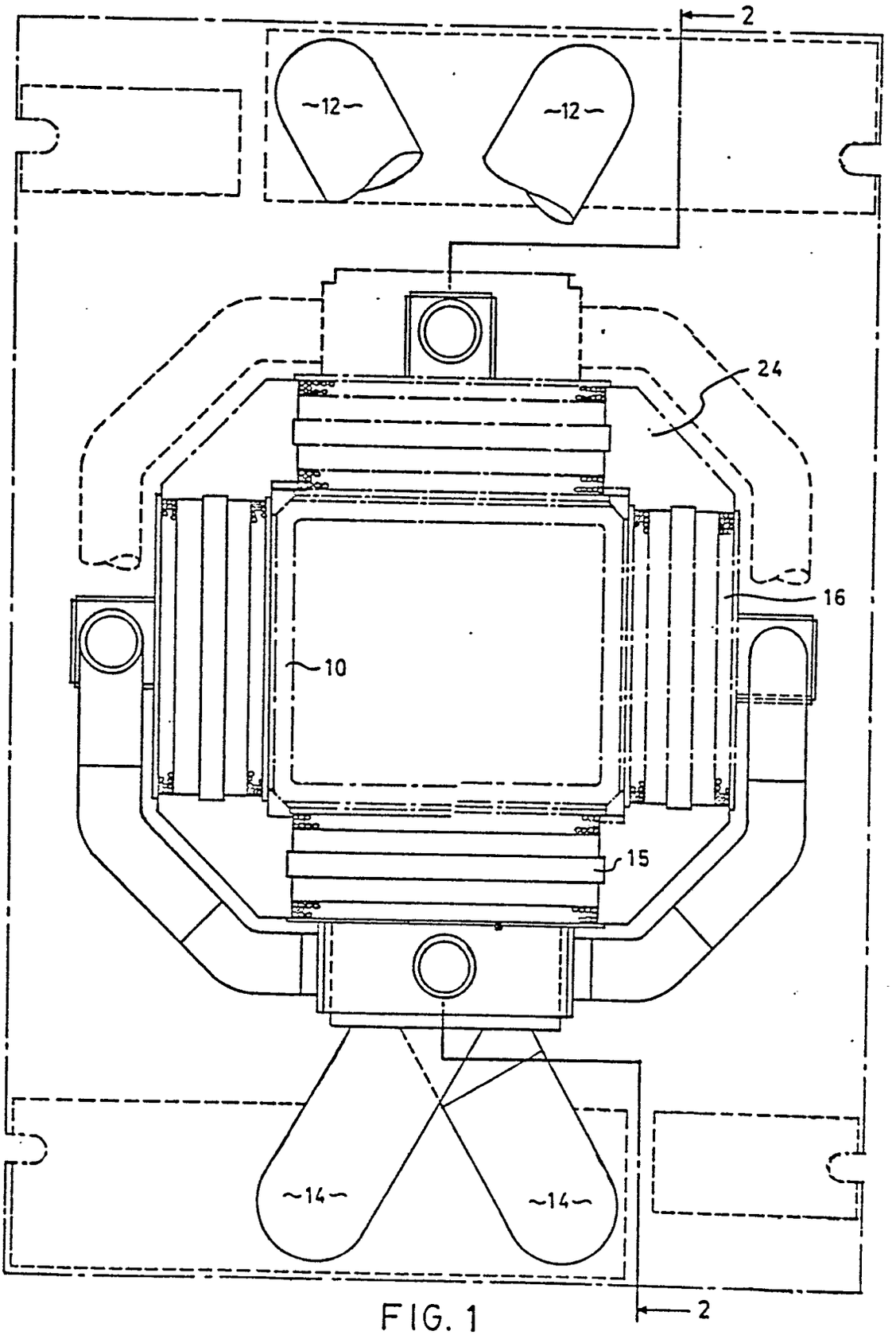

FIG. 1

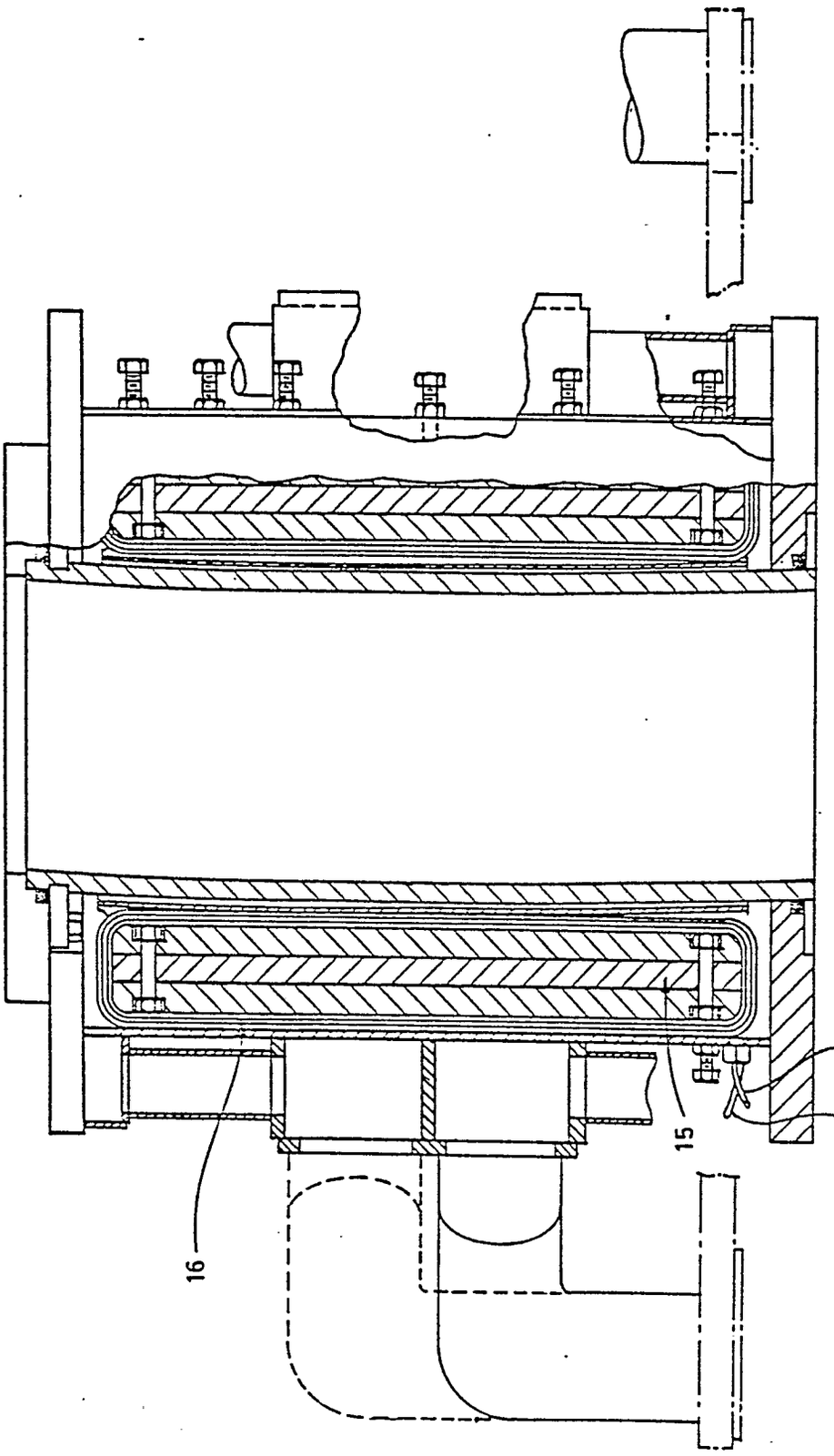

FIG. 2

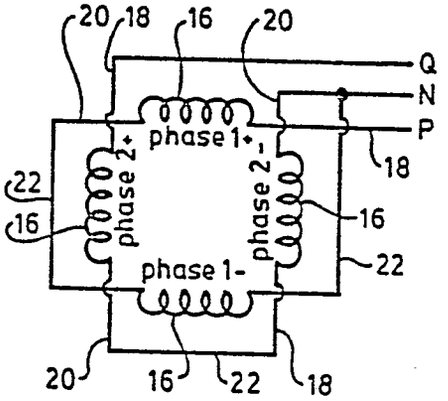
20
18
16
20
Q
N
P
18
22
16
phase 2+
phase 1+
phase 2-
16
22
phase 1-
20
16
22
18

FIG. 3

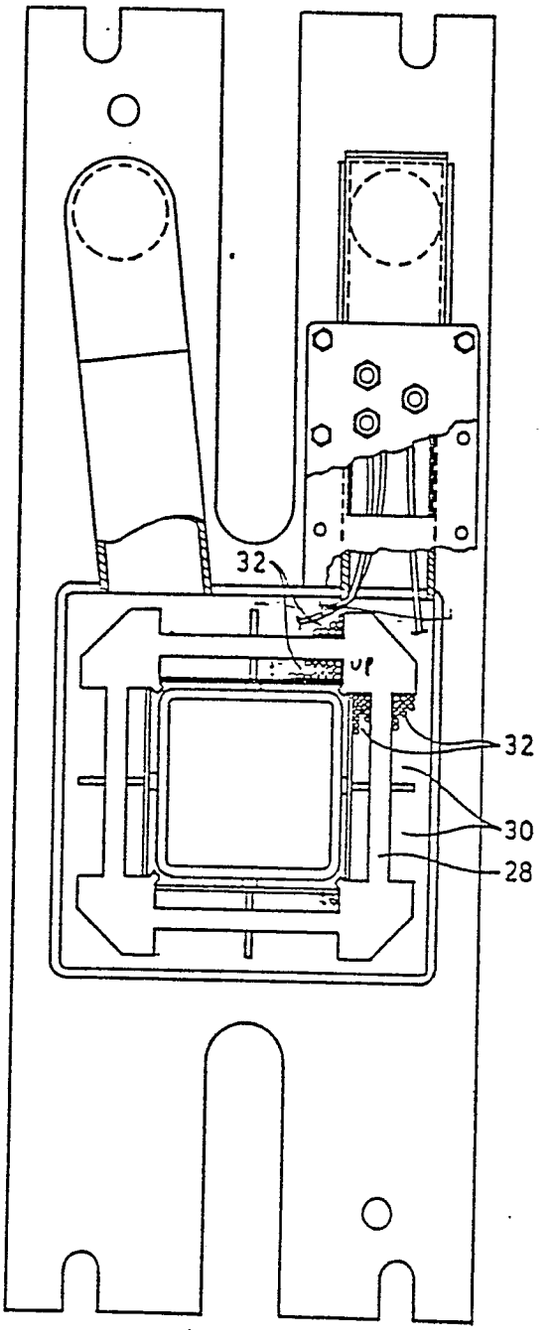
32
32
30
28

FIG. 4

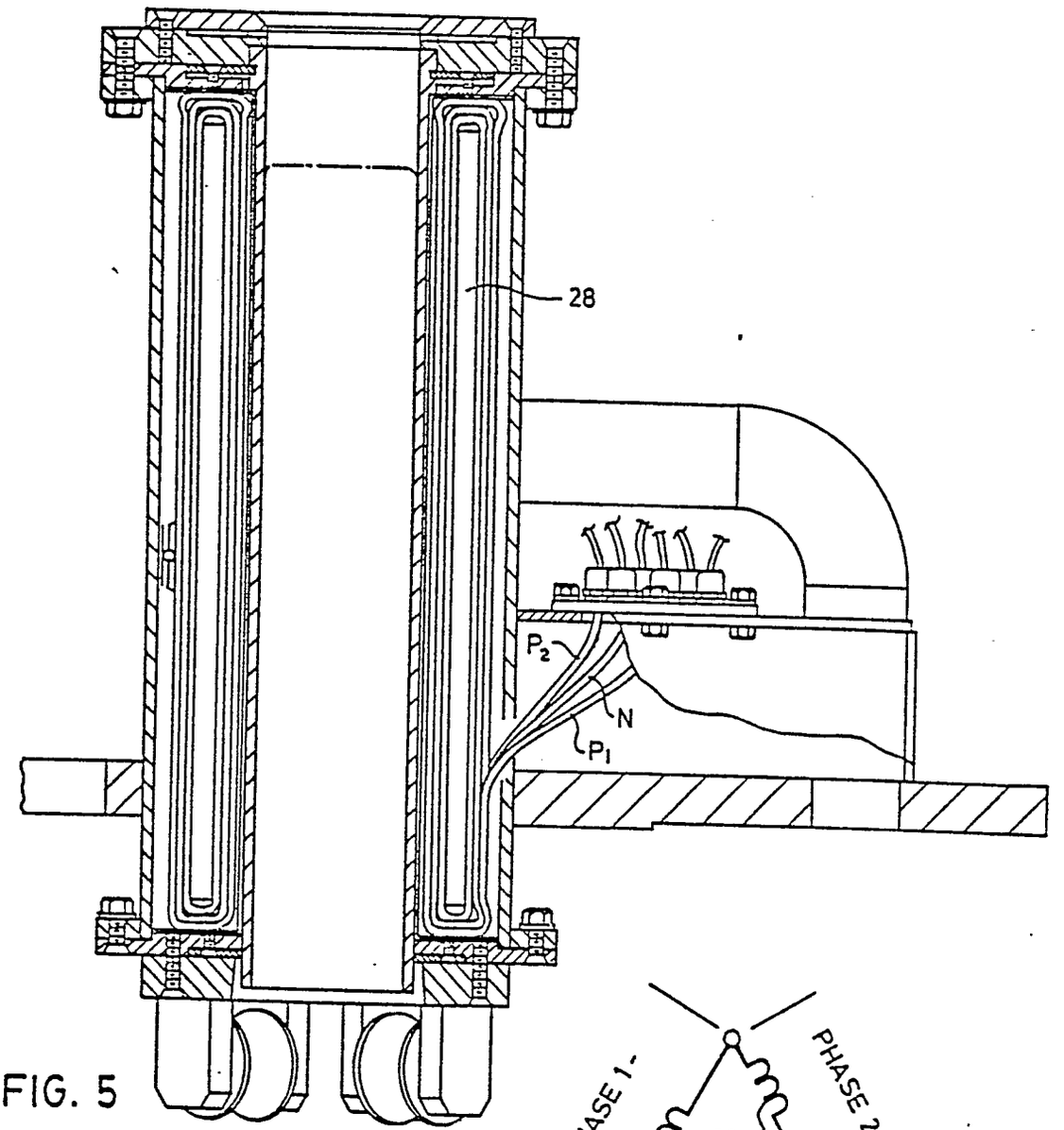
28
P2
N
P1

FIG. 5

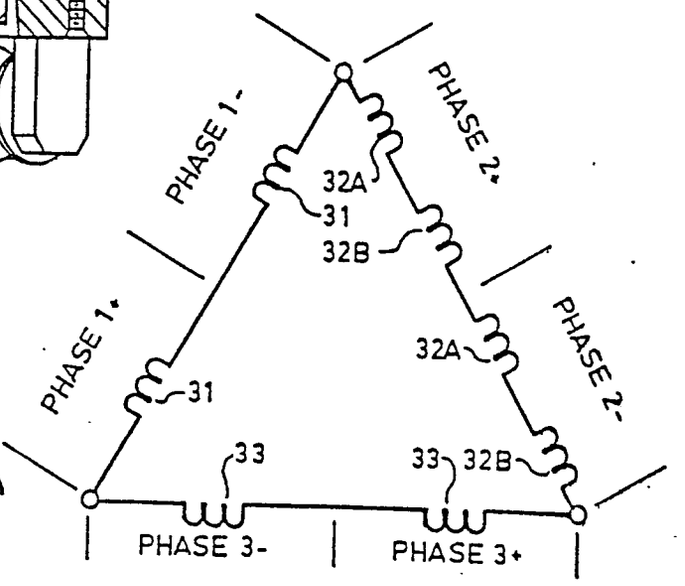
PHASE 1-
PHASE 2+
32A
31
32B
PHASE 1+
PHASE 2-
32A
31
33
33
32B
PHASE 3-
PHASE 3+

FIG. 6A

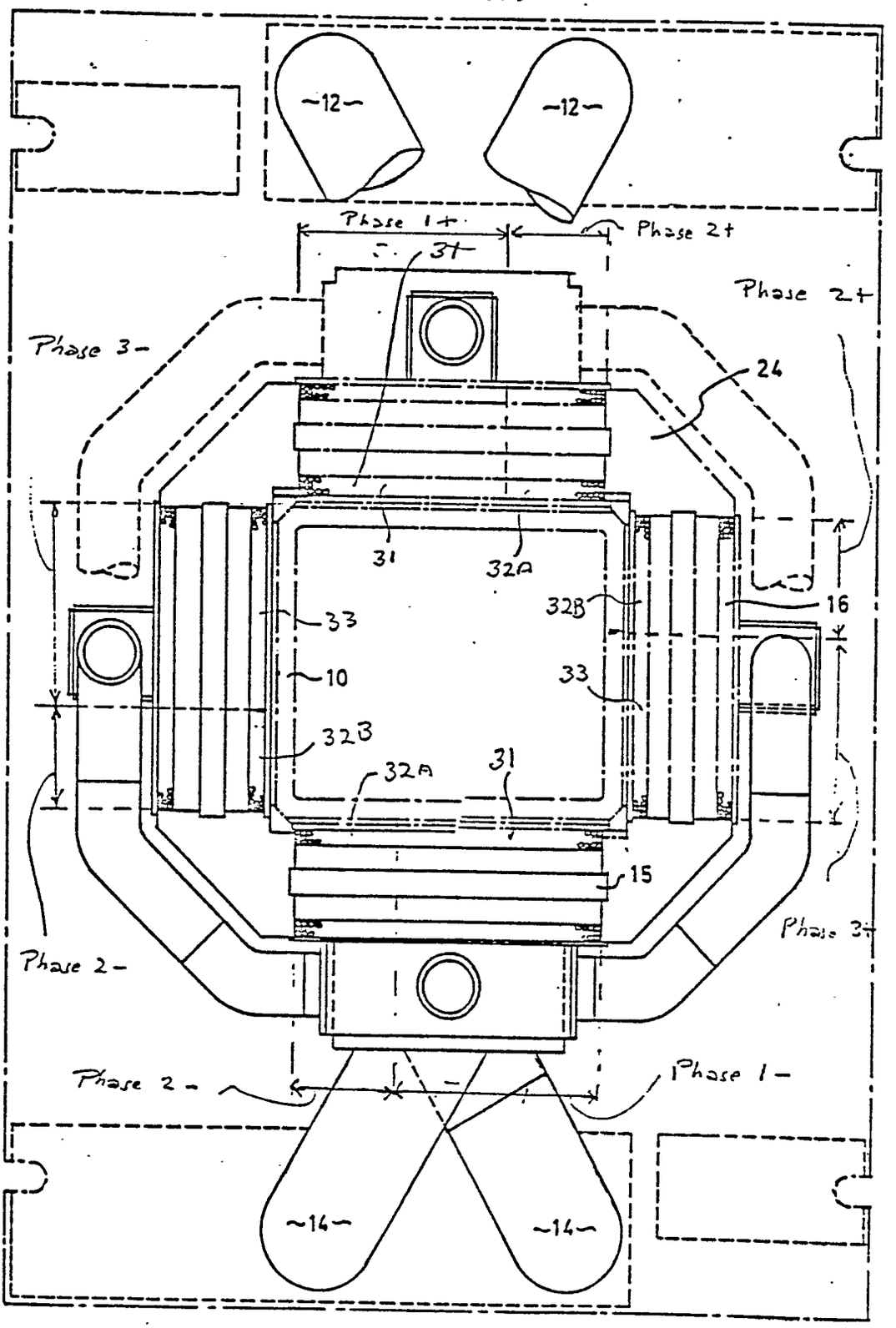
12
12
Phase 1+
Phase 2+
31
Phase 2+
Phase 3-
24
31
32A
32B
16
33
10
33
323
32A
31
15
Phase 3+
Phase 2-
Phase 2-
Phase 1-
14
14

FIG. 6

2277-20

European Patent Office

EUROPEAN SEARCH REPORT

0058048

Application number

EP 82 30 0550

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. 3)
A	FR - A - 1 064 849 (ROSSI) * Figure 1 * ----	1,3,5,6	B 22 D 11/10 27/02 H 05 B 6/34

TECHNICAL FIELDS SEARCHED (Int.Cl. 3)

B 22 D 11/10
27/02
H 05 B 6/34
6/36

CATEGORY OF CITED DOCUMENTS

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X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	06-05-1982	SCHIMBERG

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