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(54) Travelling wave induction heater.

(57) A travelling wave induction heater comprising a plurality of primary windings (W) and associated core means (P_1-P_2), and means to connect successive windings (W) to successive phases of a multi-phase electric supply to provide the primary of the travelling wave induction heater, whereby, in use, a travelling magnetic field is produced and there being an electrically conductive member (20), in which eddy currents are induced by the magnetic field, and which acts as a secondary of the heater and is thereby heated, wherein the primary windings (W) are arranged in a plurality of sets, there being means to connect successive windings of each set to successive phases of a multi-phase electric supply whereby each set produces a travelling magnetic field.

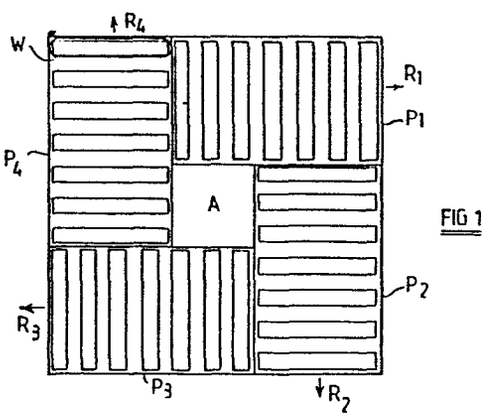

FIG 1

EP 0 170 417 A1

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Title: "Travelling wave induction heater"

This invention relates to a travelling wave induction heater comprising a plurality of primary windings and associated core means, and means to connect successive windings to successive phases of a multi-phase electric supply to provide the primary of the travelling wave induction heater, whereby, in use, a travelling magnetic field is produced and there being an electrically conductive member, in which eddy currents are induced by the magnetic field, and which acts as a secondary of the heater and is thereby heated. Such a heater is referred to hereinafter as being of the kind specified.

In heaters of the kind specified, the heating of the secondary may not be uniform for a uniform primary winding distribution and an object of the invention is to overcome this problem.

According to one aspect of the present invention, this problem is overcome by providing a heater of the kind specified in which the primary windings are arranged in a plurality of sets, there being means to connect successive windings of each set to successive phases of a multi-phase electric supply whereby each set produces a travelling magnetic field.

Preferably, the travelling magnetic field produced by one set travels in a direction which is different to the direction of travel of the travelling magnetic field produced by the, or at least one of, the other sets of windings.

There may be four sets of windings disposed in the quadrants of a rectangle defined by orthogonal axes passing through the mid points of the sides of the rectangle.

The travelling waves produced in each quadrant may travel in directions inclined at 90° to each other so that the angle between the direction of travel in adjacent quadrants add algebraically to 360°.

Alternatively, the travelling wave produced in two adjacent quadrants may travel in parallel directions whilst the travelling wave in the other two quadrants may also travel in parallel directions but opposite to the direction of travel of the waves in the first mentioned quadrants.

The sets may be arranged in a square configuration and the sets may themselves each be square, in which case a corner of each set meet at the centre of the square.

Alternatively, when the heater is square, the sets may be rectangular and disposed so as to provide a square or rectangular opening at the centre of the square heater.

When the heater is rectangular, the sets may also be of a corresponding but smaller rectangular configuration.

The core means of each set may be discrete and separate from the core means of each other set.

Alternatively, the core means of each set may comprise a part of a common core having pole pieces of appropriate orientation to provide the above mentioned direction of travel for the travelling wave produced by each set.

The secondary is preferably a single secondary member of a shape complementary to the shape of the primary.

Alternatively, the secondary may comprise a plurality of discrete and separate secondary members each of a configuration complementary to the configuration of an associated set of primary windings and core means.

If desired, the secondary may have a non-uniform electrical conductivity, the distribution of electrical conductivity being such as to provide a desired distribution of heating in the secondary.

The secondary may comprise at least part of a workpiece to be heated.

Alternatively, the secondary may comprise a heating member which, in use, heats a workpiece by heat transfer.

The secondary may comprise a component of a relatively high electrical conductivity material such as copper or aluminium or zinc or brass, having at least one opening therein and/or area of lower conductivity and/or area of different thickness.

The secondary may comprise a single element or be fabricated from a plurality of elements.

The secondary may also comprise an element of ferro magnetic material such as cast iron, soft iron or steel.

In this case the secondary may be formed separately from the remainder of the secondary and may be secured thereto. Alternatively it may comprise a coating applied to the remainder of the secondary, for example by spraying.

Alternatively the component may comprise the whole of the secondary, particularly where the secondary comprises said heating member.

In one application of the invention the secondary comprises a mould of a moulding apparatus.

The mould may be positioned between a pair of relatively movable press members for the application of pressure to the mould.

Examples of the invention will now be described, with reference to the accompanying drawings, wherein:-

FIGURE 1 is a diagrammatic plan view of the primary of a heater of square overall configuration with a central aperture and embodying the invention;

FIGURE 2 is a diagrammatic perspective view of part of the primary of the heater shown in Figure 1;

FIGURE 3 is a diagrammatic plan view of the primary of another embodiment of the invention where the heater is square without a central aperture;

FIGURE 4 is a diagrammatic plan view of the primary of another embodiment of the invention showing a rectangular heater;

FIGURE 4a is a diagrammatic plan view of a modification of the heater shown in Figure 4;

FIGURE 5 is a diagrammatic perspective view of a secondary of a further embodiment of the invention; and

FIGURE 6 is a side elevation of a further modification embodying the invention.

Referring to Figures 1 and 2, a travelling wave induction heater embodying the invention comprises a primary core made up of four discrete and separate core members P_1-P_4 arranged as shown in Figure 1 so as to produce a heater of square overall configuration with a central square aperture A. As best shown in Figure 2, each core member P_1-P_4 comprises a plurality of iron laminations 10 which may be insulated to reduce eddy current effects and are clamped together by nut and bolt fasteners 11 to provide a series of adjacent teeth 12 having coplanar pole faces 13. The teeth 12 are insulated in conventional manner and copper wire windings W are formed around the teeth with successive windings being connected to successive phases of a multi-phase supply in conventional manner to produce a travelling wave. In the present example, the multi-phase supply is three phase. If desired, the supply may be of other than three phase, although

three phase supply is preferred as it is readily commercially available. Also if desired, the winding may be any other pattern that produces a travelling field. In Figure 1 windings W are shown around one tooth only for clarity. This is also the case in Figures 3, 4 and 4a.

The thus formed primary member is then embedded in epoxy resin (not shown) in conventional manner and a terminal box (not shown) is provided for connection to the multi-phase supply.

The thus formed primary members are then assembled together and electrical connection to the multi-phase supply established so that the separate travelling wave produced by each set of windings associated with a core member P_1-P_4 travels in the direction indicated by the arrows R_1-R_4 shown in Figure 1. The windings of the sets being connected in parallel, although they may be connected in series if desired. A secondary (not shown) comprising a sheet of copper of the same overall square configuration as the primary P is positioned over the pole faces 13 in conventional manner. If desired, the secondary may be provided with an opening above the aperture A in the primary to permit of, for example, accommodation of an injection nozzle where the heater is used in a plastics moulding apparatus, or, of course, for any other desired purpose.

It will be appreciated that the sets of primary windings and associated pole members P_1-P_4 are arranged in the pattern described so that the hotter end of one unit is adjacent to the colder end of another unit, thereby achieving a more uniform heating of the secondary.

Where a central aperture is not required, the core members P_1-P_4 may be of square configuration provided with associated sets of primary windings and disposed as shown in Figure 3 to produce again a heater of square overall configuration but without a central aperture, and again with the hotter end of one set of primary windings being adjacent to the colder end of another.

In Figure 4, a further alternative is illustrated where the heater is of rectangular overall configuration, in which case the pole members P_1-P_4 are of corresponding but smaller rectangular configuration and may be arranged to produce travelling waves as indicated by the arrows R1-R4, or alternatively as shown in Figure 4a by the arrows R1-R4.

Although in the above examples heaters of square or rectangular overall configuration have been described and made up of four sets of primary windings and associated core members, if desired, the heater may be of different overall configuration and/or may be made up of a different number

of sets of primary windings and associated pole members. The present invention envisages any number of sets of primary windings and associated pole members from two upwards and envisages disposing of the primary windings and associated pole members in any desired configuration to achieve a desired pattern of travelling wave direction to achieve a desired heating effect. The windings associated with the cores are connected in parallel but may be connected in series if desired.

Although in the above examples, the primary members have been described as being made as discrete and separate components, if desired they may be made as a single core member with different parts of the core member being formed to produce pole faces 13 having an orientation as shown in the figures, and of course in non-illustrated embodiments mentioned above, again the sets of primary windings from two upwards may be provided in association with core members which are not formed as separate and discrete members but as parts of a single member formed to appropriate configuration, and the windings of the sets connected in parallel or in series.

Further alternatively, instead of the secondary being a single member of the same shape as the overall shape of the primary, the secondary may be made of a number of secondary members which may be of the same shape, in plan view, as the parts of the core means associated with each set of windings or may be made from separate members of different configuration.

In a further embodiment of the invention illustrated in Figure 5, the secondary may be provided with regions of different electrical conductivity, for example, and as illustrated in Figure 5, a workpiece to be heated such as a block of steel is indicated at 20 and a sheet of copper is secured to the undersurface of the block 20 as indicated at 21 so as to be disposed between the block 20 and the primary.

The sheet 21 has a series of rectangular openings 22 formed therein, the longer axes of which extend at right angles to the direction of motion of the field. In Figure 2 only a small number of openings is shown for clarity. It is found in practice, that by providing the sheet 21 with the openings 22 therein, that the heating of the block 20 is more uniform.

Instead of providing the sheet 21 with the openings 22, the sheet 21 could be of composite construction comprising a relatively high conductivity copper in a region corresponding to the unapertured parts of the plate 21 and a material of lesser conductivity, such as iron, in a region corresponding to the apertures 22.

Further alternatively, the plate 21 could be of different thickness in regions corresponding to the unapertured parts of the plate 21 and the apertured parts of the plate 21 to achieve the desired variation in conductivity.

Another embodiment is shown in Figure 6 in which the primary P is as described above. The secondary is formed in two portions 24 and 25 in facial contact, the portion 25 having a relatively high resistivity such as iron or steel as described above, and the portion 24 having a relatively low resistivity such as copper, aluminium etc. as described above, and being positioned between the portion 24 and the primary. Grooves 26 extending at right angles to the direction of motion of the field are formed in the portion 24 between longitudinal edges of the portion 24 which are provided with copper or other low resistivity areas 27 which extend in the direction of motion of the field. These three features can be used singly or in any combination.

In certain circumstances, a still further improvement may be obtained by periodic reversal of the travelling wave direction. This is easily achieved using control equipment to reverse the phase rotation of the a.c. supply. However, it should be noted that reversal of the travelling wave direction does not necessarily swap the hot and cold end effects in a predictable manner.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, or a class or group of substances or compositions, as appropriate, may, separately or any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS:

1. A travelling wave induction heater comprising a plurality of primary windings (W) and associated core means (P_1-P_2), and means to connect successive windings (W) to successive phases of a multi-phase electric supply to provide the primary of the travelling wave induction heater, whereby, in use, a travelling magnetic field is produced and there being an electrically conductive member (20), in which eddy currents are induced by the magnetic field, and which acts as a secondary of the heater and is thereby heated, characterised in that the primary windings (W) are arranged in a plurality of sets, there being means to connect successive windings of each set to successive phases of a multi-phase electric supply whereby each set produces a travelling magnetic field.

2. A heater according to claim 1 wherein the travelling magnetic field produced by one set travels in a direction which is different to the direction of travel of the travelling magnetic field produced by the, or at least one of, the other sets of windings (W).

3. A heater according to claim 1 or claim 2 wherein there are four sets of windings (W) disposed in the quadrants of a rectangle defined by orthogonal axes passing through the mid points of the sides of the rectangle.

4. A heater according to claim 4 wherein the travelling waves produced in each quadrant travel in directions inclined at 90^{o} to each other so that the angle between the direction of travel in adjacent quadrants add algebraically to 360^{o}.

5. A heater according to claim 4 wherein the travelling wave produced in two adjacent quadrants travel in parallel directions whilst the travelling wave in the other two quadrants also travel in parallel directions but opposite to the direction of travel of the waves in the first mentioned quadrants.

6. A heater according to any one of the preceding claims wherein the sets are disposed so as to provide an opening at the centre of the heater.

7. A heater according to any one of the preceding claims wherein the core means (P_1-P_4) of each set is discrete and separate from the core means (P_1-P_4) of each other set.

8. A heater according to any one of claims 1 to 6 wherein the core means of each set comprises a part of a common core having pole pieces of appropriate orientation to provide the above mentioned direction of travel for the travelling wave produced by each set.

9. A heater according to any one of the preceding claims wherein the secondary (20) is a single secondary member of a shape complementary to the shape of the primary.

10. A heater according to any one of claims 1 to 8 wherein the secondary (20) comprises a plurality of discrete and separate secondary members each of a configuration complementary to the configuration of an associated set of primary windings and core means.

11. A heater according to any one of the preceding claims wherein the secondary (20) has a non-uniform electrical conductivity, the distribution of electrical conductivity being such as to provide a desired distribution of heating in the secondary.

12. A heater according to any one of the preceding claims wherein the secondary (20) comprises a component (21) of a relatively high electrical conductivity material such as copper or aluminium or zinc or brass, having at least one opening therein and/or area of lower conductivity and/or area of different thickness.

13. A heater according to any one of the preceding claims wherein the secondary comprises a mould of a moulding apparatus.

14. A method of providing a desired pattern of heating in a secondary of a travelling wave induction heater comprising a plurality of primary windings (W) and associated core means (P_1-P_2), and means to connect successive windings (W) to successive phases of a multi-phase electric supply to provide the primary of the travelling wave induction heater, whereby, in use, a

travelling magnetic field is produced and there being an electrically conductive member (20), in which eddy currents are induced by the magnetic field, and which acts as a secondary of the heater and is thereby heated, characterised by the steps of disposing the primary winding in a plurality of sets, disposing the sets in a predetermined mutual relationship, and connecting successive windings of each set to successive phases of a multi-phase electric supply whereby each set produces a travelling magnetic field which travel in a predetermined mutual relationship.

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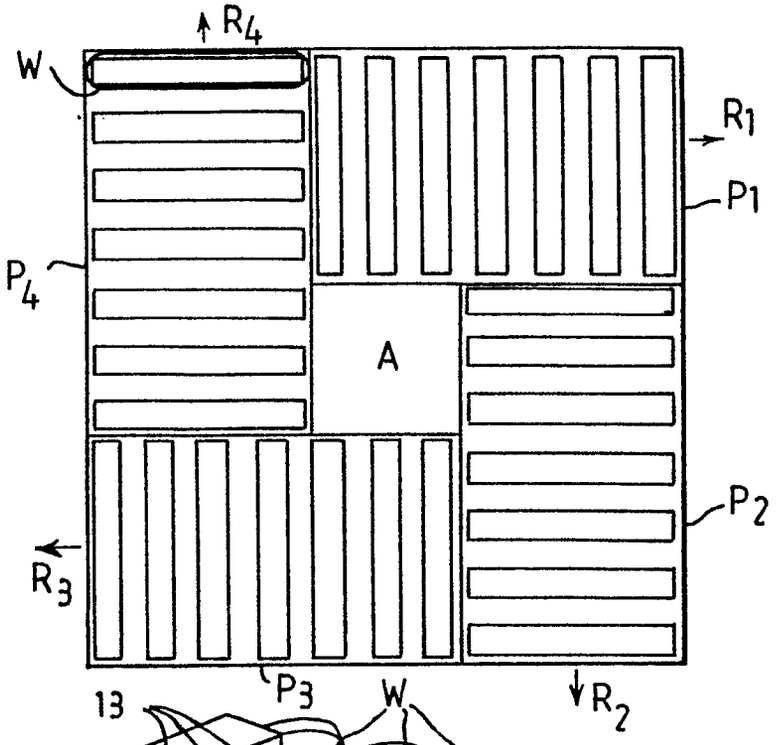

FIG 1

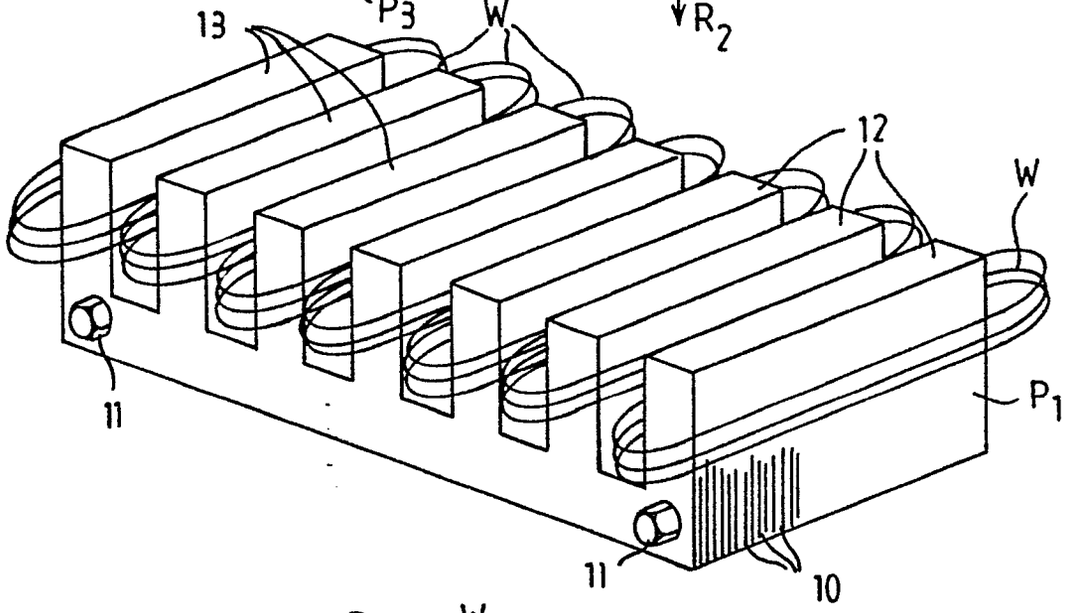

FIG 2

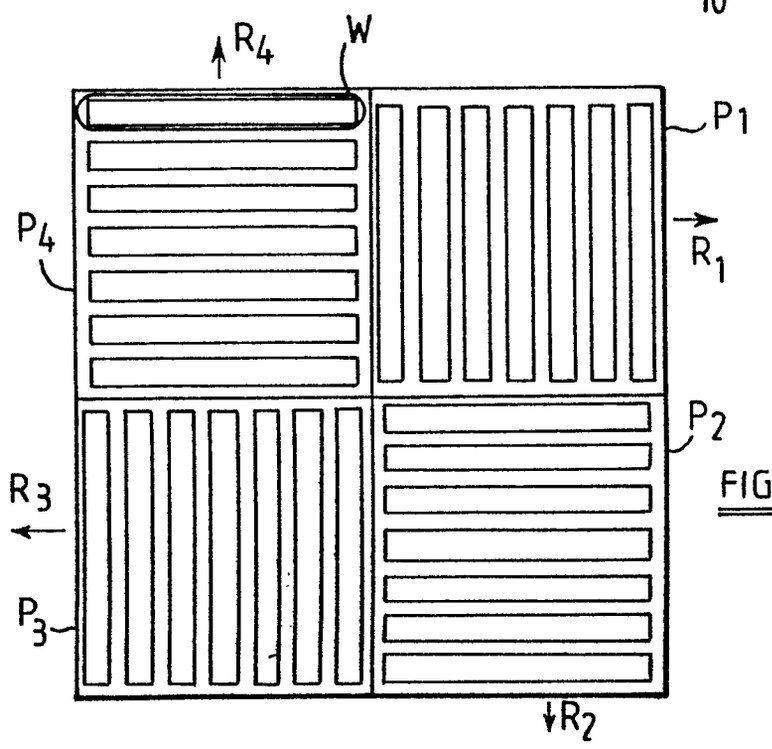

FIG.3

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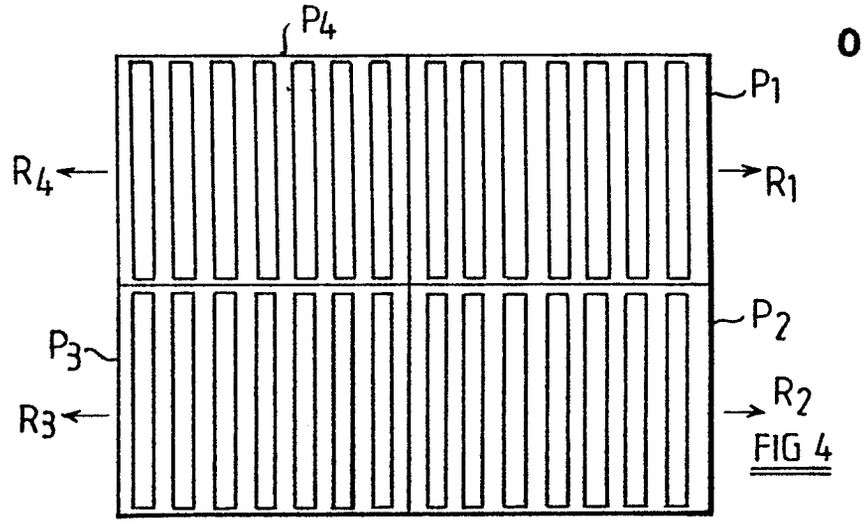

FIG 4

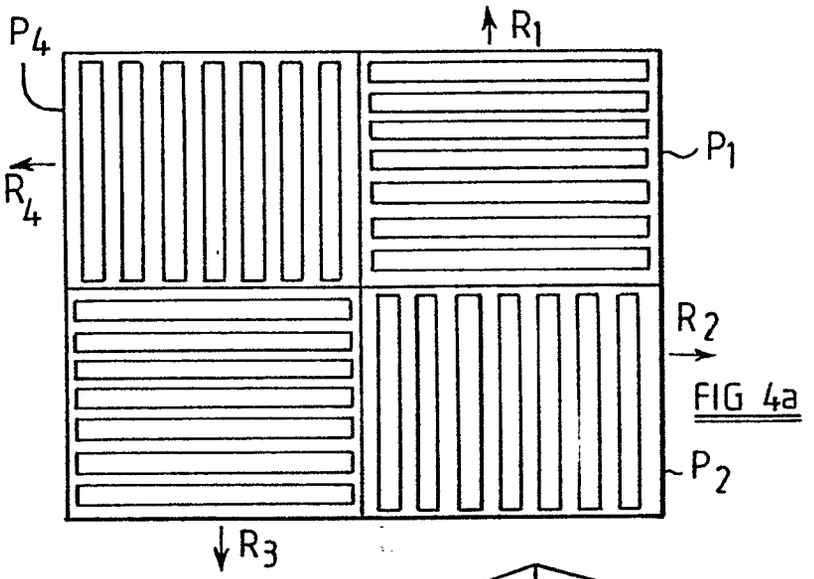

FIG 4a

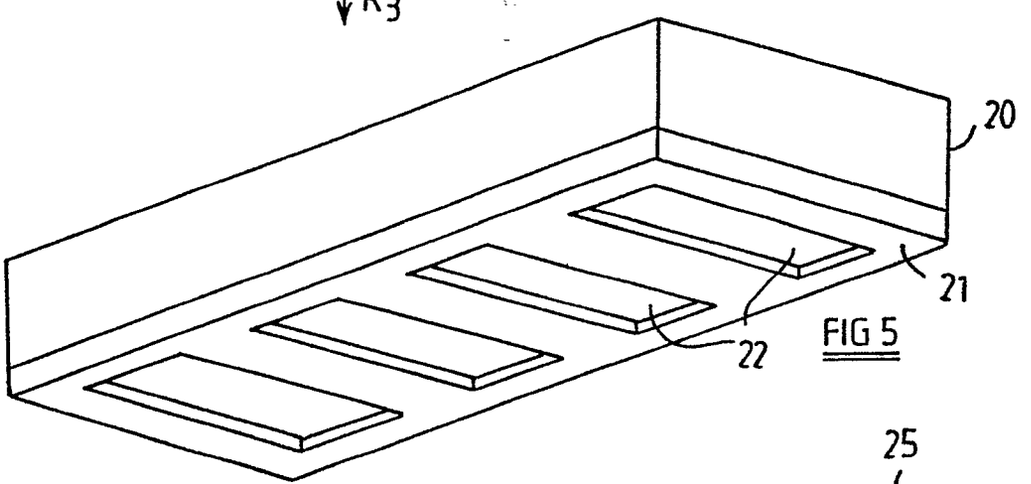

FIG 5

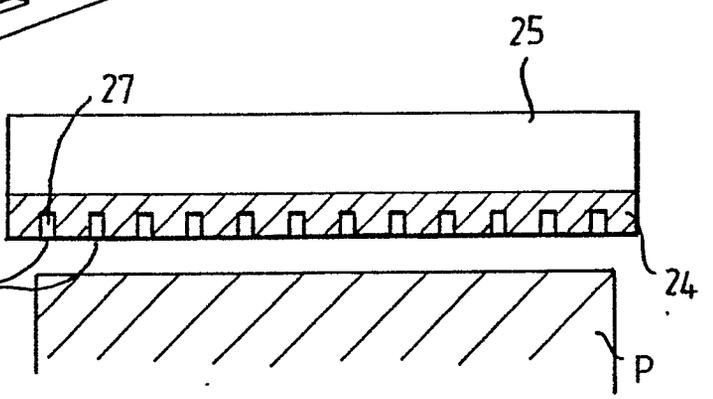

FIG 6

European Patent Office

EUROPEAN SEARCH REPORT

0170417 Application number

EP 85 30 4651

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)
Y	FR-A-2 495 750 (IRSID) * Page 6, lines 7-22; page 6, line 36 - page 7, line 6; figure 1 *	1,2,5, 7-9,14	H 05 B 6/02 H 05 B 6/44
Y	DE-A-1 788 154 (XYNETICS) * Page 5, last paragraph; page 6, line 1 - page 8, line 1; figures 2,4 *	1-9,11 ,14	
P,A	EP-A-0 135 025 (FORCE ENGIN.) * Page 2, line 26 - page 3, line 25; figures 1,2 *	8-13	
A	DE-A-1 908 850 (SAWYER)		TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	FR-A-1 202 900 (PENN INDUCTION)		H 05 B 6/00 H 02 K 41/00
A	EP-A-0 087 345 (CEM)		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30-09-1985	RAUSCH R.G.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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