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(54) Magnet arrangements.

(57) In a magnet arrangement suitable for providing PPM focusing, cylindrical magnets 4 have inclined inner faces 6 and 7 meeting at an edge 8. Pole pieces 9 are contiguous with the inclined faces 6 and 7 to provide a relatively large field within the volume enclosed by the arrangement. Preferably, the magnet is of a type II magnetic material.

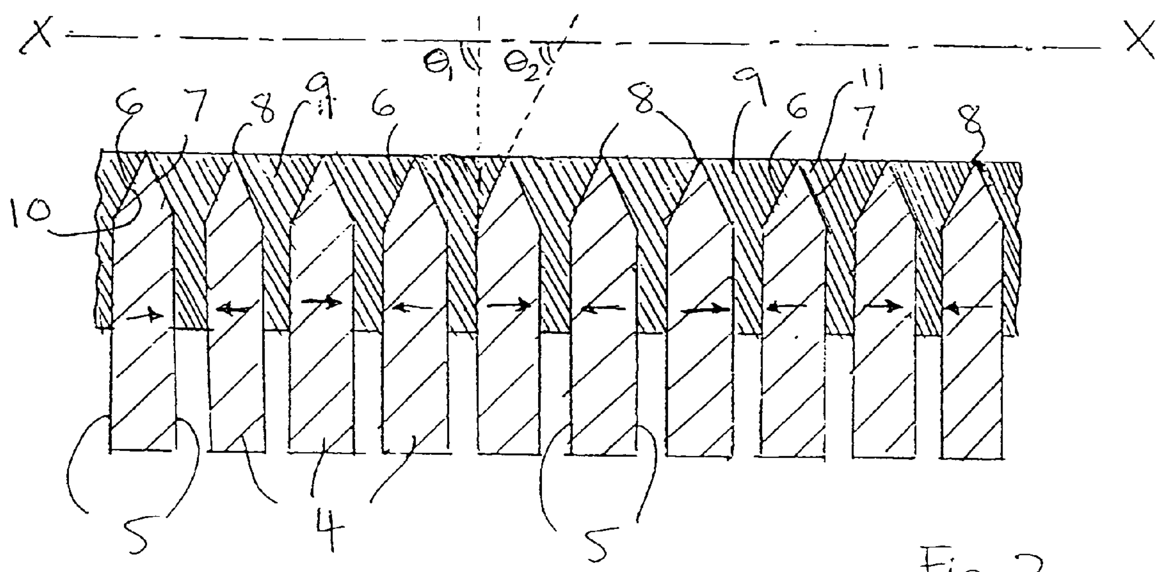

Fig. 2

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This invention relates to magnet arrangements and is more particularly, but not exclusively, applicable to periodic permanent magnetic (PPM) focusing stacks.

PPM focusing is used to confine and focus a beam of charged particles to oppose mutual charge repulsion and prevent the particles colliding with the walls of a surrounding structure. Such arrangements may be employed in linear electron beam tube devices such as travelling wave tubes (TWTs) and klystrons. A PPM stack consists of a plurality of cylindrical magnets arranged about a common longitudinal axis and defining a central aperture along which the beam to be focused is directed. Adjacent magnets have opposite polarities so as to produce a magnetic field having an amplitude which varies sinusoidally in the axial direction. One such conventional arrangement is schematically illustrated in Figure 1, which is a longitudinal section showing only half of the arrangement which is cylindrically symmetrical about its longitudinal axis X-X.

Adjacent magnets 1 have opposite polarities as indicated by the arrows and are interposed with annular pole piece discs 2 which are of a soft ferromagnetic material, typically iron. The pole pieces provide a path for the magnetic flux and concentrate the magnetic field in the aperture at the centre of the arrangement. Cylindrical spacers 3 are included within the magnets 1 and serve to accurately locate the magnets 1 to prevent radial movement. The spacers have an internal diameter which is substantially the same as that of the pole piece discs 2 and are of a non-magnetic material, for example nickel, such they do not affect the magnetic field configuration. Although as shown, the components of the stack arrangement are in a close touching relationship, in practice, there are often small gaps between them.

The present invention arose from an attempt to provide an improved magnet arrangement which is particularly useful for PPM focusing stacks. However, it is envisaged that the inventive arrangement may be advantageously employed in other applications.

According to the invention, there is provided a magnet arrangement comprising: cylindrical magnet means surrounding a volume and having a longitudinal axis with a radially inner face portion inclined relative to the longitudinal axis and end face portions making larger angles with the axis; and pole piece means including a portion substantially contiguous with the inclined inner face portion for concentrating the magnet field in the said volume.

By employing the invention, a magnet arrangement may be provided which has reduced diameter and weight compared to a conventional geometry used to produce the same magnetic field in the volume. Furthermore the inventive arrangement may advantageously require fewer components hence facilitating fabrication.

The inclined face portion of the magnet means directs the magnetic flux inwardly and, in combination with the contiguous pole piece portion, permits a greater proportion of the available flux to be directed towards the volume rather than being lost to the outside compared to conventional configurations.

The radially inner face portion of the magnet means may be the innermost part of the magnet means in a radial direction. In alternative embodiments, there is an additional face portion which is extensive radially inside the inclined inner face portion. The additional face portion may be arranged to be inclined or parallel relative to the axis depending on the particular application.

As the inventive geometry permits more efficient use of the available flux, a reduction in the amount of magnetic material required may be made compared to a conventional design for providing the same magnetic field. Hence, the arrangement may be of smaller diameter and reduced weight. The volume saving is particularly advantageous for those applications in which space is limited.

The improvement in the amount of available magnetic flux which may be achieved using the invention may be exploited to improve ease and accuracy of manufacturing and assembly of the arrangement. In a conventional magnetic circuit, it is usual to ensure that material of the pole piece means does not extend continuously between the poles of the magnet. Otherwise, if a complete path does exist between the poles via pole piece material, flux tends to be channelled through this. Hence the magnetic flux is reduced in the free space where it is required.

By employing the invention, material of the pole piece means may extend in a continuous circuit between poles of the magnet means without reducing the magnetic field in the volume, or increasing the size of the magnet required, compared to that obtainable with a conventional geometry. Although some of the flux is confined within the pole piece material, this is compensated for by the improvement in efficiency of a geometry in accordance with the invention. By choosing a configuration in which pole piece material extends substantially continuously between the poles, the pole piece means may thus comprise a unitary member extensive from one of the end faces of the cylindrical magnet means, continuing inside the magnet means in an axial direction and to the other end face. The pole piece means may thus comprise one member rather than the usually provided two members for each magnet means. The number of components to be manufactured and handled during assembly is thus reduced. The thickness of the pole piece means in the region inside the magnet means is determined by the amount of flux loss from the volume which can be tolerated. Furthermore, use of single pole piece member across both poles may improve the mechanical stability and strength of the final assembly.

Where the magnet means is included as part of a PPM stack a single pole piece member may be used in association with a plurality of magnet means, this significantly reducing the number of components necessary compared to a conventional assembly. The pole piece member may be a single complete cylinder but it may be convenient in some applications to use separate parts which are joined together to form the member. Use of the invention thus gives a flexibility in approach to enable the most appropriate to be selected.

The pole piece means may thus be of unitary construction and may be manufactured by metal removal techniques to form its shape from solid bar or tubular ferromagnetic material.

This aspect of the invention is also advantageous because it permits the pole piece means to be manufactured to higher tolerances, for example, by using CNC (Computer Numerical Control) techniques, than a series of single pole pieces brazed to the body tube of a TWT. The risk of misalignment when using a monolithic pole piece member is much reduced. The magnet means may be aligned by the unitary pole piece means such that each magnet of a PPM stack, say, lies at right angles to the axis in every plane. This presents reduced distortion in the PPM field and thus enhances the TWT's rf performance.

The pole piece means may define a vacuum enclosure with a slow wave structure, in a TWT, being mounted directly in its inner volume. The arrangement could be dimensioned, in alternative devices, such that it slides over a standard metal body tube which acts as the vacuum envelope.

Another advantage obtained using the invention is that the normally provided spacers for locating the magnet means may be omitted. The inclined surface is located against the pole piece means and hence displacement of the magnet means in the radial direction is substantially prevented. The relative positions of the magnet and pole piece means can thus be maintained in the required alignment during shipping and use. Also, it allows correct positioning to be readily achieved during manufacture of the arrangement. There is an additional saving in weight by elimination of spacers. The elimination of spacers reduces the number of components included in the magnet arrangement, further facilitating manufacture.

In one embodiment of the invention, in longitudinal section the inner face and an end face portion have straight edges. The inner face portion may adjoin the end face portion. Alternatively, there could be one or more intervening straight sections such that a longitudinal section through the magnet means gives a polygonal geometry. In another arrangement, a curved intermediate portion may be included between the straight inner and end face portions.

In another arrangement in accordance with the invention, in longitudinal section the inner face portion has a continuously curved surface. Such a surface may be, for example, semi-circular, hyperbolic or parabolic in shape.

The portion of the pole piece means contiguous with the inclined face portion is preferably in contact with it. However, a small gap or, for example, an interposed adhesive say, does not significantly detract from the magnetic properties of the arrangement and may be included if convenient. The pole piece means may be contiguous over only part of the area of the inclined face portion but the invention is more effectively implemented if the whole of the inclined face portion is contiguous with the pole piece means.

The cylindrical magnet means may be formed as a unitary member. However, it may be convenient to form it from a number of component parts, which may be spaced apart from one another or touching. Typically, two semi-cylindrical parts are assembled together to form the complete arrangement.

In one preferred embodiment the end face portions are substantially normal to the axis as this configuration may be accurately achieved and it also allows ease of matching to adjacent pole piece members. However, the end face portions could be slightly inclined relative to the transverse direction although the angles they make with the axis are relatively large when compared to that made by the radially inner face portion.

Although the invention has been described in relation to a circularly cylindrical magnet means, its cross section could be square for example. However, this reduces the symmetry of the arrangement and is usually, therefore, not desirable.

Non-symmetrical geometries may be suitable in some circumstances and may also advantageously make use of the invention.

It is preferred that the magnet means has two radially inner face portions inclined relative to the axis and meeting to define an innermost edge. Thus, the flux is directed radially inwardly from two poles of the magnet means to give higher fields within the volume. In one preferred embodiment of the invention, the inner face portions make substantially the same angle with the axis and preferably this angle is 45°.

The invention is particularly advantageously employed when the magnet means comprises a type II magnetic material. Type II magnets have a permeability close to unity and uniform magnetisation in the magnet reduces leakage, all the flux tending to come to the terminals of the magnet. The inclusion of an inclined face portion in accordance with the invention exploits this characteristic. A discussion of the properties of type II magnets may be found in "Advances in Permanent Magnetism" by R.J. Parker and published by Wiley International Science (1990).

In one advantageous embodiment of the invention, the pole piece means comprises two pole piece members, each having a portion substantially contiguous with a respective different inclined face portion and wherein the pole piece members are in no more than point contact with each other at the innermost edge. If this amount of contact is exceeded, then pole piece means tends act as a "keeper" such that the flux remains confined within the pole piece material and consequently the field within the volume is reduced. The pole piece members may be clipped short so that there is no contact at all made between them. In one preferred embodiment of the invention, the inner volume of the arrangement is substantially wholly defined by inner surfaces of the pole piece means.

In an alternative embodiment of the invention, material of the pole piece means is located coaxially inside the magnet means such that it is substantially continuous over the axial length of the inner part of the magnet means. As discussed above, although this reduces the field in the volume compared to what could be obtained, this loss may be balanced by the added efficiency arising from the invention. Manufacturing and structural improvements arising from the approach may be more desirable than increased flux within the volume or a reduction in size and weight of the magnet arrangement.

The pole piece members may each be unitary in construction. However, as in the case of the magnet means, they may each be made of an assembly of component parts and may include different materials. For example, they may incorporate a portion of high thermal conductivity material to aid in the conduction of heat away from the centre of the magnet arrangement.

Although the magnet arrangement in accordance with the invention may be used with advantage in many different applications, it is particularly useful in arrangements comprising a plurality of magnet means and pole piece means each in accordance with the invention and arranged adjacent to one another around a common longitudinal axis. The resultant stack may be arranged to provide PPM focusing by suitable choice of the polarities of the magnet means. The invention may then be applied to linear electron beam tubes such as klystrons and travelling wave tubes where the reduction in volume and weight compared to conventional arrangements is particularly desirable.

Some ways in which the invention may be performed are now described by way of example with reference to the accompanying drawings in which:

Figure 2 schematically illustrates in longitudinal section an arrangement in accordance with the invention, only half of the arrangement being shown about the longitudinal axis X-X; and

Figures 3, 4 and 5 schematically illustrate in longitudinal section respective different arrangements in accordance with the invention.

With reference to Figure 2, a magnet arrangement is cylindrically symmetrical about its longitudinal axis X-X and comprises a plurality of cylindrical magnets 4 which are of samarium cobalt. The magnets 4 have a circular symmetry and surround a central volume in which the magnetic field is concentrated. The polarities of adjacent magnets 4 are reversed so as to provide PPM focusing along the longitudinal axis X-X suitable for focusing an electron beam. The cylindrical magnets have end face portions 5 which lie in planes substantially normal to the longitudinal direction at an angle θ_1. The magnets 4 each have two radially inner face portions 6 and 7 which are inclined at an angle θ_2 of 45° with respect to the axial direction and meet to define an edge 8. Pole piece members 9 are interposed between the magnets 4 and include portions 10 and 11 which are contiguous with the inclined face portions 6 and 7 respectively. The pole piece members 9 are thus generally configured as apertured discs having inner portions which flare outwardly towards the centre of the arrangement. The pole piece members 9 are arranged such that adjacent ones are in point contact to form a substantial part of the inner wall of the arrangement around the enclosed volume.

The outer diameter of the magnets 4 is larger than that of the pole piece members 9 to reduce losses to the exterior of the arrangement.

With reference to Figure 3, another arrangement in accordance with the invention includes a plurality of cylindrical magnets 12 having interposed pole pieces 13. The inner face portions 14 are smoothly curved such that in longitudinal section they present a parabolic boundary with the pole pieces 13. The angle θ_2 which the inner face portions 14 make with the longitudinal axis X-X is determined by constructing a tangent to the surface. The end face portions 15 are again substantially normal to the longitudinal axis X-X. The curved inner faces provide increased contact area with the interposed pole piece means 13.

With reference to Figure 4 in another arrangement in accordance with the invention, the inner faces 16 of magnets 17 are straight sided in longitudinal section and intermediate sections 18 are interposed between them and end faces 19. In longitudinal section, the magnets thus are a polygonal approximation to the configuration illustrated in Figure 3 which also permits increased contact area between the inner faces of the magnet and the interposed pole pieces 20. In this arrangement the radially innermost faces 16 and the intermediate sections 18 all contribute in co-operation with the pole pieces 20 to concentrate the magnetic flux into the internal volume of the arrangement.

With reference to Figure 5, in another arrangement in accordance with the invention, a PPM focusing stack comprises a plurality of cylindrical magnets 21 having inner faces 22 inclined relative to the longitudinal axis X-X and end faces 23 substantially normal to the axis. Each magnet 21 includes an innermost face 24 which is extensive substantially parallel to the axis X-X.

In this arrangement, the pole piece means associated with each of the magnets 21 is a single structure 25 extensive along the axis. The thickness t of the pole piece means 25 radially inside each of the magnets is large enough that the pole piece means 25 is self supporting and able to support and locate the magnets 21. The maximum thickness t which is acceptable is governed by the magnitude of magnetic field required in the central volume for the size of magnets being used.

In this embodiment, the pole piece means 25 is a unitary structure machined from a single block of material. However, it could be composed of several sections which are brought together in the finished assembly, being joined in transverse and/or longitudinal planes.

Other geometries may also utilize the principles illustrated in Figure 5. For example, the arrangements shown in Figures 2, 3 and 4 may be modified such that the pole piece members are no longer merely in a touching relationship but instead extend in a continuous manner within the magnets.

Claims

1. A magnet arrangement comprising: cylindrical magnet means (4, 12) surrounding a volume with a radially inner face portion (6, 7, 14) inclined relative to the longitudinal axis (X-X) and end face portions (5, 15) making larger angles with the axis; and pole piece means (9, 13) including a portion substantially contiguous with the inclined inner face portion for concentrating the magnetic field in the said volume.

2. An arrangement as claimed in claim 1 wherein the end face portions (5, 15) are substantially normal to the axis.

3. An arrangement as claimed in claim 1 or 2 wherein, in longitudinal section, the inner face (6, 7, 16) and an end face portion (5, 19) have straight edges.

4. An arrangement as claimed in claim 3 wherein the inner face portion (6, 7) adjoins the end face portion (5).

5. An arrangement as claimed in claim 1 or 2 wherein, in longitudinal section, the inner face portion (14) is a continuously curved surface.

6. An arrangement as claimed in any preceding claim wherein the magnet means (21) comprises two radially inner face portions (22) inclined relative to the axis and an innermost face portion (24) extensive between them.

7. An arrangement as claimed in claim 6 wherein the innermost face portion (24) is extensive in a direction substantially parallel to the longitudinal axis.

8. An arrangement as claimed in any one of claims 1 to 5 wherein the magnet (4, 17) means has two radially inner face portions(6, 7, 16) inclined relative to the axis and meeting to define an innermost edge (8).

9. An arrangement as claimed in claim 8 wherein the pole piece means comprises two pole piece members (9, 20) each having a portion (10, 11) substantially contiguous with a respective different inclined face portion (6, 7, 16) and wherein the pole piece members (19, 20) are in no more than point contact with each other at the innermost edge.

10. An arrangement as claimed in any of claims 1 to 8 wherein material of the pole piece means (25) is located co-axially inside the magnet means (21) such that it is substantially continuous over the axial length of the inner part of the magnet means (21).

11. An arrangement as claimed in claim 10 and including a plurality of said pole piece means (25) and associated magnet means and wherein the material of the plurality of pole piece means is substantially continuous in the axial direction.

12. An arrangement as claimed in claim 11 wherein a unitary member (25) constitutes a plurality of the pole piece means.

13. An arrangement as claimed in any preceding claim wherein the magnet means (4) has two radially inner face portions (6, 7) inclined relative to the axis which make substantially the same angle with the axis.

14. An arrangement as claimed in claim 13 wherein the inner face portions (6, 7) are inclined at substantially 45° to the axis.

15. An arrangement as claimed in any preceding claim wherein the said volume is substantially wholly defined by inner surfaces of the pole piece means (22).

16. An arrangement as claimed in any preceding claim wherein the magnet means (4) comprises a type II magnetic material.

17. An arrangement as claimed in any preceding claim wherein the magnet (4) and pole piece means (9) are substantially cylindrically symmetrical.

18. An arrangement as claimed in any preceding claim wherein the magnet (4) and pole piece means (9) are substantially symmetrical about a central transverse plane normal to the axis.

19. An arrangement as claimed in any preceding claim wherein the outer diameter of the magnet means (4) is greater than that of the pole piece means (9).

20. An arrangement as claimed in any preceding claim and comprising a plurality of said magnet means (4) and said pole piece means (9) arranged adjacent to one another along a common longitudinal axis.

21. An arrangement as claimed in claim 20 wherein the pole piece means comprises pole piece members (9), each having a radially inner part of greater axial length than its outer part.

22. An arrangement as claimed in claim 20 or 21 wherein the said pluralities are arranged to provide PPM focusing.

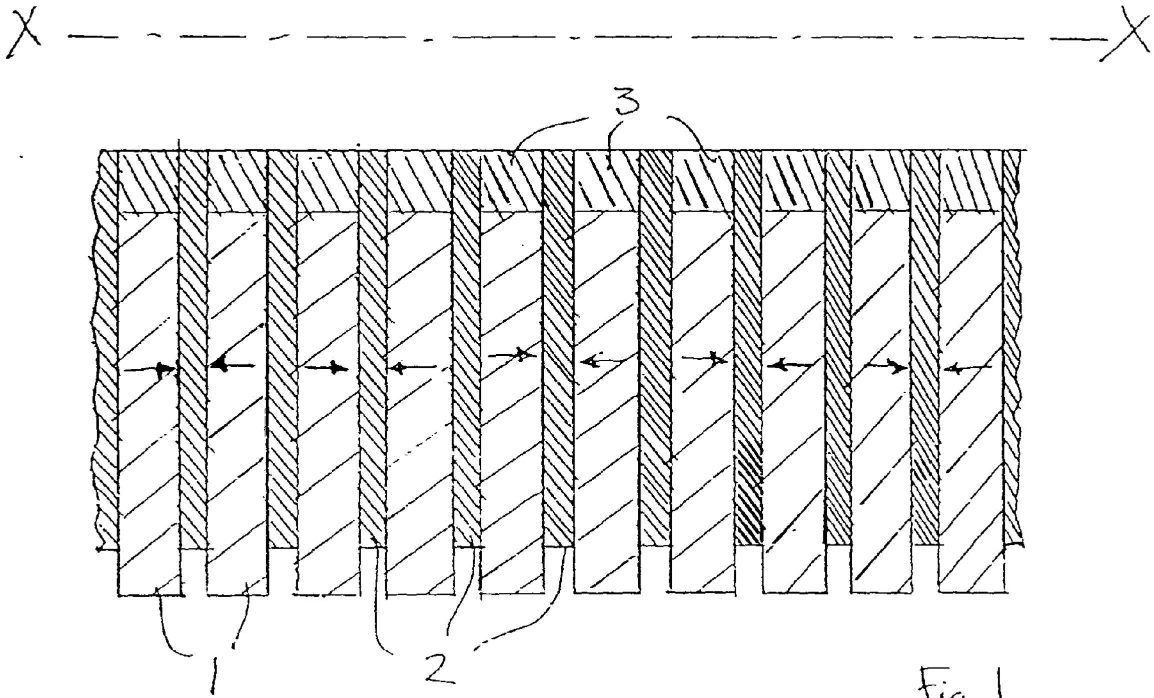

Fig. 1

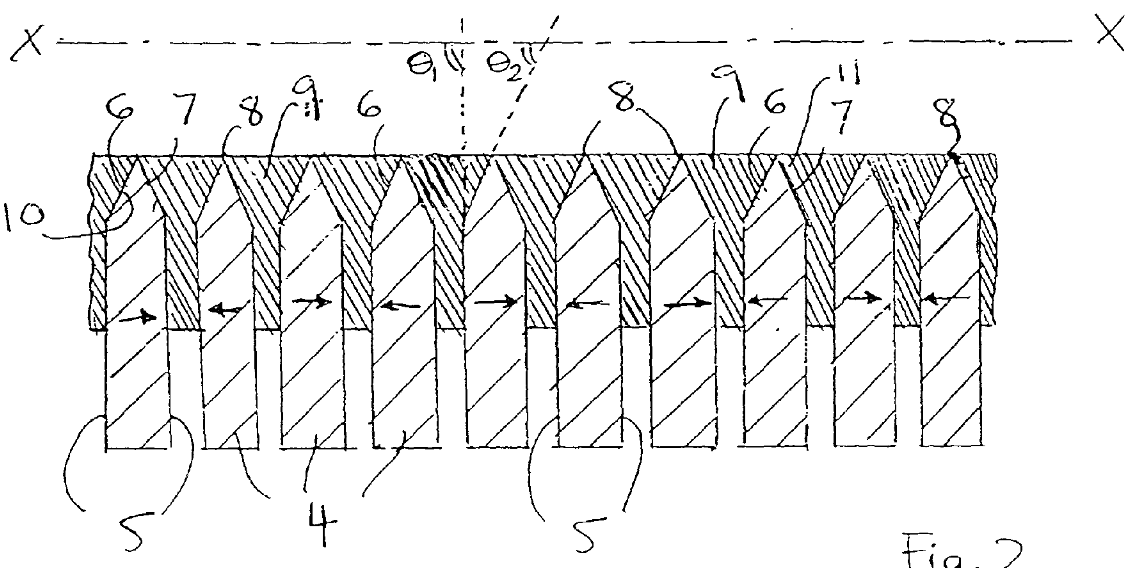

Fig. 2

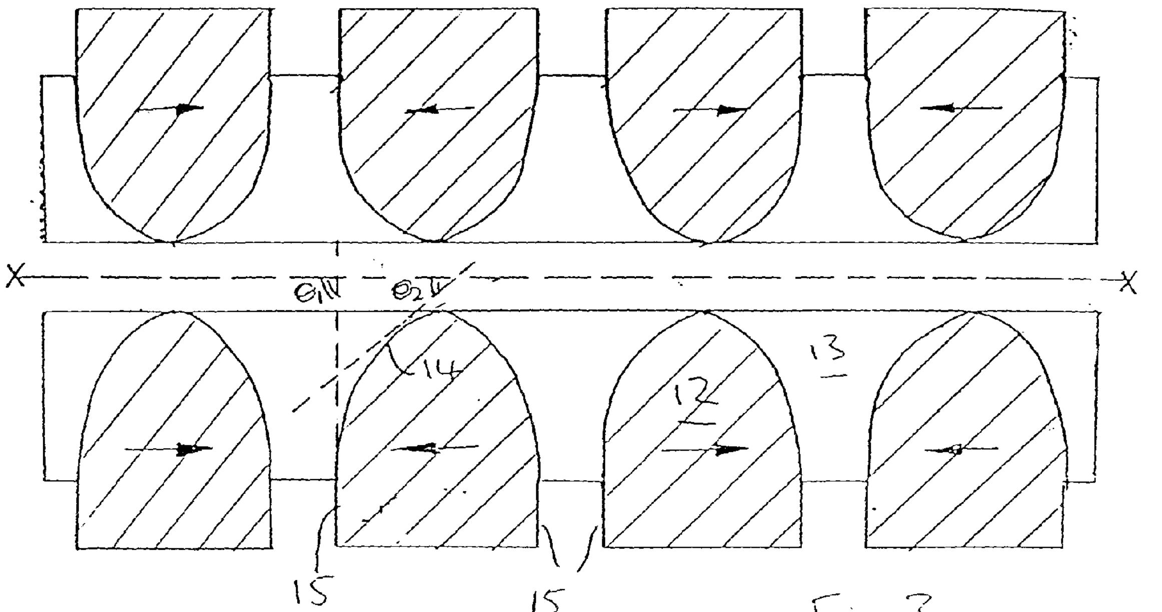

Fig 3

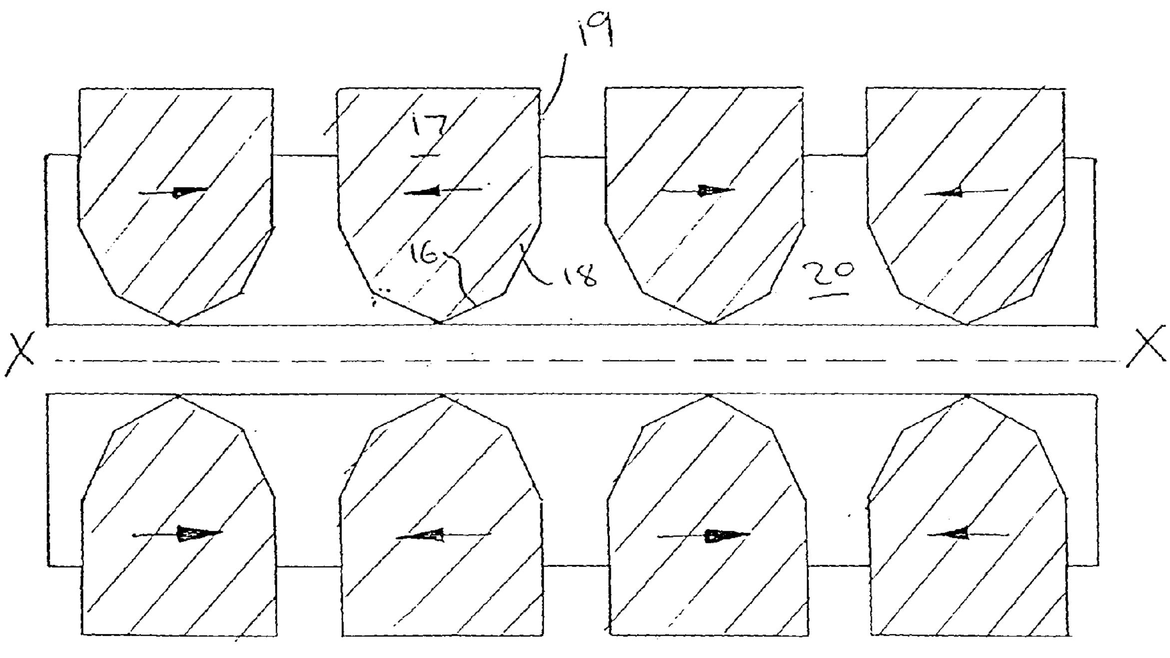

Fig 4

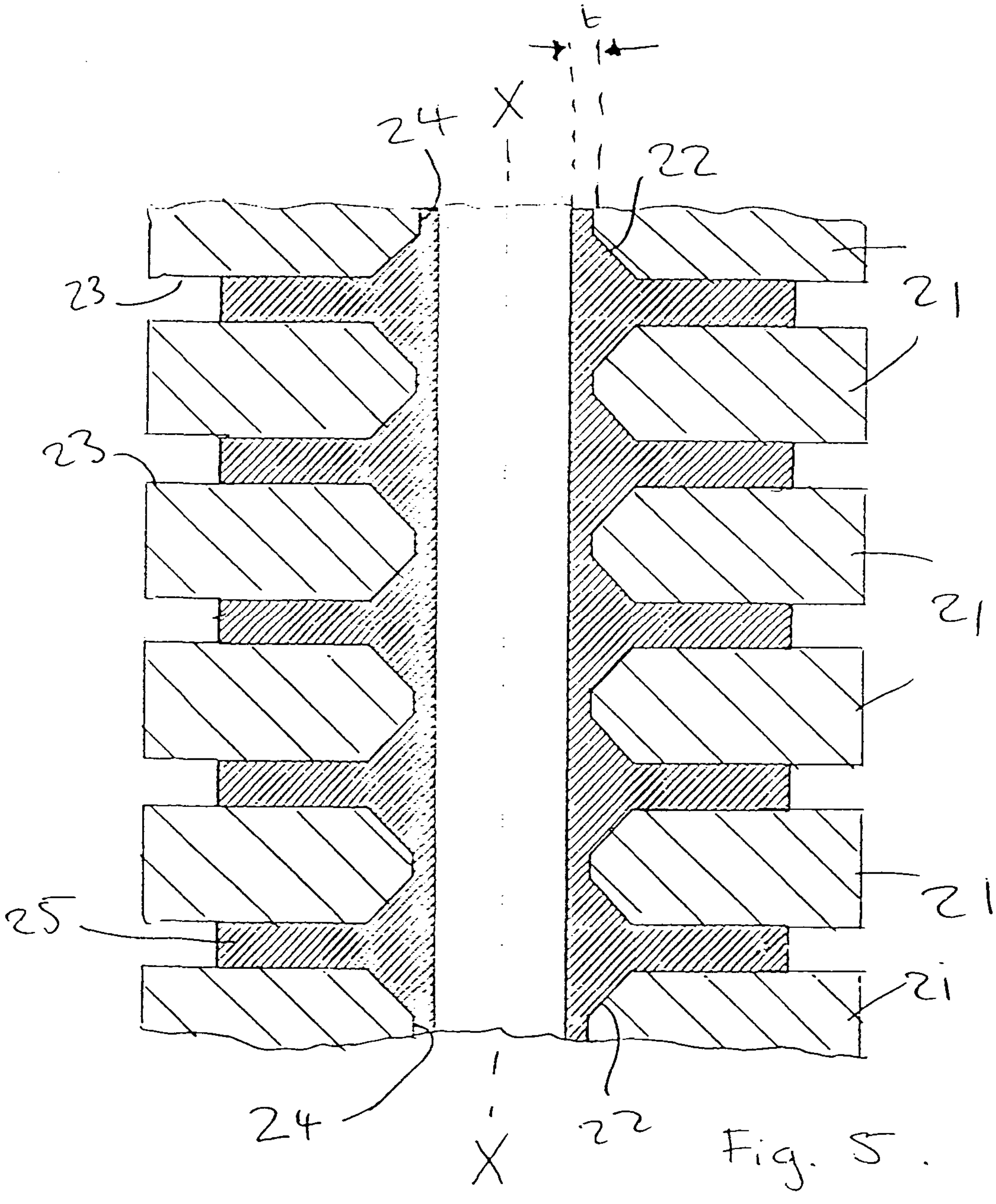

Fig. 5.