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FERROMAGNETIC ROD CORRECTION MEANS FOR THE MAGNETIC FIELD OF A MICROTRON

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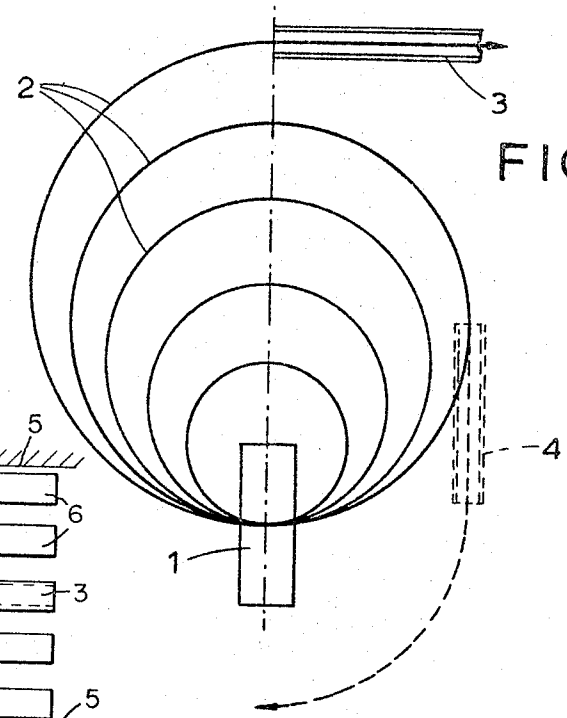


FIG. 1.

FIG. 4

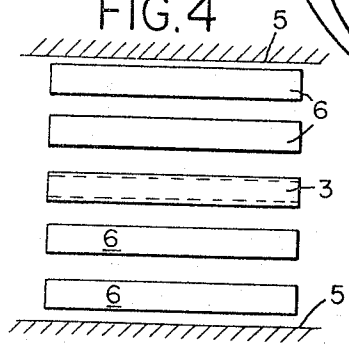


FIG. 2.

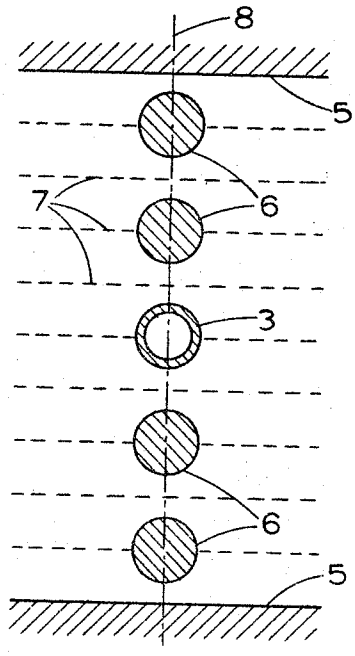
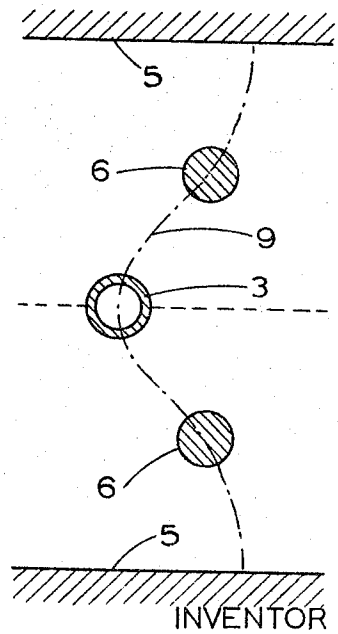


FIG. 3.



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FERROMAGNETIC ROD CORRECTION MEANS FOR THE MAGNETIC FIELD OF A MICROTRON

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9 Claims. (Cl. 313—62)

ABSTRACT OF THE DISCLOSURE

A microtron employing field compensating members symmetrically positioned about the plane of the beam of charged particles. Each of the compensating members, which are rods of ferromagnetic material, has its axis parallel to a ferromagnetic tube provided in the path of the charged particles. Each of the rods are spaced from the pole-pieces.

This application is a continuation of application, Ser. No. 471,943 filed on July 14, 1965, now abandoned.

This invention relates to microtrons.

The invention will be described with reference to the drawing in which:

FIG. 1 is a plan view of a prior art microtron;

FIGS. 2 and 3 are sectional views of microtrons according to the invention and,

FIG. 4 is an elevational view of the microtron shown in FIG. 2.

The principle of a microtron is indicated in FIGURE 1 of the accompanying drawings. The electron beam describes successively larger circular orbits 2 all passing through a resonator 1 and lying in a plane (the plane of the drawing). The magnetic field which ideally should be uniform, is applied at right angles to this plane. On each passage through the resonator 1 the electrons receive a predetermined energy increase and consequently pass to the next orbit. In such machines it is known to provide a ferromagnetic tube in the path of the beam to create a substantially field-free space in which the electrons travel linearly. Such a tube may be used as an extraction tube (tube 3, FIGURE 1) or as a device (tube 4, FIGURE 1) for deflecting the beam within the microtron. Such a ferromagnetic tube gives rise to a distortion of the otherwise substantially uniform magnetic field within the microtron.

The iron tube normally used for beam extraction in a microtron gives rise to a distortion of the preceding orbits of the electron beam in two ways: firstly, it causes a right-left asymmetry of the magnetic field in relation to the axis passing through the resonator and the centre of the machine which results in a displacement of the circular orbits; secondly, in their travel past the iron tube on their last orbits the electrons encounter a magnetic field which diminishes in the radially outward direction, whereby the previously parallel beam is focussed vertically and then diverges beyond the focus. Both these effects lead to beam losses, which in existing machines may amount to 25 to 80% of the total beam current. Moreover, for many purposes it is very undesirable to have a divergent beam.

One known method for avoiding this distortion is to deflect the electrons outwardly in the last quadrant of their path by electrostatic means to such an extent that the extraction tube can be so widely spaced from the previous orbit as not to distort that orbit. This procedure is costly because of the high voltages and the mechanical precision which are necessary in the deflector. Furthermore, a separate deflector is necessary for each terminal energy of the electrons, i.e. for each orbit.

A further known method resides in providing a so-called dummy tube which extends in axial alignment with the extraction tube, but on the other side of the central axis through the resonator. In this way it is possible to overcome the above-mentioned right-left asymmetry. The focussing action of the magnetic field which diminishes outwardly is not corrected but in fact is augmented.

It has further been proposed to reduce field distortion in the central plane of a microtron by shimming. By "shimming" is meant the application of ferromagnetic compensating bars or rings to the pole faces of the magnet in order to increase the magnetic field in the central plane. For the present purpose the shims must extend along the pole faces above and below the extraction tube and parallel thereto, because the extraction tube gives rise to a reduction in the magnetic field in the central plane. It has been found, however, that this arrangement gives only a negligible improvement, because the range over which the two compensating bars exercise an influence is substantially greater than is the case for the iron extraction tube. If the dimensions of the bars are correctly chosen in respect of the field correction in the next to last orbit, then there is a considerable over-correction in the second from last orbit and so on. This method of compensation is satisfactory only for very small microtrons with only a few orbits, but it is not satisfactory for larger microtrons.

More recently a compensating device has been described in which the field distortion is removed completely be providing a current carrying coil on the surface of the extraction tube. This arrangement certainly achieves the object of complete compensation, but it is technically very complicated to execute. It is necessary to provide a stabilised source of current for high direct-current output and the heat generated within the vacuum vessel has to be removed by water cooling. If for the purpose of varying the energy of the beam extracted from the microtron it is desired to make the extraction tube movable within the vacuum vessel, then a complicated mechanical arrangement is necessary within the vacuum because of the heavy current-carrying connections and the water pipes.

The present invention has for its object to provide a method of achieving almost complete compensation in a simple manner, the degree of compensation being sufficient to keep the distortion in the last orbits within the tolerable limit, even with very large microtrons.

According to the present invention, in a microtron including a ferromagnetic tube in the path of the beam, the distortion produced in the magnetic field by said tube is compensated by the provision of at least two ferromagnetic compensating rods in an arrangement which is symmetrical about the plane of the path of the beam, each of said rods having its axis parallel to the axis of the said tube and at least one rod on each side of said plane being spaced from the adjacent magnetic pole face.

In its simplest form a construction according to the invention can be regarded as a modification of the above-mentioned known method of shimming in such a manner that the ferromagnetic compensating bars are detached from the magnetic pole faces and are arranged in the space between the pole faces and the extraction tube. In this way the range over which the bars produce their effect can be reduced and by suitable choice of the geometrical dimensions the effect can be adapted to that of the extraction tube. In its simplest form, the arrangement of tube and bars according to the invention has the appearance of a three-element grid. The compensating bars are arranged symmetrically and parallel to the extraction tube, and their axes and that of the extraction tube lie in a plane which is at right angles

to the plane of the microtron orbits. The commencement of the compensating bars should lie approximately over the inlet end of the extraction tube; their length must be at least so large that at their end the separation of the extraction tube from the penultimate orbit is sufficiently great for the field distortion to be negligible. In all microtron constructions so far known this point lies within the vacuum vessel, so that the utilisation of the compensation bars does not introduce the necessity for any modifications in the vacuum vessel. If for special purposes a short iron tube for beam deflection (tube **4** in FIGURE 1) is provided within the microtron in addition to or in place of the extraction tube (tube **3** in FIGURE 1), then the field distortion created by this tube can also be compensated by suitable compensating bars. The beginning and the end of the compensating bars coincide approximately with the beginning and end of the beam deflecting tube.

From theoretical considerations it is to be expected that optimum compensation will be obtained if the beginning of the compensation bars projects by a small amount beyond the plane of the end face of the extraction or deflection tube; in the case of the deflection tube the ends of the compensating bars should also project slightly. In practice it is sufficient if the bars do not project and the corresponding ends of the bars and the tube are arranged in the same plane which simplifies the assembly.

There are microtrons in which there are particularly severe requirements in respect of the compensating of the field distortion caused by the extraction tube, for example in very large machines or in those machines in which for the purpose of utilising a special extraction principle, a short iron tube must be positioned relatively close to the penultimate orbit for the purpose of beam deflection (e.g. the tube **4** as shown in dotted lines in FIGURE 1). To satisfy these requirements use may be made of a multiple-element grid (five, seven or more elements) instead of the simple three-element grid. In principle it is possible to improve the compensation effect by increasing the number of elements, that is by reducing the spacing from the iron tube which then produces a smaller distortion.

A considerable amount of calculation would be necessary in order to determine the optimum geometrical dimensions of a three-element or multi-element grid. It is simpler to make a different approach. The grid is chosen so as to be completely uniform geometrically. All the compensating bars have the same diameter as the extraction tube and are equally spaced from each other and the actual distance of the outermost bars from the adjacent pole faces is half the spacing between the grid elements. A regular five-element grid is shown by way of example in FIGURE 2 which is on a larger scale than FIGURE 1 and shows a fragmentary cross-section. The extraction tube **3** and the compensating bars **6** all lie with their axes in a common plane **8** extending at right angles to the magnetic pole faces **5**. The equipotential planes **7** of the magnetic field are indicated by broken lines, in other words each of these lines could be a pole face of the microtron. It follows that the outermost bars could be semi-circular bars lying with their flat faces against the pole faces. The virtual or effective pole spacing is very small, so that it is clear qualitatively that the range over which the distortion occurs is reduced. The range over which the bars have an effect and the field strength in the central plane can be calculated precisely quantitatively by known methods. It can be shown that by increasing the number of bars the actual value of the field strength at the penultimate orbit in the microtron can be caused to approach asymptotically to the desired value.

For microtrons with a very high magnetic field strength or with a relatively small separation between the magnetic poles there is a limit to the increase in the number of grid elements because of the occurrence of saturation effects. A substantial improvement in respect of delaying the onset of saturation can be achieved in the following way. A regular three-element grid is converted into an irregular three-element grid by displacing the two compensating bars a little towards the centre and increasing them in diameter. In this way it is achieved that the actual value of the field strength in the central plane somewhat exceeds the desired value, whereas in the case of a regular grid the actual value always lies below the desired value. Consequently the point at which the disturbance is smaller than a prescribed value is brought considerably closer to the iron tube than is the case with a regular grid. This procedure can be applied in an analogous manner and with the same effect in the case of a multi-element grid: the bars are moved a little towards the centre and are increased in diameter. It is possible to achieve an equal compensating effect with a smaller number of bars.

All the methods hereinbefore described cannot be utilised if the extraction tube has a diameter which is large in comparison with the separation of the magnetic poles, because then the compensating bars also must have a large diameter and either there is not enough space to accommodate them above and below the extraction tube, or else they give rise to saturation effects. According to a further feature of the invention the compensating bars are moved out of the plane passing through the extraction tube (plane **8** in FIGURE 2) and are displaced towards the penultimate orbit. This results in an arrangement as shown for a three-element grid in FIGURE 3, where corresponding parts are indicated by the same reference numerals as in FIGURE 2. Whereas in FIGURE 2 the axes of all the grid elements lie in a plane **8**, in FIGURE 3 these axes lie on a curved surface **9** which is concave towards the centre of the microtron. In an arrangement according to FIGURE 3, the same compensation can be achieved with a smaller diameter for the compensating bars. In this way saturation effects are avoided and a very high degree of field correction can be achieved.

The compensating bars of a microtron according to the present invention are not necessarily circular but may be oval or polygonal; for example flat rectangular bars may be used.

What is claimed is:

1. A microtron comprising a pair of spaced pole-pieces defining a path for charged particles in a plane therebetween, a ferromagnetic tube having a given axis in the path of the beam, and means compensating for distortion produced in the magnetic field by said tube, said compensating means comprising at least two ferromagnetic compensating rods symmetrically positioned about the plane of the path of the beam between the tube and the pole-pieces, each of said rods having its axis parallel to the axis of the said tube and at least one rod on each side of said plane being spaced from the adjacent magnetic pole face.

2. A microtron as claimed in claim **1** in which the ends of the rods and the entry end of the tube lie in a plane at right angles to the path of the beam at the said entry end.

3. A microtron as claimed in claim **2** in which the tube is a beam deflection tube within the microtron and the rods are the same axial length as the tube.

4. A microtron as claimed in claim **1** in which the tube and the rods are all of the same diameter.

5. A microtron as claimed in claim **4** in which the tube and the rods lie in a plane which is at right angles to the plane of the path of the beam.

6. A microtron as claimed in claim **5** in which the tube and the rods form a grid-like structure with a uniform spacing between adjacent members of the grid.

7. A microtron as claimed in claim 6 in which the spacing between each of the outermost members of the grid and the adjacent magnetic pole face is equal to half the spacing between the adjacent grid members.

8. A microtron as claimed in claim 6 in which the rods are of circular section.

9. A modification of the microtron as claimed in claim 8 in which the outermost rods are semi-circular in section and the flat face of each abuts against the adjacent magnetic pole face.

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