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NONDISPERSIVE MAGNETIC DEFLECTION METHOD

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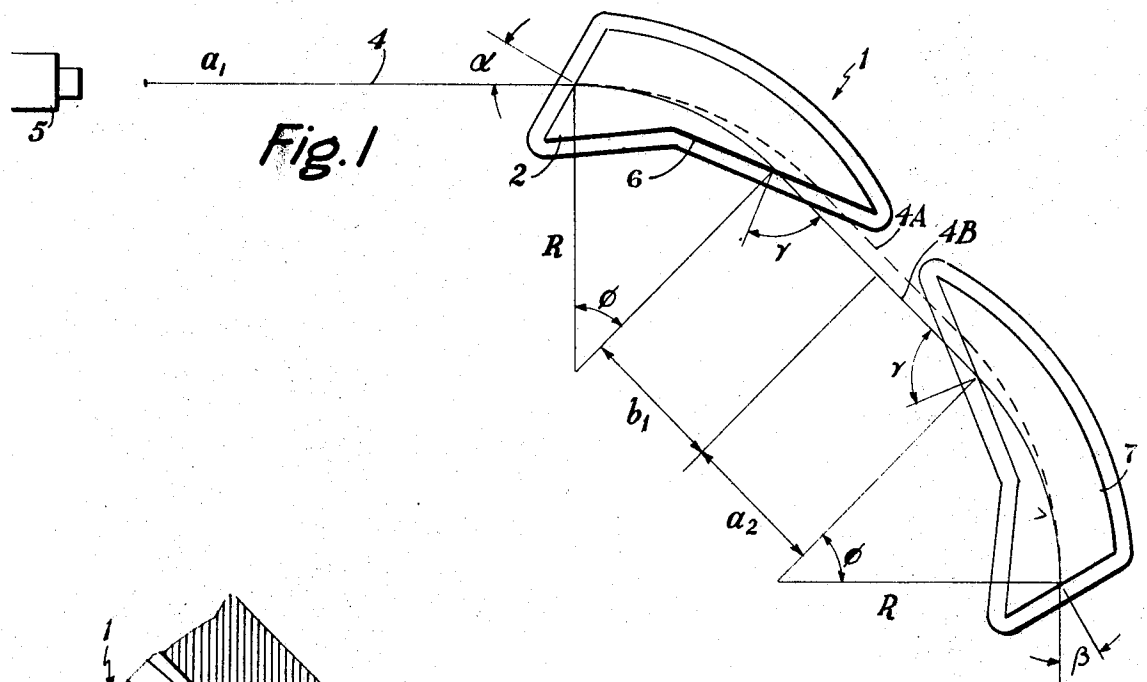


Fig. 1

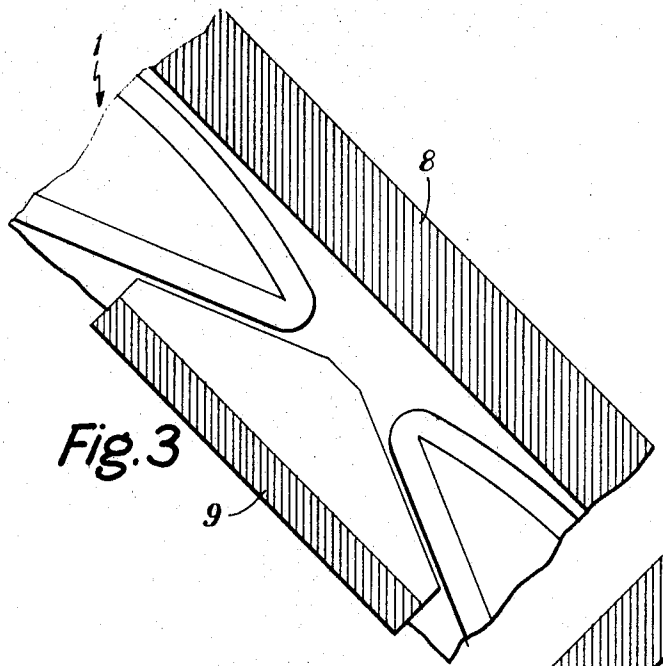


Fig. 3

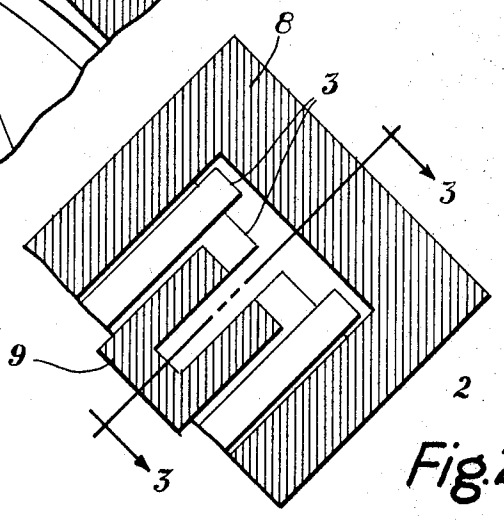


Fig. 2

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NONDISPERSIVE MAGNETIC DEFLECTION METHOD

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U.S. Cl. 335—210 1 Claim

ABSTRACT OF THE DISCLOSURE

A method of deflecting beams of charged particles without subtantial dispersion of the beam and to novel magnetic apparatus for carrying out the method. Briefly summarized, a two-magnet, nondispersive system particularly adapted to deflection by 90 degrees or more of linear accelerator beams, or any ion or electron beam with an energy spread of up to several percent. For the 90-degree case, each magnet deflects the beam 45 degrees, the exit shim angle of the first magnet and the entrance angle of the second magnet are both 67½ degrees, and in accordance with the invention one can determine the other shim angles and the magnet separation for any reasonable object and image distances which will be encountered in practice.

In connection with particle accelerators for the acceleration of charged particles to high energy, it is frequently desirable to have additional apparatus for changing the direction of the charged particle beam which has been accelerated by the particle accelerator. For example, a need to bend the charged particle beam may be caused by geometrical limitations of the room in which the particle accelerator is located, or it may be desired to direct the charged particle beam alternatively into one of several beam utilization areas. In electron irradiation installations, wherein products are irradiated on a conveyor by an electron beam from an electron accelerator, space limitations frequently require that the accelerator be mounted horizontally, but the need for a horizontal product conveyor may make it desirable to have the emergent beam travelling in the vertical direction as it strikes the product. Again, it will occasionally be desirable in radiographic installations to cause the electron beam to be deflected before striking the target for the production of X-rays. In the case of large accelerators for the acceleration of charged particles to high energy for studies in nuclear physics and the like, the cost of operating the accelerator and the original capital cost of the accelerator are so large that such an accelerator will be used for a variety of purposes, so that generally there will be several beam utilization areas associated with such an accelerator, and some sort of beam bending device is required (such as a switching magnet) in order to direct the beam into one of the beam utilization areas.

It will be apparent from the foregoing that the invention is not limited to any particular deflection angle. However, for the purposes indicated, a very common angle of deflection is 90° and so the invention will be described with particular reference to 90° bending, but it will be apparent from the following that the invention is not limited to a 90° bending.

Of course, it is well known that a magnetic field transverse to the direction of motion of a charged particle will exert a deflecting force on the charged particle. However, the deflecting action itself always introduces some focusing or defocusing action which will have an undesirable result unless proper precautions are taken. In particular the inherent energy spread in the beam from a

microwave linear electron accelerator introduces problems which are not encountered in magnetic systems used with accelerators producing a monoenergetic beam. In general, for such beams it is necessary to consider both the focusing and dispersive properties of a magnet system. A median plane is defined by the central ray of the beam as it is bent by the bending apparatus, and in this plane there is both spatial focusing (or defocusing) and momentum dispersion. In the curved surface which includes the central ray of the charged particle beam and which is perpendicular to the median plane, there is, to first order in small quantities no dispersion, but generally spatial focusing. A magnet system in which the dispersion of one part of the system is cancelled by the dispersion of another part of the system so that particles of different momenta entering along the central ray also exit along the central ray, is called achromatic.

The invention may best be understood with reference to the folowing detailed description thereof having reference to the accompanying drawings in which:

FIG. 1 is a somewhat diagrammatic top view of the lower pole faces of a pair of horizontally disposed bending magnets constructed in accordance with the principles of the invention, wherein the magnet yokes have been omitted for clarity.

FIG. 2 is a sectional view of the apparatus shown in FIG. 1; and

FIG. 3 is a sectional view along the line 3—3 of FIG. 2, and is similar to the view of FIG. 1, but includes the magnet yokes.

Referring to the drawing a first magnet **1** having a pair of pole faces **2, 3** is positioned in the path of a charged particle beam **4** which may be produced, for example, by a suitable charged particle accelerator **5** so that the charged particle beam **4** enters between the pole faces **2, 3** of the magnet **1**. Of course, this charged particle beam **4** will in general have to travel in an evacuated region and accordingly a suitable vacuum chamber (not shown) must surround the beam **4** at all times during its trajectory. Charged particles traveling through the magnetic field between the pole faces **2, 3** of the magnet **1** will travel in a circle having a radius of curvature R which is proportional to the momentum of the particle and inversely proportional to the strength of the magnetic field, as is well known. The pole faces **2, 3** are flat and equidistant, so that the magnetic field is uniform. As a result, the radius of curvature of the trajectory of the particles will be proportional only to the momentum of the particles. As a result, momentum dispersion will be introduced into the charged particle beam **4**, as shown in FIG. 1.

The momentum dispersion which is introduced by bending a charged particle beam through a uniform magnetic field may be corrected in accordance with the invention by proper shaping of the exit surfaces of the pole faces **2, 3** of the magnet **1**, at an angle to the beam trajectory **4**, so that the charged particles having higher momentum remain in the magnetic field for a longer period of time than charged particles having lower momentum with the result that, as all the charged particles emerge from between the pole faces **2, 3** of the magnet **1** along tangents to their respective circular paths at the exit surface **6**, the trajectories **4A** of the higher momentum charged particles will be directed so as to be parallel with the trajectories **4B** of the lower momentum charged particles.

The process is reversed by the second magnet **7** so that the trajectories of the particles coincide after deflection. Momentum focusing (achromatism) has thus been achieved. This result is achieved, in accordance with the invention, by having the magnetic fields in the vicinity of the beam uniform and of the same strength, by causing

the angle γ between the central ray and the second boundary zone of the first magnetic field to be the same as the angle (γ) between the central ray and the first boundary zone of the second magnetic field, by causing the angle of deflection ϕ through the first magnetic field to be equal to the angle of deflection (ϕ) through the second magnetic field. From the foregoing it follows that the radius of curvature R of the central ray is the same in both magnetic fields. The angle γ which produces this effect is in the general case $\gamma=90°-\phi/2$. Insofar as first order effects are concerned, no momentum dispersion is produced in the transverse plane nor is any momentum focusing produced therein.

In accordance with the invention spatial focusing in the median plane and in the transverse plane may be added to the momentum focusing hereinbefore described by varying the entrance angle α, the exit angle β and the distance b_1+a_2. The techniques for calculating the values of these parameters that will produce a stigmatic image at the desired distance b_2 are well known. In the median plane the beam will form an intermediate image in the space between the two magnets. In the transverse plane the rays may be parallel in this same region. This is not a necessary condition, but one which simplifies the calculations somewhat.

The magnetic circuit is completed by a return yoke **8** which may be common to both magnets **1, 7**, as shown in FIGS. 2 and 3; alternatively, a separate return yoke may be used for each magnet **1, 7**. In order to reduce any stray magnetic field in that portion of the beam trajectory which lies between the magnets **1, 7**, a magnetic shield **9** may be provided.

I claim:

1. A method for effecting deflection of beams of charged particles without substantial dispersion of the beam, which method comprises producing and maintaining a first magnetic field and a second magnetic field, each having at least a first and a second boundary zone, producing a beam of charged particles having a central ray and directing said beam sequentially through said first magnetic field and said second magnetic field, each of said magnetic fields being generally transverse to the central ray with lines of flux defining mutually parallel planes which are perpendicular to the median plane defined by the central ray so that each boundary zone may be represented by a straight line in the median plane, the magnetic fields in the vicinity of the beam being uniform and of the same strength, the angle between the central ray and the second boundary zone of the first magnetic field being the same as the angle between the central ray and the first boundary zone of the second magnetic field, said angles being equal to the complement of one-half the angle of deflection through the first magnetic field, which angle of deflection is equal to the angle of deflection through the second magnetic field.

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