

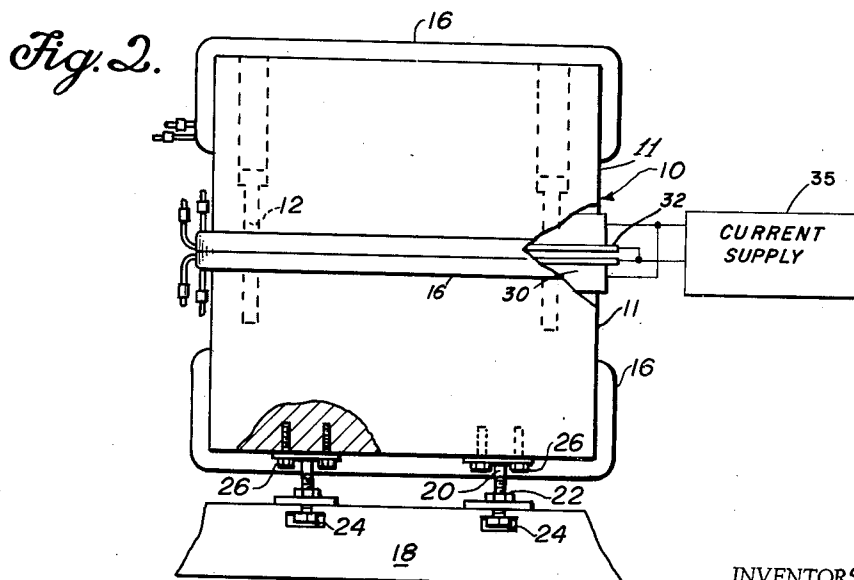
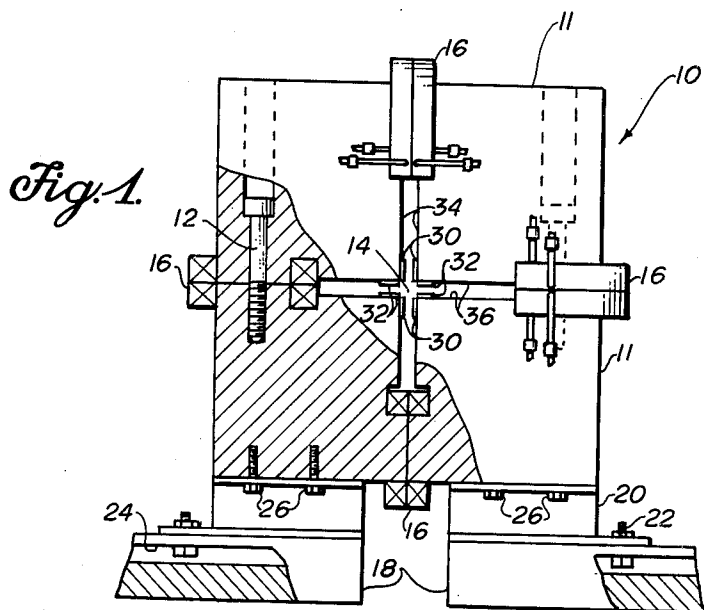
Aug. 17, 1965

J. BALLAM ETAL
MAGNETIC MOMENTUM ANALYZING SLIT WITH CURRENT CONDUCTING
STRIPS SECURED TO THE MAGNETIC POLES

3,201,585

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2 Sheets-Sheet 1



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Fig. 3.

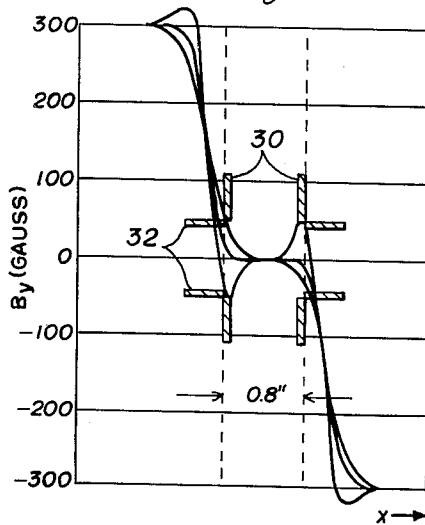


Fig. 4.

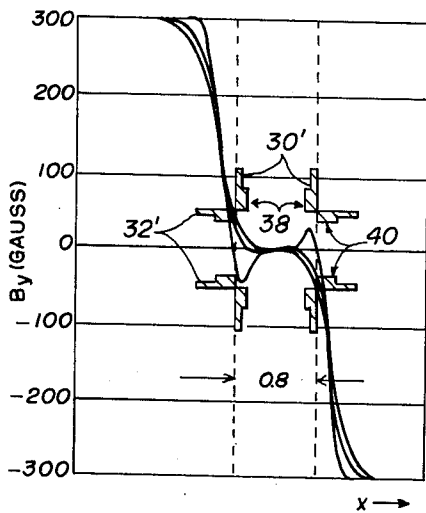
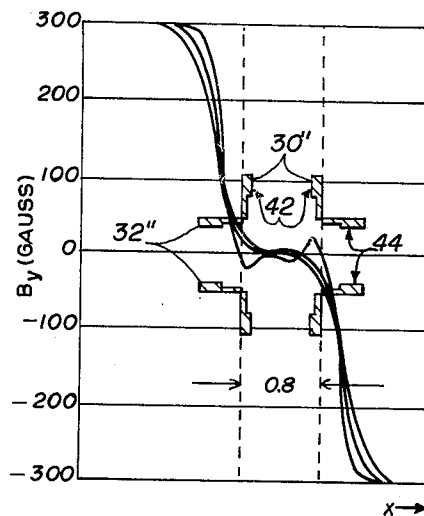


Fig. 5.



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MAGNETIC MOMENTUM ANALYZING SLIT WITH CURRENT CONDUCTING STRIPS SECURED TO THE MAGNETIC POLES

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The present invention relates generally to a device for separating charged particles of given momentum range in a high energy beam, and in particular to a magnetic momentum analyzing slit for separating charged particles of a given momentum range, utilizing appropriately placed current conductors to provide a zero magnetic field in a central aperture defined therein.

Previous methods for physically separating particles of a desired momentum range have generally utilized an adjustable slit made from common materials such as lead, iron or copper. The slit is generally utilized in conjunction with a collimator placed thereafter in the path of the beam, wherein the dimensions of the slit and collimator are determined mainly by the average momentum of the particles in the beam. Since this type of conventional apparatus utilizes physical contact between a portion of the apparatus and the unwanted particles passing therethrough, a good deal of the energy of such unwanted particles is dissipated in the slits and collimators. When utilized for separating particles of very high intensity beams of the order of, for example, 20 beV., the amount of energy to be dissipated is extremely high and causes serious problems concerning the requisite cooling of the device and the generation of radioactivity. In addition, many particles are scattered from the edges of the conventional slit to appear later as unwanted particles in the beam, thus causing a degeneration in the optical quality of the beam.

The present invention therefore provides a magnetic momentum slit capable of separating particles within a desired momentum range by utilizing a shaped magnetic field which is excited therein without resorting to conducting structures inside the area of the passing beam. In particular a magnetic field is employed which must satisfy certain symmetry conditions so as to eliminate polar effects which would otherwise interfere with separation and to otherwise provide the most effective conditions for separation.

Accordingly, it is an object of the present invention to provide means for physically separating particles having a given range of momentum in a very high energy charged particle beam.

It is still another object of the present invention to provide a magnetic momentum slit for separating charged particles in a beam, utilizing a magnet and field compensating current conductors to create an essentially zero magnetic field in the slit gap.

It is yet another object of the present invention to provide a particle separating device having a central aperture or slit wherein is generated an associated magnetic field, wherein field compensating current conductors are arranged to cancel the fringe field within a particle separating slit so that there is effectively zero field existing along a center-most portion thereof.

Still another object of the present invention is to provide a magnetic momentum slit for separating charged particles in a high energy beam passing therethrough, wherein the particles of unwanted momentum are deflected to an advantageously situated disposal region rather than being allowed to impinge upon a solid material obstruction.

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Yet another object of the present invention is to provide a magnetic momentum slit for separating high energy particles without giving rise to serious problems of water cooling and radioactivity generation.

Other objects and advantages will be apparent in the following description and claims considered together with the accompanying drawing in which:

FIGURE 1 is a partially broken-out end view of the magnetic momentum slit of the present invention.

FIGURE 2 is a side view of the invention shown in FIG. 1.

FIGURE 3 is a graph depicting the vertical magnetic field as a function of x , illustrating the field cancellation achieved with the specific configuration of current strips of FIG. 1.

FIGURE 4 is a graph depicting the vertical magnetic field as a function of x , illustrating the field cancellation achieved by use of an alternative configuration of current strips within the slit.

FIGURE 5 is a graph depicting the vertical magnetic field as a function of x , illustrating the field cancellation achieved in the slit by use of still another alternative configuration of current strips.

Consider first a conventional magnetic moment slit, formed for example of a pair of C-type magnets arranged at right angles and assume a beam of a specified magnetic momentum spread which has been previously dispersed over a particular distance in the horizontal plane by a deflecting magnet and focused by a magnetic lens system to a particular vertical width. Separation of the particles may be accomplished by suitably positioning the magnetic slit transversely across the beam cross section having the desired moments. With the above set of circumstances when using a conventional magnetic momentum slit, the path of particles entering to the left of the center line of the slit system will be bent towards the left and that of particles entering to the right of the center line will be bent towards the right. The deflected particles will then impinge on the structure of the magnetic slit. In addition, because of the fringing fields within the magnetic slit only an infinitesimal number of particles, namely those that enter exactly in the center of the slit, will be undeflected. However, with the present invention, means is provided to cancel the fringe field over a finite volume of substantial size in the region of the magnetic slit gap, whereby a greatly increased number of particles of desired momentum ranges will pass undeflected while unwanted particles are effectively deflected and an optimum physical separation of wanted and unwanted particles will be achieved with essentially no contact between the particles and solid portions of the apparatus.

In accordance with the present invention, the cancellation of the above-mentioned fringe field existing in the gap within a magnetic slit is theoretically demonstrable to be feasible by utilizing a series of current sheets, and to be physically achievable by the use of field compensating current conducting strips or conductors appropriately disposed in the gap or centrally-extending aperture of a magnetic slit. In essence the current conductors are arranged to cause the corrective magnetic field generated thereby to approximate an octopole magnetic field. Such octopole field is provided in such a manner as to cooperate with the magnetic field of the conventional magnetic slit to achieve a cancellation, or near cancellation, of the magnetic field within a predetermined volume of the slit aperture. To visualize the manner in which the foregoing combination or superimposition of fields operates to effect the desired separation of particles, consider, for example, a high-energy beam of charged particles of momentum range $p_0 \pm \Delta p$ where p_0 is the average particle momentum and wherein the beam has emerged from a

momentum-analyzing magnet, and is traveling in the positive z -direction along the axis of a particle accelerator. For such a beam there exists a definite correspondence between the particle momentum and one of the particle transverse coordinates. Let the particles traveling with an average momentum p_0 have the coordinate $x=0$, and the particles traveling with a momentum p have the coordinate $x=x(p)$. Thus, x is an odd function of $p-p_0$ in the limit of vanishing $p-p_0$.

Then assume that the beam is passed through an elongated magnetic device called a momentum slit. Let the total cross section of the momentum slit gap or aperture be defined by $-b \leq x \leq b$ and $-a \leq y \leq a$ with $a < b$, where $2a$ is the gap thickness and $2b$ is the gap width. The purpose of using the slit is to separate the particles of a very narrow momentum range ($p_0 \pm \delta p$) from the remainder of the beam. The function of the slit may be described most simply by assuming an ideal magnetic field as follows:

$$B_z = B_x = 0 \text{ everywhere} \quad (1a)$$

$$B_y(x, y) = \begin{cases} +\mu_0 I & a < x \leq b, -a \leq y \leq a \\ 0 & -a \leq x \leq a, -a \leq y \leq a \\ -\mu_0 I & -b \leq x < -a, -a \leq y \leq a \end{cases} \quad (1b)$$

where B_y is the magnetic field component in the y -direction, B_z the component in the z -direction, and B_x the component in the x -direction, μ_0 is a proportionality constant, and I the current in the conductor strips. The particles in the desired momentum range are directed to enter the central part of the slit where the magnetic field vanishes; therefore these particles will pass through the slit without being deflected. The particles having momentum greater than $p_0 + \delta p$ and less than $p_0 - \delta p$, enter the slit on opposite sides of the field-free region where they experience a constant transverse field. The polarity of the field is such that off center particles will be deflected continuously away from the central plane ($x=0$) as they travel forward. Thus the unwanted particles may be separated from the wanted ones to any desired degree by increasing the length of the momentum slit.

The component B_y of the above-described ideal field changes discontinuously with x at the plane surfaces $x = \pm a$. It is not possible to excite such an ideal field unless current sheets are used at the surfaces of discontinuity. If this were possible, the ideal field could then be excited by the use of four infinite sheets of current located at $x = \pm a$ and $x = \pm b$. The current in these sheets should flow in the z -direction only. Let I_x denote the surface current in units of amperes per meter. If

$$I_x = \begin{cases} +I & \text{on } x = \pm a \\ -I & \text{on } x = \pm b \end{cases}$$

the field inside the region of the slit will be as specified by Eqs. 1a and 1b supra. While the magnetic field does have the ideal configuration, the slit region is not free of obstruction to the passage of the beam. There are conducting planes $x = \pm a$ inside this region. These planes would intercept part of the wanted and the unwanted beams, giving rise to heating, generation of radioactivity and the scattering of particles as mentioned above.

To avoid such difficulties the slit region should be free from any obstructing material. To satisfy this condition the magnetic field inside the slit must be an analytic function of coordinates x and y . Hence no region of non-vanishing volume inside the slit can be entirely field-free. This situation, however, does not preclude the possibility that the field in the central region of the slit may be made sufficiently small to obtain the desired result as will now be disclosed with reference to practical embodiments for accomplishing the desired result.

More particularly, referring to FIGS. 1 and 2, there is

shown a magnetic momentum slit 10 of the present invention, having a configuration approximating that of a quadrupole magnet. A plurality of C-type magnetic pole pieces 11 forming the slit are assembled by means of a suitable plurality of bolts 12 to define therethrough an elongated, centrally extending gap or aperture 14. A magnetic field is generated within gap 14 by means of suitable coils 16 disposed circumjacent the center leg portions of the magnetic pole pieces 11, which coils 16 are connected to suitable sources of electrical energy (not shown). The magnetic slit 10 is suitably mounted on a support member 18 by means of "I" channels 20 and a plurality of bolts 22 slidably disposed within mounting grooves 24 formed in the support members 18. The "I" channels 20 are secured to the magnetic slit 10 by a series of bolts 26. Although a particular mounting means is herein shown, it is obvious that other mounting systems may be utilized to support the slit.

Accordingly, the magnetic slit 10 may be seen to comprise, generally, a plurality such as four elongated rectangular pole pieces, arranged in parallel with outer abutting planar edges, forming the legs of said C-type magnets and inner proximate edges defining a central or axial square aperture 14 having four radially extending rectangular lobes. For convenience in construction coils 16 are wound about the aforesaid magnet by portions.

In keeping with the concept of the present invention, a series of current strips or conductors 30 and 32 are rigidly secured, preferably by adhesives or welding, to the vertical and horizontal surfaces 34 and 36 respectively of the magnetic slit pole faces defining the aforesaid aperture lobes along the axial length thereof adjacent the square portion of said aperture. In the most general configuration of the present invention, see FIG. 1, the conductors 30 and 32 are rectangular in cross section. However, as further discussed infra, various cross-sectional configurations are possible depending upon the particular magnetic field gradient characteristics desired within the slit 10. The cancellation of the fringe magnetic field of previous mention within the slit aperture 14, is achieved by passing currents through the conductors 30 and 32 to generate therealong a compensating magnetic field. To provide a self-cancelling effect of the compensating fields, conductors 32 carry current in an opposite direction with respect to conductors 30 across gap lobes. Thus conductors 30, 32 provide a cancellation or near cancellation of the magnetic field over a volume of predetermined dimensions for the particular axial length of the magnetic slit 10. The return conductors (not shown) for the conductors 30, 32 are coupled to a suitable current source 35, preferably a pulsed, direct-current source, and are disposed a sufficient distance from the centrally extending aperture 14 to preclude their influencing the field distributions inside the aperture 14. The conductors 30, 32 shown in FIG. 1 generally have a thickness varying from 0.2 cm. to 1 cm. The aperture 14 of the slit 10 system need not always have a square cross section, but could, for example define a rectangle. Likewise, it is preferable that the aperture 14 width should be adjustable in order to vary the chosen range of desired particle momentum. If the slit 10 is not sufficiently long in the axial, i.e., z -direction, the end effects likewise may become important. Thus it may be seen that the actual design and dimensions of the iron-core slit 10 may vary somewhat in practice dependent upon the length of magnetic slit needed and the size and shape of the aperture therethrough.

As noted, the various possible cross sections of conductors 30, 32 may be varied to vary the magnetic field gradient characteristics within the centrally extending aperture 14. FIG. 3 shows the magnetic field gradient achieved by means of current conductors 30, 32 having a rectangular cross section such as shown in FIG. 1. The aperture 14 spacing is arbitrarily taken as 0.8 inch. It is to be understood that the strips 30, 32 could be embedded

in the magnet pole faces to lie entirely flush, or partially within the surfaces thereof. FIG. 4 shows the effect of the conductor strips on a vertical magnetic field within the aperture 14 using an alternative configuration of current strips. In such alternative configuration of current conductors 30', 32', disposed on the corners of the pole faces in the same manner as heretofore shown on FIG. 1, the cross section has been varied such that the thickness of approximately half of their width has been doubled as shown in the region 38, 40 respectively thereof.

The effect on the vertical magnetic field within the aperture 14 with still a second alternative configuration of current strips is shown on FIG. 5, wherein the current conductors 30'', 32'' are shaped to define a further modified cross section. In this second alternative configuration the thickness of conductors 30'', 32'' as shown at 42, 44 respectively, is thickened for that half of the conductor furthest removed from the corner of the pole faces. As may be seen from the FIGS. 3, 4 and 5, the cancellation of magnetic field achieved with the arrangement of strips is such that the slope of the field fall-off as well as the flatness of the field at the center of the aperture 14 are both satisfactory for the intended operation of the magnetic slit 10. However, as seen on FIG. 3, the reverse wings of the magnetic field which occur near the top and bottom of the gap are rather large. As may be seen in FIG. 5, a decided reduction of the reverse wings is accomplished by the use of the particularly shaped cross section of the conductors 30'', 32''.

Although the variation of the magnetic field with regards to a variable cross section of the current conductors has herein been shown, it is to be understood that the magnetic field gradient will also vary for various dimensions of aperture 14, which dimensions for example, may vary from zero to 4 cm. in width. Likewise, the field distribution may vary for various values of current which is passed through the compensating conductors.

While the invention has been disclosed with respect to one embodiment and several modifications thereof, it will be apparent to those skilled in the art that various variations and modifications may be made within the spirit and scope of the invention, and it is not intended to limit the invention except as defined in the following claims.

What is claimed is:

1. In a magnetic momentum analyzing slit for isolating particles having a desired momentum range from a particle beam, including magnetic field generating means having a series of magnetic poles spaced in circumjacent relation about an axis to define an axially-extending aperture of substantially rectangular cross section in the region along said axis, coil windings disposed about portions of said magnetic poles, and current source means coupled to said coil windings to generate a magnetic field across said aperture the improvement comprising;

(a) a plurality of current conducting strips secured in integral relation along the lengths of said series of spaced magnetic poles along the edges thereof nearest the axis and in the region of said axially extending aperture, said strips further defining a plurality of facing parallel pairs of strips circumjacent to disposed about said axis;

(b) a current source connected to said plurality of current conducting strips for introducing electrical current thereto;

(c) said current source being connected to alternate pairs of strips of said plurality of current conducting strips in opposing polarity relation to generate a compensating magnetic field in said axially extending

aperture, said compensating magnetic field disposed to cancel the fringe magnetic field generated within said centrally extending aperture by said coil windings to define an effectively field-free region of finite volume there along, the lateral boundaries of said field-free region being defined by sharp magnetic field changes of opposite polarity.

2. The magnetic momentum slit according to claim 1 wherein said current conducting strips further comprise solid flat elongated strips of rectangular cross section, secured to respective poles with one edge thereof lying flush with the respective magnetic pole edge along the axial lengths thereof.

3. The magnetic momentum slit according to claim 1 wherein said current conducting strips further comprise solid flat elongated strips, wherein substantially one-half the width of each strip is approximately twice the thickness of the remaining width of the strip, and wherein the thinner edge of the strip lies flush with the respective magnetic pole edge along the axial lengths thereof.

4. The magnetic momentum slit according to claim 1 wherein said current conducting strips further comprise solid flat elongated strips, wherein substantially one-half the width of each strip is approximately twice the thickness of the remaining width of the strip, and wherein the thicker edge of said strip lies flush with the magnetic pole edge along the axial lengths thereof.

5. A magnetic momentum analyzing slit for selectively isolating particles of a desired momentum range from a particle beam passing along a central axis thereof comprising;

(a) magnetic field generating means including a plurality of C-type magnets having magnetic poles of substantially rectangular cross section, said magnetic poles being disposed in circumjacent relation about an axis to define between the adjacent edges thereof an axially extending aperture of substantially rectangular cross section;

(b) a current conducting strip integrally secured to each surface of each of said magnetic poles along the circumjacent spaced edges thereof, the edges of said strips nearest said axis being arranged to lie flush with the edge of their respective poles along the axial length thereof said strips thereby defining pairs of facing parallel strips;

(c) current source means for supplying pulsed direct current to said current conducting strips, wherein said current source means is connected to alternate pairs of strips such that alternate pairs of strips exhibit an opposing polarity relation;

(d) wherein said pairs of strips generate a compensating magnetic field along said axially extending aperture to cancel the fringe field of said magnetic field generating means to define an effectively field-free region of finite volume there along, the lateral boundaries of said field-free region being defined by sharp magnetic field changes of opposite polarity.

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