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J. PINEL

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DEVICE TOWARD A Laterally SHIFTED TARGET
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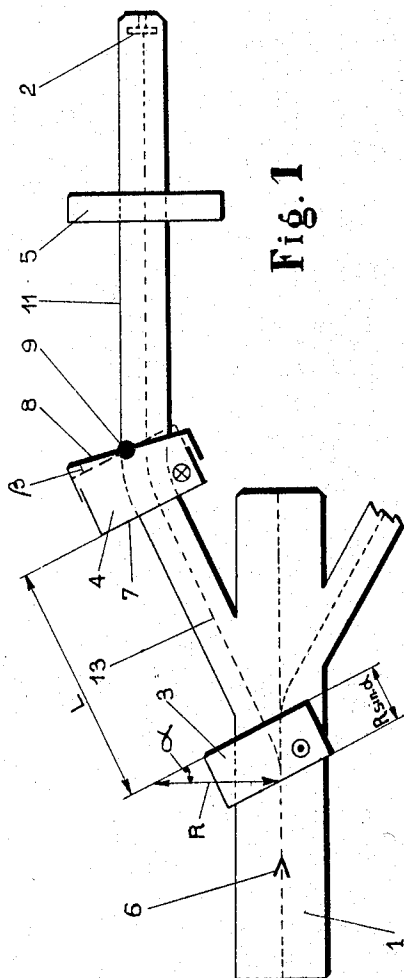


Fig. 1

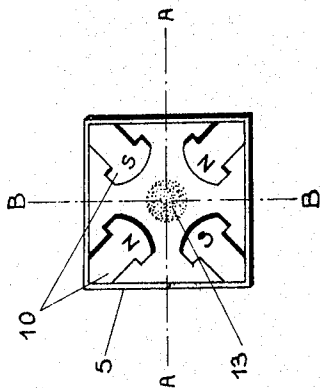


Fig. 2

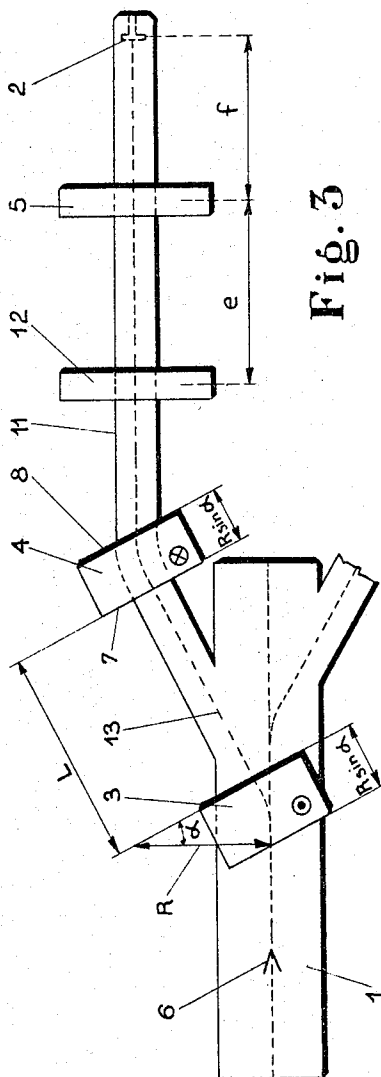


Fig. 5

INVENTOR:

J. PINEL

BY *Craig & Freudenberg*
ATTORNEYS

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FOCUSING ARRANGEMENT FOR GUIDING PARTICLES FROM AN ACCELERATOR DEVICE TOWARD A LATERALLY SHIFTED TARGET

Jacques Pinel, Paris, France, assignor to Compagnie Generale de Telegraphie Sans Fil, Paris, France

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The present invention relates to a particle accelerator installation, and more particularly to the guiding and focusing arrangement of such an installation for use with a beam of charged particles derived from a particle accelerator, properly speaking.

In the exploitation of charged particles accelerators, it is current usage to derive from the accelerated beam or in the course of acceleration thereof, several beams each corresponding to a band of predetermined energy, and to direct each of these beams against a target located at a utilization point or site of which the emplacement or location with respect to the source of the beam is fixed in advance. Generally, for that purpose a magnet is used which curves the trajectories of the particles in a plane perpendicular to the lines of force thereof in such a manner that the same leave the magnet at a certain angle with respect to the beam within the accelerator and that they follow a guide which connects the output of the magnet, i.e., the side of the magnet at which the particle beam emerges from the gap, to the desired point of utilization thereof.

If a given stream within the beam is considered, for example, of an electron beam, this stream contains electrons of different energies, and the magnet in question acts on these different electrons, i.e., on the electrons of different energies in such a manner that they follow different trajectories which are spread out in planes parallel to the pole faces of the magnet and which intersect either at a real or a virtual point usually called the "focus of energy." If, on the other hand, parallel streams within the beam are considered, and if within all of these streams only the electrons having the same energy are considered, and if further the input and output faces of the magnet, i.e., the faces through which the beam respectively enters or emerges from the gap of the magnet, are parallel, then such magnet does not exercise any focusing action on these parallel streams within the plane of symmetry of the magnet gap perpendicular to the lines of force so that the beam will not have within this plane, which will be called hereinafter for convenience sake the "horizontal plane," any focus to be referred to hereinafter as the "horizontal focus." Within the plane which will be referred to hereinafter for convenience's sake as the "vertical plane," perpendicular to the last mentioned plane, i.e., to the "horizontal plane," this magnet will, in contrast thereto, behave like a lens in such a manner that the parallel streams of the charged particles having the same energy will have within the vertical plane a focus which will be referred to hereinafter for convenience's sake as the "vertical focus" of which the position within space will not coincide, however, in the general case with the "energy focus." Thus, the prior art system utilizing a derivating magnet provides at the output thereof a beam which is horizontally afocal, i.e., the horizontal focus of which is shifted to infinity, and which has a vertical focus which does not coincide with the energy focus thereof.

However, the targets utilized at the utilization points or locations are generally of very small dimensions, and there exists a keen interest to focus the beam on the targets with respect to energy as well as horizontally and vertically. In other words, it is necessary that the guid-

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ing system be such that the energy focus, the horizontal focus and the vertical focus coincide all three with the predetermined point within space where the target is installed, a problem which has never received any satisfactory solution within the guide systems of the prior art.

The present invention aims at a guide installation for a beam of charged particles derived from an accelerator which provides the solution to the problem mentioned hereinabove, that is, which brings into coincidence, without inadmissible aberration, the three foci mentioned hereinabove at a point predetermined in space.

Accordingly, it is an object of the present invention to provide a guidance and focusing system for charged particles derived from a particle accelerator which obviates the shortcomings and inadequacies of the prior art installations in an effective and simple manner.

Another object of the present invention resides in the provision of a focusing arrangement by the use of magnets which brings about an essential coincidence of the energy focus with the orthogonal foci of the beam at a predetermined point in space coinciding with the relatively small target.

A further object of the present invention resides in the provision of a guiding and focusing system which, by simple means, permits a more effective utilization of the output derived from a particle accelerator in the form of a beam or beams of charged particles.

A still further object of the present invention resides in the provision of a guiding and focusing system which utilizes simple means to bring about the desired results enumerated hereinabove.

These and other objects, features and advantages of the present invention will become more obvious from the following description when taken in connection with the accompanying drawing which shows, for purposes of illustration only, two embodiments in accordance with the present invention and wherein,

FIGURE 1 is a schematic plan view of a guidance and focusing system for charged, accelerated particles in accordance with the present invention,

FIGURE 2 is a side view of one embodiment of a magnetic lens utilized in the embodiment of either FIGURE 1 or FIGURE 3, and

FIGURE 3 is a plan view, similar to FIGURE 1 of a modified embodiment of a guidance and focusing system in accordance with the present invention.

The guidance and focusing installation according to the present invention is characterized by the fact that it includes a pair of magnets having lines of force mutually parallel but respectively opposite, the input and output faces of the first magnet and the input face of the second magnet being parallel whereas, between the output face of the second magnet and the point of utilization, a magnetic lens is interposed having difference characteristics of convergence within the horizontal plane and within the vertical plane thereof.

For example, the lens may be divergent within one of these orthogonal planes and convergent in the other. Such a lens may be realized in a simple manner whereby the absolute values of the focal distances within such lens are equal within the two planes thereof.

In the case in which the output face of the second magnet is not parallel to the input face thereof, while nevertheless remaining perpendicular to the horizontal plane, such installation with two magnets and a lens is sufficient to obtain the desired result.

In the contrasting case, in which the input and output faces of the two magnets are parallel, a second magnetic lens is interposed between the output face of the second magnet and the first lens, this second lens being of the same type as the previous lens, that is, having different

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characteristics of convergence in the two orthogonal planes thereof.

Referring now to the drawing wherein like reference numerals are used throughout the various views to designate corresponding parts, and more particularly to FIGURE 1, reference numeral 1 designates therein schematically an accelerator for charged particles, for example, a linear electron accelerator. Reference numeral 2 thereby designates a utilization point including a target on which it is desired to focus the accelerated electrons. For that purpose, a guidance system is provided in accordance with the present invention which includes a pair of magnets 3 and 4 and a magnetic lens 5. The magnet 3 corresponds to the classic magnet of conventional construction utilized to derive a partial beam at a given point of the accelerator 1. The lines of force of magnet 3 are thereby assumed to be perpendicular to the plane of FIGURE 1. This plane, i.e., the plane of the drawing, will, therefore, be considered as the "horizontal plane" according to the definitions given hereinabove, it being understood that the term "horizontal" is used herein only in an arbitrary manner to designate one of the two orthogonal planes which may in practice assume any position in space, such nomenclature being for convenience's sake only.

The lines of force of the magnet 3 are directed toward the observer, whereby the deviation of the electrons derived from the electron accelerator 1 takes place toward the left with respect to the initial direction of the beam indicated by arrow 6. The input and output faces of the magnet 3 are parallel and are inclined at an angle α with respect to the perpendicular to the direction 6. The intensity B of the magnetic field in magnet 3 is chosen such that the radius of curvature of the trajectory of the electrons of average energy E is equal to R. The values of B, E and R are interrelated by the well known equation

$$B \cdot R = \frac{E}{3} \cdot 10^4 \quad (1)$$

wherein B is in gauss, R in centimeters, and E in mev. Finally, the size of the magnet is taken equal to $R \sin \alpha$ if it is desired that the beam emerges from the magnet 3 perpendicularly to the output face thereof as indicated in FIGURE 1.

The second magnet 4 is located at a distance L from the first magnet 3 which distance L, representing the distance between the output face of the first magnet 3 and the input face 7 of the second magnet 4 may be selected arbitrarily. The input face 7 of the second magnet 4 is parallel to the two faces of the magnet 3 whereas the output face 8 of the second magnet 4 is inclined within the horizontal plane at an angle β with respect to the input face 7 thereof while nevertheless remaining perpendicular to the horizontal plane. The lines of force of the second magnet 4 are perpendicular to the plane of FIGURE 1 but opposite to those of the magnet 3, i.e., directed toward the plane of the drawing away from the observer. It is understood, of course, that the angle β may be rendered adjustable in any suitable known manner, for example, by providing a mechanism which permits to pivot the face 8 about the vertical axis 9 thereof. An example of such mechanism which permits adjustment of the angle β is disclosed, for instance, in the German Patent 860,871.

The second magnet 4 curves the electronic trajectories in the opposite direction to that of magnet 3 and one may always select the parameters R, L, α and β in such a manner that the trajectory leaving the magnet 4 passes through the predetermined point 2. The choice of combinations of different values available for these parameters permits to direct on as many different utilization points or targets as is desired, different beams derived from the same accelerator by the use of a corresponding number of installations of the type described hereinabove.

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In order to achieve the focusing action, a magnetic lens of the type having different characteristics of convergence in the two mutually perpendicular planes, i.e., in the orthogonal planes, is disposed between the output face 8 of the second magnet 4 and the target 2, for example, providing respectively the convergence and the divergence within these two planes, with an equality of absolute values in the corresponding focal distances. Such a lens is shown in side view in FIGURE 2. The lens shown in FIGURE 2 includes a frame 5 on which are fixed two pairs of magnetic poles 10 at 45° with respect to the desired convergence and divergence planes. The poles of the same polarity face each other on the same diagonal. It may be readily determined that if the beam 13 is composed of electrons and moves toward the observer in the plane of the drawing, the arrangement shown in FIGURE 2 including the north poles N at the upper left and lower right and the south poles S at the lower left and upper right assure the convergence within the plane A—A and the divergence within the plane B—B of the lens 5. The lens 5 within FIGURE 1 is therefore disposed, in order to make the electron beam move from left to right as viewed in this figure, in such a manner that the plane B—B coincides with the "horizontal plane," i.e., the plane of FIGURE 1.

By calculating such an installation in a manner known to a person skilled in the art, it is always possible to arrive at a set of values for R, L, α and β , for the respective distances of the lens 5 from the target 2 and from the magnet 4 and for a value of convergence of the lens 5 equal to the value of divergence except for the sign in such a manner that simultaneously the conditions of passage of the beam 13 through the point 2 and the triple focusing action of the beam in this exact point, i.e., focusing with respect to energy, focusing in the horizontal and in the vertical plane, are completely satisfied. The installation is then completed by an enclosure 11, for example, a guide in which the vacuum may be established and in which the beam may propagate until capture thereof by the target 2.

OPERATION

Without becoming involved in the possible variations of the calculations which depend on each particular case, the operation of the focusing and guidance system in accordance with the present invention may be described qualitatively and in general as follows:

It is known that a pair of magnets, such as magnets 3 and 4 offer the property or characteristics that the energy focus thereof coincidences with the horizontal focus thereof, the common distance of this dual focus to the output face 8 of the magnet 4 depending on the angle β . This distance is finite when the angle β is not equal to zero, and the dual energy and horizontal focus is, therefore, found somewhere along the axis of the beam emerging therefrom within the horizontal plane. At the same time, the distance of the vertical focus depends in general from the dimension L, but this vertical focus is located on the same axis as the dual focus mentioned hereinabove and in general at a point different from the latter. It is, therefore, possible to dimension the system in such a way that the target 2 is placed between the dual focus mentioned hereinabove and the vertical focus. The lens 5, suitably dimensioned and positioned within the system, thereby acts by the divergence thereof in such a manner as to extend or increase the distance of one of these two foci and by the convergence thereof in such a manner as to shorten the focal distance of the other. The two distances of the common focus and of the vertical focus are therefore susceptible to become essentially equal to the distance between the output face 8 of the second magnet 4 and the target 2 in such a manner that a triple focusing action on this target 2 is effectively realized.

A particular case in accordance with the present invention corresponds to the condition in which the angle β is

equal to zero, that is, in which parallelism exists between all the input and output faces of the two magnets 3 and 4. The assembly of these two magnets 3 and 4, therefore, conserves the property of coincidence of the energy focus with the horizontal focus but this dual focus is projected at infinity, that is, the system in effect is horizontally afocal. In that case, the system of FIGURE 1 is modified as illustrated in FIGURE 3 in which the same reference numerals are again used to designate analogous parts. An auxiliary lens 12 is then interposed between the lens 5 and the output face 8 of the second magnet 4, which in that case is parallel to the input face thereof. The auxiliary lens 12 is of the same structure as lens 5, that is, essentially similar to the lens illustrated in FIGURE 2. However, the lens 12 is rotated by 90° with respect to the lens 5, that is, the plane of convergence A—A is now placed horizontally, i.e., in the plane of the drawing. The role of this auxiliary lens 12 is to bring back the dual focus from infinity to a finite distance along the axis of the beam which re-establishes the conditions of those complete focal coincidences in FIGURE 1.

For purposes of illustration only, the results of the calculation will be given hereinafter for the system in the case of FIGURE 3 in which the output face of the magnet 3 is perpendicular to the beam emerging from the accelerator 1, this system being rendered still further a particular case by a dimensioning thereof in such a manner that not only the horizontal focus but also the vertical focus are projected to infinity, that is, the system of magnets is afocal both horizontally and vertically. This dimensioning is given by the known equation:

$$L=2R(\cot \alpha -\alpha) \quad (2)$$

In this case, by designating by e the distance between the two lenses 12 and 5, by f the distance between the lens 5 and the target 2, and by D_1 and D_2 the respective convergence or divergence of the lenses 12 and 5, the calculation gives for lens 12 the following equation:

$$D_1=\pm \frac{1}{\sqrt{e(e+f)}} \quad (3)$$

and for lens 5:

$$D_2=\mp \frac{1}{f}\sqrt{\frac{e+f}{e}} \quad (4)$$

wherein D_1 and D_2 are in diopters, if e and f are in meters. In all cases, the calculation also will indicate that the aberration error is negligible.

While I have shown and described two embodiments in accordance with the present invention, it is understood that the present invention is not limited thereto but is susceptible of many changes and modifications within the spirit and scope of the present invention. For example, the present invention also encompasses all installations including the necessary elements indicated hereinabove for the proper guidance and focusing actions even if the dimensioning thereof does not correspond exactly to that indicated by the calculations given herein, provided that the triple focusing action desired in accordance with the present invention is reasonably realized. Obviously, the present invention is not limited to electron accelerators but the general principles thereof as indicated hereinabove in connection with the triple focusing action is also applicable to proton accelerators or accelerators of other particles having a positive charge provided suitable modifications in the dimensions and orientations of the magnetic lines of force are made in such case.

Thus, it is obvious that the present invention is susceptible of many changes and modifications within the spirit and scope of the present invention, and I, therefore, do not wish to be limited to the particular examples shown and described herein, but intend to cover all such changes and modifications as are encompassed by the scope of the appended claims.

I claim:

1. A focusing system for focusing charged particles derived from a particle accelerator onto a target located at a predetermined point in space with respect to energy as well as with respect to orthogonal planes relative to movements thereof, said point being located outside of the particle trajectory within said accelerator, comprising first magnet means for deriving said charged particles from the normal particle trajectory within the particle accelerator and for effectively providing coincidence at said point of target location of the energy focus and the focus in one of the two orthogonal planes thereof, and second magnetic means for effectively producing coincidence of the focus in the other of the two orthogonal planes with said first-mentioned dual focus at said target.

2. A focusing and guiding system for focusing charged particles derived from a particle accelerator onto a fixed target with respect to the energy of the particles as well as with respect to the orthogonal planes essentially perpendicular to the normal propagation of the particles positioned outside of the trajectory of said particles within said accelerator, comprising first magnet means for deriving said charged particles from the normal particle trajectory within the particle accelerator and for effectively providing coincidence at said target of the energy focus and of the focus in one of the two orthogonal planes thereby producing a dual focus, and second magnetic means constituting a magnetic lens for producing coincidence of the focus in the other of the two orthogonal planes with said first-mentioned dual focus essentially at said target.

3. A focusing system for focusing particles derived from a particle accelerator onto a fixed, predetermined target positioned outside of the trajectory of said particles within said accelerator, comprising first and second magnet means for deriving said charged particles from the normal particle trajectory within the particle accelerator and for effectively providing coincidence of the energy focus and of the focus in one of two orthogonal planes, and magnetic lens means for providing coincidence at said target of the focus in the other of the two orthogonal planes with said first mentioned dual focus.

4. A focusing system for focusing a beam of charged particles derived from a particle accelerator onto a target positioned outside of the trajectory of said particles within said accelerator, comprising first and second magnet means having input and output faces for said beam for effectively providing coincidence of the energy focus and of the focus of equi-energetic particles of said beam in one of the two orthogonal planes essentially perpendicular to the propagation of said beam, and magnetic lens means for providing coincidence at said target of the focus in the other of the two orthogonal planes with said first mentioned focus, the input and output faces of at least one of said magnet means being parallel and forming an angle α with the plane perpendicular to the direction of propagation of said beam within said accelerator, said one magnet means having field intensity B and a length $R \sin \alpha$, where R is the radius of curvature of the particles of average energy E in said one magnet means and essentially satisfying the equation of

$$B \cdot R = \frac{E}{3} \cdot 10^4$$

where B is in gauss, R in centimeters, and E in mev.

5. A focusing system according to claim 4, wherein one of the faces of the other magnet means is essentially parallel to said parallel faces of said one magnet means, the other face of said other magnet means subtending an angle β with respect to a plane of said one face, the distance between said one face of said other magnet means and of the face closest thereto of said one magnet means being L , and $\beta \neq 0$.

6. A focusing system according to claim 5, wherein $\beta = 0$ and wherein said lens means includes two lenses

having each different characteristics of convergence in two orthogonal planes.

7. A focusing system according to claim 6, wherein $\beta=0$, wherein $L_{em}=2R$ (ctg $\alpha-\alpha$), and wherein the respective convergence D_1 of the one of said two lenses and D_2 of the other is given essentially by the following equations:

$$D_1 = \pm \frac{1}{\sqrt{e(e+f)}}$$

and

$$D_2 = \mp \frac{1}{f} \sqrt{\frac{e+f}{e}}$$

D_1 and D_2 being in diopters with e and f in meters, whereby e is the distance between said two lenses, and f the distance between said target and the lens closest thereto, the plus sign denoting a positive convergence of one of said lenses in one of said planes and of the other lens in the other plane, and the minus sign denoting a negative convergence constituting a divergence in said other plane for said one lens and in said one plane for said other lens.

8. A focusing system for focusing a beam of charged particles derived from a particle accelerator onto a predetermined target positioned outside of the trajectory of said particles within said accelerator, comprising means for guiding said beam to pass through said target including focusing means for focusing said beam at said target with respect to energy and with respect to two orthogonal planes.

9. In a charged particle accelerator installation having at least one guiding duct defining in its interior a path for charged particles between an accelerator output and a target positioned at a predetermined location outside of the normal trajectory of said particles within said accelerator, a guide system for guiding said particles along said path, comprising, along said duct, a first and a second magnet having lines of force mutually parallel but respectively opposite, the input side for said particles of said first magnet, the output side of said first magnet and the input side of said second magnet having parallel faces, and a magnetic lens between the output side of said second magnet and said target, said lens having different convergence characteristics in two mutually perpendicular planes.

10. The combination according to claim 9, wherein said lens is divergent in one of said planes and convergent in the other.

11. The combination according to claim 10, wherein the absolute values of the focal distances of said lens in both said planes are essentially equal.

12. The combination according to claim 9, wherein said output side of said second magnet has a face inclined at a predetermined angle with respect to said input side face while remaining parallel to said lines of force of both said magnets.

13. The combination according to claim 12, further comprising means for varying said angle.

14. The combination according to claim 9, wherein said output side of said second magnet has a face parallel to said input side face thereof, and further comprising a second magnetic lens located between said first mentioned magnetic lens and said target, said second magnetic lens having different convergence characteristics in two mutually perpendicular planes.

15. The combination according to claim 14, wherein both said lenses are divergent in one of said planes and convergent in the other, the respective convergence planes being crossed at right angles.

16. The combination according to claim 10, wherein said lens includes four magnetic poles inclined at 45° with respect to said convergence and divergence planes, each pair of mutually spatially opposite poles having the same magnetic polarity, and polarities in both pairs being opposite.

17. The combination according to claim 14, wherein both of said lenses include four magnetic poles inclined at 45° with respect to said convergence and divergence planes, each pair of mutually spatially opposite poles having the same magnetic polarity, and polarities in both pairs being opposite.

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JOHN W. HUCKERT, *Primary Examiner.*

ARTHUR GAUSS, RALPH G. NILSON, GEORGE N. WESTBY, DAVID J. GALVIN, *Examiners.*

R. F. POLISSACK, J. E. BECK, A. M. LESNIAK,
Assistant Examiners.