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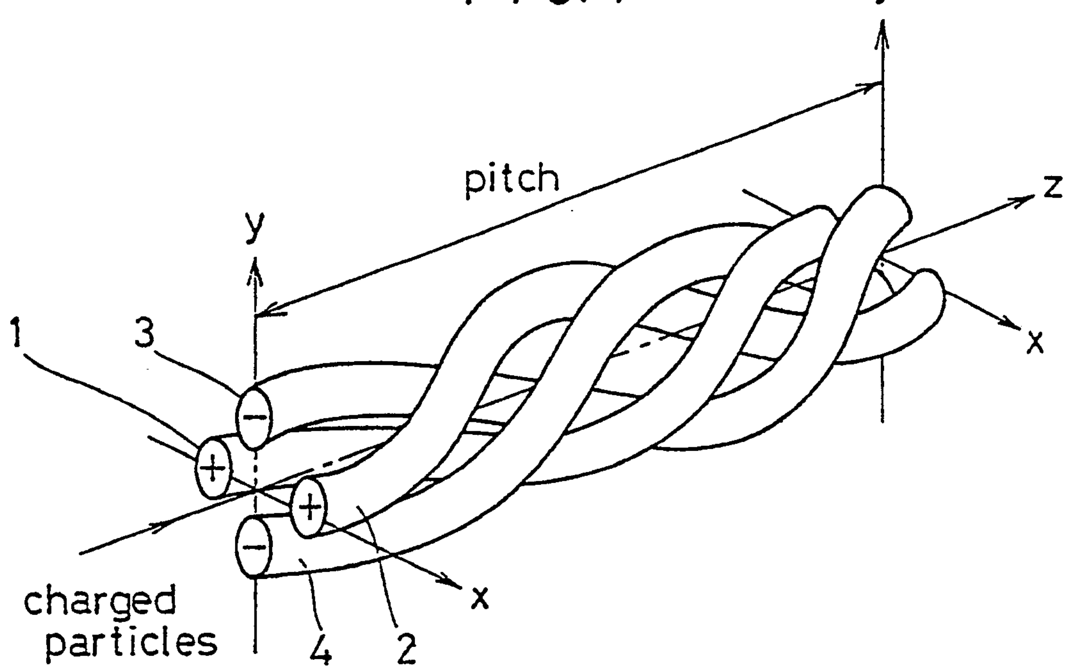
(54) **Charged particle convergence device.**

(57) The present invention relates to a charged particle convergence device provided with a plurality of even-numbered substantially prolongated poles (1, 2, 3, 4) arranged along a central axis (z) of a transport path of charged particles. Each pair of the poles (1, 2, 3, 4) are opposed to each other in a symmetrical manner with respect to the central axis (z) of the transport path. With keeping the opposing relation, the plurality of even-numbered prolongated poles spiral around the central axis (z) of the transport path. The same-polarized electric or magnetic potential is applied to each pair of the opposing poles while the reverse-polarized electric or magnetic potential is applied to the adjacent pair of the poles.

This device may be applied for transporting charged particles generated, for example, in an ion injection machine.

F I G. 1



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CHARGED PARTICLE CONVERGENCE DEVICE

BACKGROUND OF THE INVENTION

The present invention relates to a charged particle convergence device for transporting charged particles generated, for example, in an ion injection machine.

Conventionally, there is known a quadrupole lens (or Q lens) as shown in FIG. 5 [See for example, "Electron Ion Beam Handbook" 2nd Edition, the Japan Society for the Promotion of Science, NO.132 committe, published by Nikkan Industrial Newspaper Inc. pp 72~82.] The lens of FIG. 5 comprises four linear rod-like poles 51~54 symmetrically arranged in the x-y plane within the x-y-z rectangular coordinate system.
Positive potential (or North magnetic potential) is applied to the pair of poles 51 and 52 while negative potential (or North magnetic potential) is applied to the opposite pair of poles 53 and 54. Each of the poles 51~54 is arranged at the right angles. The similar poles 61~64 are arranged along the z-axis, so that they can be arranged to form a duplicate, a triplicate or a multiple quadrupole lens structure. In the multiple construction, the adjacent poles along the z-axis have the reversed electric (or magnetic) potential.

Thus, using the poles having the above-mentioned electric (or magnetic) potential, there is provided, within the space enclosed by the poles, a field for imparting strong convergence and strong divergence to charged particles traveling along the z-axis direction. A composite lens is provided for forcing the charged particles to converge at a point on the z-axis.

However, the quadrupole lens has the problem that the positive and the negative electric potentials (or the south and the north magnetic potential) must be finely controlled. Since, basically, the flow of the charged particles having the similar energy is gathered to a point in the z-axis by the quadrupole lens, it is impossible to transport the charged particles having different energy in a long distance or confine them around the z-axis. Further, the transport of the charged particles is limited only to the linear arrangement.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an improved charged particle convergence device for transporting charged particles in a long distance and providing free transport curve of the charged particles.

Briefly described, in accordance with the present invention, a charged particle convergence device is provided with a plurality of even-numbered substantially prolongated poles arranged along a central axis of a transport path of charged particles.

Each pair of the poles are arranged opposite to each other in a symmetrical manner with respect to the central axis of the transport path.
With keeping the similar relation, the plurality of even-numbered prolonged poles are set spiral around the central axis of the transport path.
The same-polarized electric or magnetic potential is applied to each pair of the opposite poles while the reverse-polarized electic or magnetic potential is applied to the adjacent pair of the poles.

According to the present invention, the plurality of poles are substantially prolongated and spiral around the central axis of the transport path of the charged particles. The plurality of poles are formed with a plurality of pairs, so that the two poles of each pair are opposed to each other with respect to the central axis of the transport path of the charged particles. With keeping this relation, the plurality of poles spirals along the prolongate side of the transport path. Differently-polarized electric or magnetic potentials are applied to the respective pairs of the opposite poles.

Therefore, in other words, the conventional quadrupole lens is set to spiral in the traveling direction of the charged particles according to the construction of the present invention. Therefore, in a plane crossing a point in the transport path of the charged particles, the charged particles receive electric or magnetic force of strong convergence in a direction connecting a pair of poles and of strong divergence in another direction connecting another pair of poles. Since the plurality of poles spiral in the transport direction, the above-described electric or magnetic force of strong convergence and of strong divergence is rotated in a plane traversing the transport path of the charged particles as the charged particles travel. In a certain distance from the point in the transport path of the charged particles, the directions of the strong convergence and the strong divergence are reversed.

As a result, all of the charged particles travel around the central axis of the transport path and cannot diverge from the space enclosed by the plurality of poles, so that all of the charged particle can travel in a long distance.

Even when the prolongated plurality of spiraling poles are twisted, the charged particles can travel along the twisted poles, so that the transport path of the charged particles can be made freely.

BRIEF DISCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein :

FIG. 1 is a perspective view of a charged particle convergence device according to a first preferred embodiment of the present invention :

FIG. 2 is a cross-sectional view of poles in the charged particle convergence device of FIG. 1, showing the electrical or magnetic potential applied to the poles ;

FIGs. 3A, 3B, 3C, and 3D show the orbits of the charged particles controlled by the charged particle convergence device in some cases ;

FIG. 4 A is a front view of another charged particle convergence device, viewed in the z-axis direction, according to a second preferred embodiment of the present invention ;

FIG. 4B is a side view of said another charged particle convergence device, viewed in the x-axis direction, according to the second preferred embodiment ;

FIG. 5 is a perspective view of a conventional charged particle convergence device ; and

FIG. 6 is a view for explanation of the operation of the conventional charged particle convergence device, showing the orbit of the beams.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the preferred embodiments, the present invention will be described with reference to the accompanying drawings. In FIG. 1, four prolongated rod-like poles 1, 2, 3 and 4 are provided for spiraling at a certain pitch around the central axis (the z-axis in this preferred embodiment) of a transport path of charged particles. At the x-y plane perpendicular to the z-axis, the rod-like poles 1 and 2 are symmetrically arranged around the z-axis while the rod-like poles 3 and 4 are also similarly set around the z-axis. The adjacent pairs of the poles 1 and 3 in one pair and the poles 2 and 4 in the other pair are arranged in the right angles in this preferred embodiment, but it is not necessary to arrange at the right angles.

The poles 1 through 4 are made of an electrically conductive material when they are made to produce an electrical field effect. They may be made of a magnetic material when they should produce a magnetic effect.

As shown in FIG. 2, the same polarized electric or magnetic potential is applied to the opposite poles while the reversely polarized eletric or magnetic potential is applied to the adjacent poles, so that a quadrupole lens is formed.

When the positive charged particles travel along the z-axis direction, the positive-negative (or N-S) arrangement of the poles 1 through 4 as shown in FIG. 2, causes a strong convergence force to the positive charged particles in the o-x direction and strong divergence force to the positive charged particles in the o-y direction. Since the poles 1 through 4 are prolongated and spiraled, the convergence force direction and the divergence force direction are varied as the charged particles travel in the z-axis direction. At a point of 1/8 pitch apart from the origin 0 shown in FIG. 2, the convergence force turns to the o-y direction and the divergence force turns to the o-x direction. Thus, the direction of the force rotates.

Here, the charged particles receive convergence force and divergence force, the directions of which are continiously changed, by the four poles 1 through 4. By controlling the electric or magnetic potential applied to the poles 1 through 4, the composed force in this system results in that all of the charged particles can travel in the z-axis with oscillating around the z-axis.

FIGs. 3A, 3B and 3C show the orbits of the charged particle. For the orbit of FIG. 3.A, an electric voltage of +10 kV is applied to the poles 1 and 2 and another electric voltage of -5 kV is applied to the poles 3 and 4 in a charged particle convergence device, into which the positive ions of 100 keV having the charge valence of 1 are injected. For the orbit of FIG. 3B, an electric voltage of +16 kV is applied to the poles 1 and 2 and another electric voltage of -8 kV is applied to the poles 3 and 4 in a charged particle convergence device, into which the positive ions of 1000 keV having the charge valence of 1 are injected. For the orbit of FIG. 3C, an electric field of +16 kV is applied to the poles 1 and 2 and another eletric field of -8 kV is applied to the poles 3 and 4 in a charged particle convergence device, into which the positive ions of 3000 keV having the charge valence of 1 are injected. Herein, the spiral pitch is set about 16 cm in the z-axis diretion. The graphs of FIGs. 3A through 3C show that the more the energy of the traveling charged particels is, the greater the oscillation cycle of the travelling charged particles becomes. Thus, although the charged particles oscillate, they can travel in the z-axis direction without escaping from the space enclosed by the poles 1 through 4. The system with the four rod-like poles 1 through 4 provides a prolongated system of transporting the charged particles.

FIG. 3D shows the orbit of the charged particles which are obliquely injected into the transport system composed by the rod-like poles 1 through 4. In this case, an electric voltage of +10 kV is applied to the poles 1 and 2 and another electric voltage of -5 kV is applied to the poles 3 and 4 to form the transport system, into which the positive ions of 100 keV having the charge valence of 1 are injected with the gradient $dx/dz = 0.05$. The graph of FIG. 3D indicates that, even though the charged particles are obliquely injected into the charged particle convergence device, the charged particles can travel along the z-axis without escaping from the space enclosed by the poles 1 through 4. This means that when the z-axis may have a curvature the charged particles can travel along the z-axis. Accordingly the transport path can be made a flexible curve, freely.

FIGs. 4A and 4B show another charged particle convergence device according to the second preferred embodiment of the present invention. In the second preferred embodiment, the rod-like poles 1 through 4 are short-cut in the z-axis, so that short pieces of rod-like poles 1a, 1b,......, 2a, 2b,......, 3a, 3b,......, and 4a, 4b,...... are linear and their positioning is slightly spiraled in the z-axis direction. An electric (or magnetic) potential is applied to 1a, 1b,..., another electric (or magnetic) potential is applied to 2a, 2b,..., a reverse electric (or magnetic) potential is applied to 3a, 3b,..., and yet another reverse electric (or magnetic) potential is applied to 4a, 4b,.... Thus, the substantially same constructure of the charged particle convergence device provided by the prolongated rod-like poles 1 through 4 of FIG. 1 can be composed. With the substantially same arangement as the structure of FIG. 1, the prolongated transport system for transporting the charged particles is provided by the structure of FIGs. 4A and 4B.

In the above preferred embodiments, the number of the poles is 4, but this should not be limited to 4. It may be possible that the number of the poles may be any multiple number, say, 8 or even more. The poles of each opposite pair should be positioned at a same distance from the central axis, but it is not necessary for all the poles to have same distance from the central axis. Further, the positive charged particles are referred to as in the above preferred embodiments, but is may be needless to say that the negative charged particles or electrons can be apllied to the present invention.

As described above, in accordance with the charged particle convergence device of the present invention, a transport system of the charged particles having a long transport path and a flexibly curved transport path is provided. More particularly, as shown in FIG. 6, the purpose of the conventional Q-lens is to gather, at a point B on the z-axis, the energy coherent charged particles. For this purpose, the following requirements are necessary.

A. The line of A point- the Q- lens axis- B point must be aligned on the same z-axis.

B. It is preferable that the distance between A and B points is about 5 to 10 times of the length of the Q-lens.

C. The charged particles having the different energy may be removed due to the mis-direction.

D. The incident angle from A point should be less than about 2°.

On the contrary, according to the spiral Q- lens of the present invention, the following features can be achieved.

E. The electrodes can be prolongated and be spiral approximately.

F. The charged particles with the large (small) energy run on the z-axis with oscillating on the z-axis at a large (small) pitch. Therefore, they cannot be removed due to the mis-direction.

G. Even if the incident angle of the charged particles may be large such as about 5°, they can run at the adjacent area of the z-axis. Therefore, if the central axis may be bent, the charged particles can run at the adjacent area of the z-axis.

These features are the same as in the case of optical fiber in which the light of different frequency or energy can be confined with the bent optical fiber and run.

Using the charged particle convergence device of the present invention, an ion injection machine or a high energy beam accelerator can be made compact and provided at a low cost.

While only certain embodiments of the present invention have been described, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope of the present invention as claimed.

Claims

1. A charged particle convergence device comprising :

   a plurality of even-numbered substantially prolongated poles (1, 2, 3, 4 ; 1a...1d, 2a..2d, 3a...3d, 4a...4d) arranged along a central axis (z) of a transport path of charged particles ;
   each pair of said poles being opposed to each other in a symmetrical manner with respect to said central axis of said transport path ;
   said plurality of even-numbered substantially prolongated poles spiraling around said central axis of said transport path ; and each pair of said opposing poles being applied to the same-polarized electric potential and the adjacent pair of said poles being applied to the reserved-polarized electric potential.

2. The charged particle convergence device as set forth in claim 1, wherein said transport path is linear.

3. The charged particle convergence device as set forth in claim 1, wherein said transport path is a curve.

4. The charged particle convergence device as set forth in claim 1, wherein said plurality of poles (1, 2, 3, 4) are prolongated rods.

5. The charged particle convergence device as set forth in claim 1, wherein said plurality of poles (1a..1d, 2a..2d, 3a...3d, 4a..4d) are short-cut and

said short pieces of the poles are arranged in a spiral.

FIG. 1

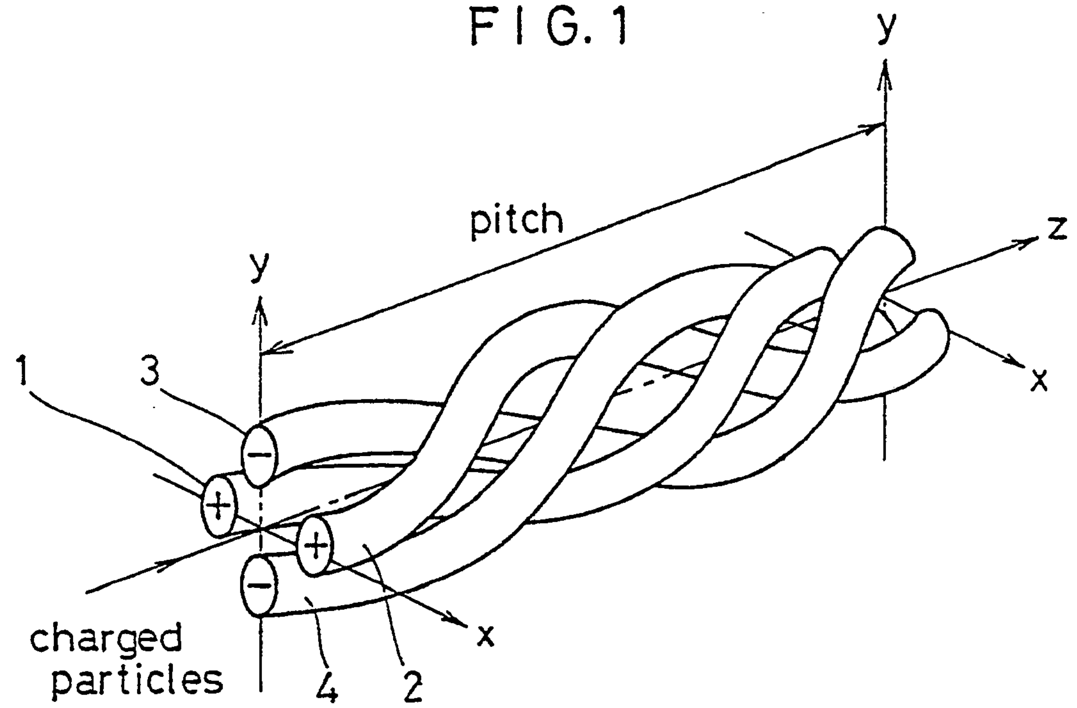


FIG. 2

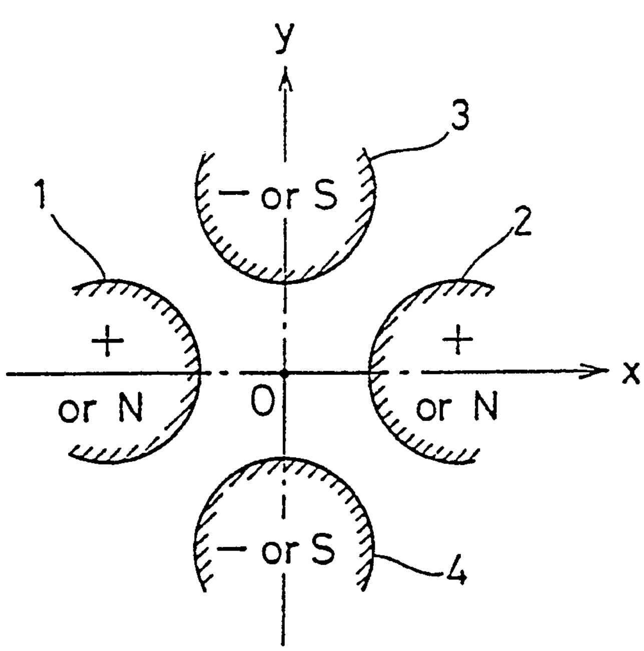


FIG. 3

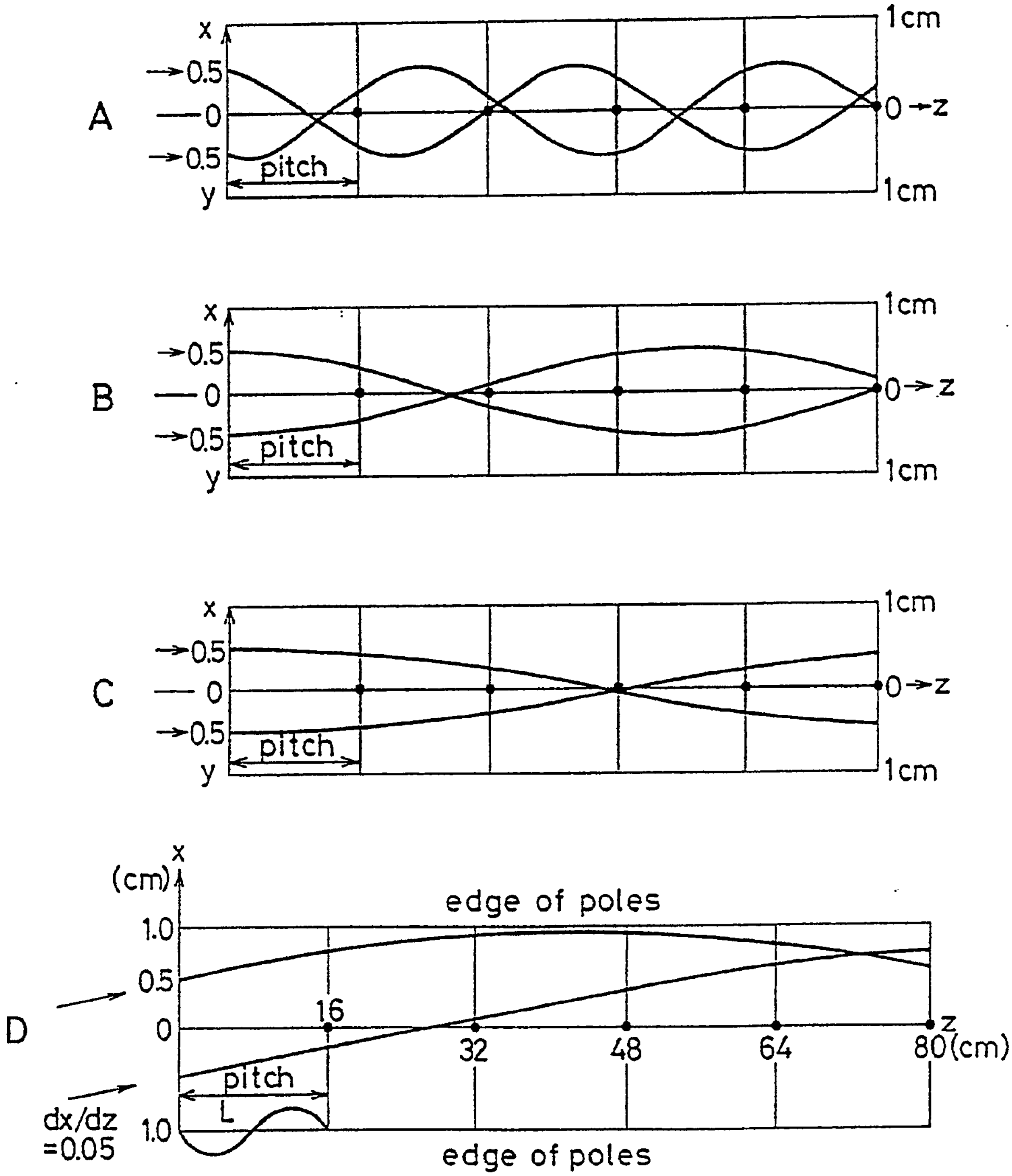
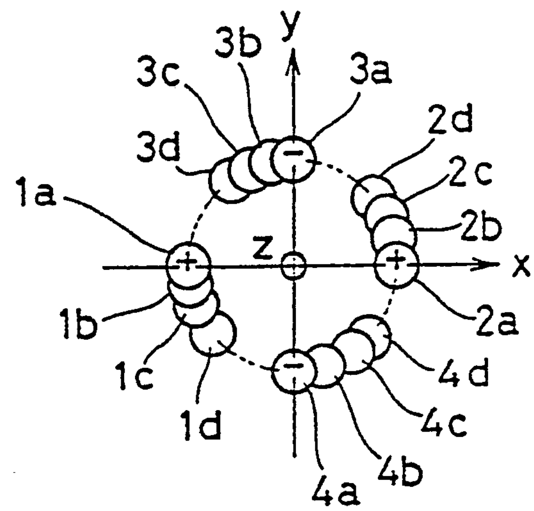

A
B
C
D
x
y
0.5
0
pitch
1cm
0 → z
(cm)
1.0
edge of poles
16
32
48
64
80 (cm)
L
dx/dz
=0.05

FIG. 4

A


y
3b
3c
3a
2d
3d
2c
1a
2b
z
x
2a
1b
4d
1c
4c
1d
4b
4a

B

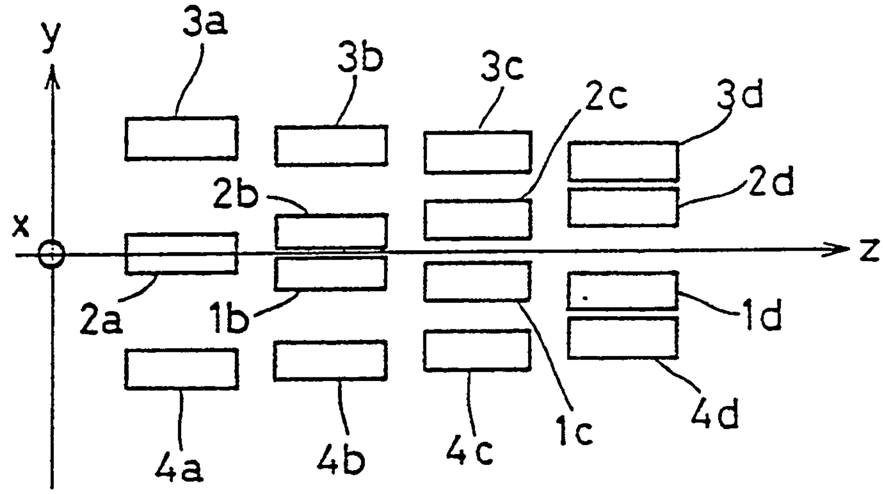

y
3a
3b
3c
2c
3d
2b
2d
x
z
2a
1b
1d
4a
4b
4c
1c
4d

FIG. 5

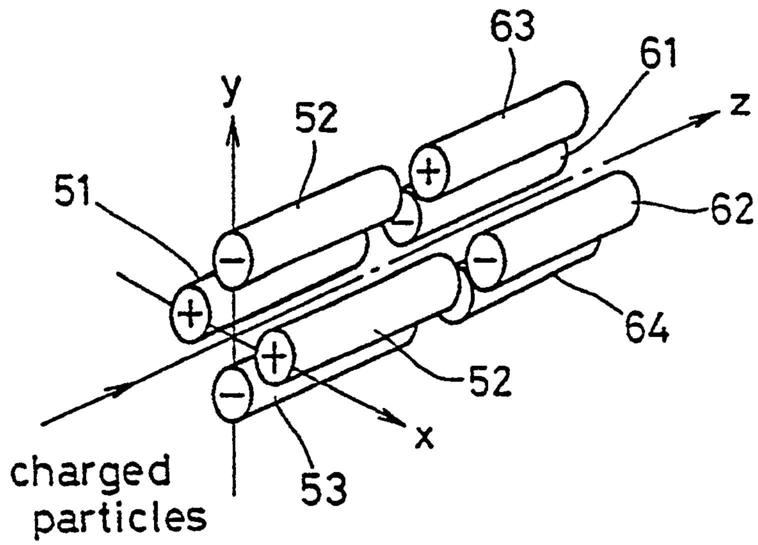


FIG. 6