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3,324,433

ELECTRON LENS SYSTEM EXCITED BY AT LEAST ONE PERMANENT MAGNET

Filed Dec. 28, 1964

2 Sheets-Sheet 1

FIG. 1

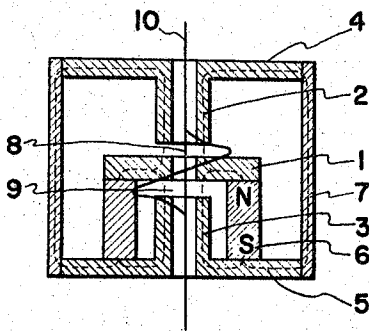


FIG. 2

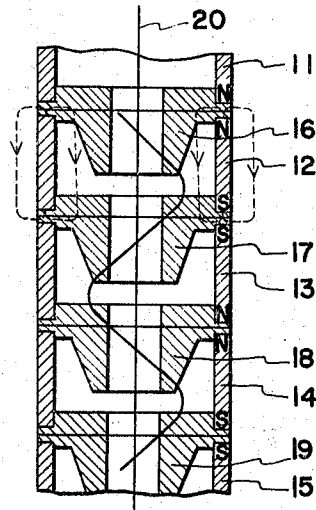


FIG. 3

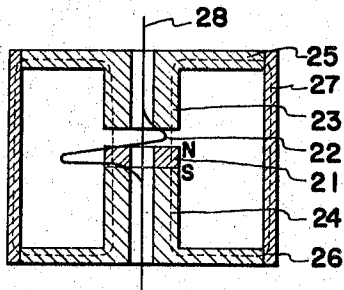


FIG. 4

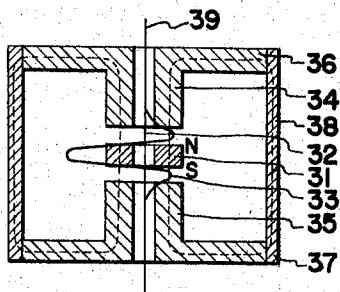
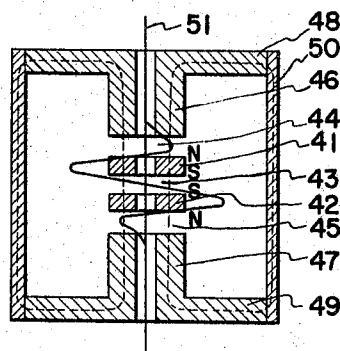


FIG. 5



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FIG. 6

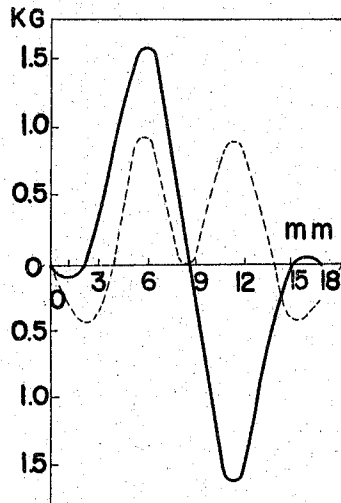


FIG. 7

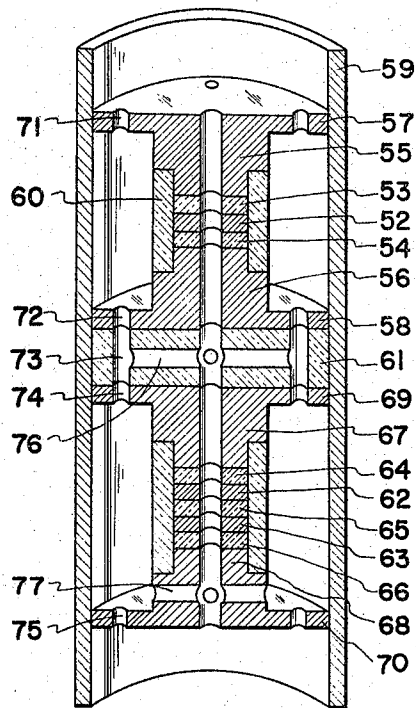


FIG. 8

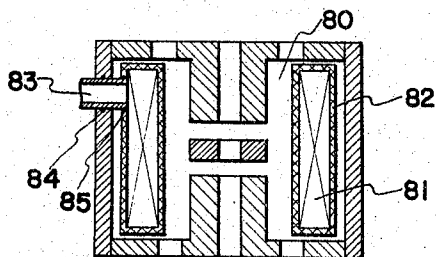
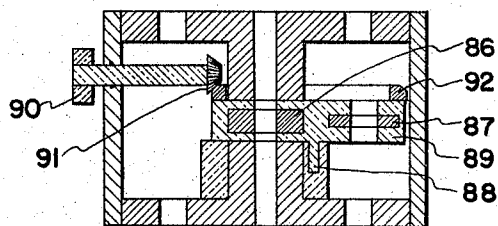


FIG. 9



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ELECTRON LENS SYSTEM EXCITED BY AT LEAST ONE PERMANENT MAGNET

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38/70,130

5 Claims. (Cl. 335—210)

This invention relates to a new electron lens system excited by at least one permanent magnet wherein, through a combination of the first magnet field produced in the through bore of at least one permanent magnet provided with the said bore in its center through which an electron beam can pass and the second magnetic fields produced between the magnet and both magnetic pole pieces disposed above and below the magnet, electron lens action is applied to said electron beam.

It is a general object of the present invention to provide an electron lens system of the above character which can be widely and generally used for devices such as electron microscopes, X-ray micro-analyzer, and traveling wave tubes.

It is well known that permanent magnets can be used for electron lens excitation in electron devices such as electron microscopes and for electron focusing in electron tubes such as traveling wave tubes. Permanent magnets have many advantages such as their obviating the necessity of exciting current sources when used in place of magnetic coils and their reliability owing to high stability.

On the other hand, however, permanent magnets have certain disadvantages such as deflection and distortion of electron beams caused by leakage fields. Particularly in the case of electron microscopes, it is necessary to arrange their magnetic circuits in a manner to reduce the effects of such disadvantages.

It is an object of the present invention to provide an electron lens system in which the above described difficulty accompanying the use of permanent magnets is eliminated.

Another object is to provide an electron lens system of simple construction, miniature size, low weight, and high performance.

Still another object is to provide an electron lens system in which the parts influencing the electron beam can be aligned in a simple manner.

A further object is to provide an electron lens system in which the focal length of the system can be readily varied over a wide range.

A still further object is to provide an electron lens system having a structure which can be utilized directly as a part of the evacuating pipe to establish a vacuum, whereby the necessity for separate piping is obviated.

Briefly stated, the present invention resides in an electron lens system excited by permanent magnet means consisting of one or more permanent magnets each having through its center a bore for passage of an electron beam, pole pieces of a magnetic material with high permeability disposed to confront the magnet means at positions upstream and downstream thereof with respect to the electron beam flow with gaps filled with either air or a non-magnetic substance provided between the pole pieces and the magnet means, the pole pieces being provided with respective center bores for electron beam passage aligned coaxially with the bore of the magnet means, and an outer magnetic structure magnetically connected to the pole pieces and, at the same time, surrounding the magnet means, thereby to form a magnetic circuit for the magnetic excitation and, at the same time, shielding with respect to leakage fields due to the magnet.

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The nature, principle, and details of the invention will be more clearly apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIGS. 1 and 2 are sectional views respectively showing examples of known electron lens systems excited by permanent magnets;

FIGS. 3, 4, and 5 are sectional views respectively showing the essential construction of preferred embodiments of the electron lens system according to the invention;

FIG. 6 is a graphical representation showing characteristic curves indicating distributions of axial magnetic field in the system shown in FIG. 5; and

FIGS. 7, 8 and 9 are sectional views respectively showing the essential construction of other embodiments of the invention.

Referring to FIG. 1, the electron lens of known construction of an electron microscope shown therein is provided with a center pole piece 1 and upper and lower pole pieces 2 and 3 corresponding to the center pole piece 1 and aligned coaxially therewith. The upper and lower pole pieces 2 and 3 are respectively connected to upper and lower flanges 4 and 5. All of these parts are made of magnetic material with high permeability. A permanent magnet 6 in the form of either a single hollow cylinder or a group of several bars is connected to the center pole piece 1 and to the upper flange 4 or to the lower flange 5. The upper and lower flanges 4 and 5 are connected respectively to the opposite ends of an outer hollow cylinder 7 made of a magnetic material and, together with this cylinder 7, surround the permanent magnet 6, being used for the purpose of a magnetic shield.

The magnetic flux due to the permanent magnet 6 passes through a magnetic circuit as indicated by dotted lines in FIG. 1 and produces parallel excitation in two pole gaps 8 and 9. Accordingly, the axial field distribution is as indicated by a full line, whereby an electron beam 10 passing through the center bores in the pole pieces is subjected to the lens action. For the permanent magnet 6 in this case, the ordinary practice is to use principally a cast magnet of the precipitation hardened type of a high energy product such as an Alnico or MKS magnet.

For example, in the case where an NKS magnet material of a coercive force of 650 oersted, magnetic induction of 11,300 gauss, and maximum energy product of 3.7×10^6 is used, and a cylindrical magnet 6 of 77 mm. outer diameter, 46 mm. inner diameter, and 15 mm. length is formed therefrom, a minimum focal length of approximately 15 mm. can be obtained with a center pole piece of 3 mm. thickness and 5 mm. bore diameter, upper and lower pole pieces of 5 mm. bore diameter, and upper and lower pole gaps of 3 mm., under the conditions of a maximum axial magnetic field of approximately 1,850 gauss and an accelerating voltage of 50 kv. In this case, the overall dimensions of this electron lens system are approximately 120 mm. outer diameter and 50 mm. height, and the weight is approximately 2.3 kg.

FIG. 2 shows one example of a known lens system heretofore used for focusing electron beams in traveling wave tubes and the like. The system shown comprises essentially a series of coaxially disposed permanent magnets 11, 12, 13, 14, and 15 and pole pieces 16, 17, 18, and 19 made of magnetic material of high permeability and disposed coaxially between the magnets to join poles thereof of the same polarity. The pole pieces 16, 17, 18, and 19 respectively have center bores, which are coaxially aligned, for passage of an electron beam 20. The axial

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magnetic distribution is as indicated by a full line in FIG. 2 and imparts a lens action on the electron beam 20.

When, in the arrangement and construction as shown in FIG. 2, the permanent magnets are made of Alnico V of 12.7 mm. length, and pole gaps each of 3.8 mm. and pole piece bore diameters each of 8.1 mm. are used, a maximum axial magnetic field of approximately 700 gauss can be obtained. Furthermore, with the use of "Ferroxdure" of 8.9 mm. length, a maximum magnetic field of approximately 1,000 gauss can be obtained. In the case of focusing magnetic fields of traveling wave tubes, in general, no special consideration is given to shielding for leakage fields as indicated by the dotted lines in the drawing.

The present invention contemplates the provision of a new electron lens system excited by at least one permanent magnet with magnet arrangements and magnetic path arrangements differing from those described above.

A specific object of the invention is to provide an electron lens system of simple arrangement and construction and remarkably miniature size, which, moreover, has amply high lens performance.

In one preferred embodiment of the invention as shown in FIG. 3, there is provided in the center of the system a permanent magnet 21 of disk shape having a central bore for passage of an electron beam and having a thickness in the axial direction which is less than the outer diameter. One of the poles of the magnet 21 confronts an upper pole piece 23 made of a magnetic material with high permeability with an air gap (or a non-magnetic gap) 22 interposed therebetween. The other pole of the magnet is magnetically connected to a lower pole piece 24. The upper and lower pole pieces 23 and 24, which respectively have center bores in coaxial alignment with the center bore of the magnet 21, are connected by upper and lower flanges 25 and 26, respectively, to an outer cylinder 27.

Thus, the flanges 25 and 26 and the cylinder 27 completely enclose the permanent magnet 21 and produce a magnetic shielding effect, at the same time forming a magnetic path as indicated by dotted line in FIG. 3. Then, the resulting axial magnetic distribution is as shown by a full line, and an electron beam 28 passing through the center bore is subjected to lens action.

It is a unique feature of the electron lens system of the invention that, since the outer surface, bore, and both end surfaces of the permanent magnet are precisely machined and finished, and lens action is imparted to an electron beam by the combination of a magnetic field produced in the center bore within the permanent magnet itself and the magnetic field produced in the gap between the magnet and the pole piece confronting the magnet, the magnetomotive force of the permanent magnet is not introduced to the pole pieces or passed through the pole pieces as in the prior practice. Accordingly it is possible to eliminate leakage permeance produced by such passing of the magnetomotive force through the pole pieces and to reduce the total permeance to a very small value. Therefore, the system is advantageous in that a permanent magnet of very small dimensions suffices. Furthermore, the permanent magnet is surrounded by a magnetic circuit which effects magnetic shielding.

In another preferred embodiment of the invention as shown in FIG. 4, there is provided in the center of the system a disk-shaped permanent magnet 31 which has an electron beam passage through its center and is precisely finished. This magnet 31 is magnetized in its axial direction and coaxially confronts pole pieces 34 and 35 made of a magnetic material with high permeability across upper and lower air gaps (or gaps filled with non-magnetic material) 32 and 33 interposed between the magnet and said pole pieces. The pole pieces 34 and 35 are connected through upper and lower flanges 36 and 37 made of magnetic material to an outer cylinder 38.

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Thus, the magnetic circuit consisting of parts 34-36-38-37-35 forms an exciting circuit as shown by dotted lines in FIG. 4 due to the permanent magnet 31, and the axial magnetic field distribution is as indicated by full lines. As a result, an electron beam 39 passing through the center of the system is subjected to lens action by a magnetic field produced in the center bore within the permanent magnet 31 itself and a magnetic field produced in the gaps 32 and 33 between the magnet 31 and the upper and lower pole pieces.

In this case also, the leakage permeance of the two magnet ends is very small in comparison with that in the conventional case where the magnetomotive force of a permanent magnet is led by way of pole pieces to an electron beam path to impart lens action. Accordingly, a permanent magnet of small dimensions suffices, and in contrast to a permeance coefficient of the order of 15 in the conventional case illustrated in FIG. 1, a permeance coefficient of the order of from 1 to 2 can be readily used in the case of the embodiment of the invention shown in FIG. 4.

In still another embodiment of the invention as shown in FIG. 5, there are provided two disk-shaped permanent magnets 41 and 42 which are precisely finished and have electron passages through their centers, and which are disposed centrally in the system with an air gap (or non-magnetic gap) 43 therebetween. The upper part of the magnet 41 and the lower part of the magnet 42 respectively confront pole pieces 46 and 47 across air gaps (or non-magnetic gaps) 44 and 45. The pole pieces 46 and 47 are connected respectively through upper and lower flanges 48 and 49 to an outer cylinder 50.

Thus, the magnetic circuit consisting of parts 46-48-50-49-47 forms an exciting circuit indicated by dotted lines in FIG. 5, whereby an axial magnetic field distribution as indicated by full lines is established, and at the same time a magnetic shielding effect is provided. As a result, an electron beam 51 passing through the center passage is subjected to lens action by the combination of the magnetic field produced in the center passages of the permanent magnets 41 and 42 themselves, the magnetic field produced in the gap 43 between the two magnets, and the magnetic fields produced in the gaps 44 and 45 between the upper and lower pole pieces and their confronting magnets.

In order to indicate more fully the details of the invention the example thereof shown in FIG. 5 will now be described with respect to specific values.

For the permanent magnets 41 and 42, two Pt-Co magnets (coercive force of 4,000 oersteds and magnetic induction of 6,300 gauss) each having a 5 mm. inner diameter, a 15 mm. outer diameter, and 3 mm. thickness are used. 3 mm. gaps are provided, and the upper and lower pole pieces are provided with through bores of 5 mm. diameter. In this case, the axial field distribution is as indicated by full line in FIG. 6, whereby it is possible to impart a maximum of 1,600 gauss.

In an actual instance of the above described parts and, furthermore, with a magnetic circuit of a construction as shown in FIG. 5 with a 60 mm. outer diameter, a 45 mm. height, and 650 grams weight, a focal length of approximately 15 mm. was obtained at an electron accelerating voltage of 50 kv.

In comparison with an example of a conventional lens system excited by a permanent magnet as shown in FIG. 1 having the same performance, the above described system according to the present invention has an exterior volume of approximately 1/4.5 and a weight of approximately 1/2.5. Therefore, in comparison with a magnetic coil system used generally, the system of the invention is of remarkably miniature size (for example, approximately 1/7.5 in terms of weight ratio, and 1/7 in terms of exterior volume).

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In the above described example, the two permanent magnets are disposed with their poles of the same polarity facing each other. In an actual instance where the two magnets were disposed with their poles of different polarity facing each other, the resulting field distribution was as indicated by the dotted line in FIG. 6, and a focal length of approximately 80 mm. was obtained at an electron accelerating voltage of 50 kv.

While the above description relates to embodiments of the invention wherein one or two permanent magnets are used, it is possible also to use three or more magnets as necessary to produce lens action by imparting an alternating magnetic field or a uniform magnetic field. Furthermore, it is not necessary in all cases to provide gaps especially between two or more than two permanent magnets, which may be disposed in contacting arrangement.

While by the practice of this invention the above described construction of the lens system is simple, and the outer cylinder forms one part of the magnetic circuit and, at the same time, functions as a magnetic shield with respect to the leakage field due to the permanent magnets, this outer cylinder can be utilized further as a pipe of an evacuating system.

In general, in the evacuating system of apparatuses such as electron microscopes, an evacuating pipe is provided separately from the principal structure of the apparatus. For example, evacuation is ordinarily carried out before and after the electron lens systems such as those of the electron gun, the specimen chamber, and the observation chamber. The reason for this arrangement is that since numerous small apertures are provided in the electron beam path of such lens systems in order to suppress scattered electrons, and, moreover, diameters of electron lens holes of the order of from 1 to 10 mm. are mostly used for considerations such as those of various aberrations and of total magnification, the mechanical resistance of the electron beam path against evacuation is substantially high. Furthermore, exciting coils or magnets are disposed about the outer periphery of the electron beam path of an electron lens system, and it has been difficult to use this part for evacuation.

In the electron lens system according to the invention, the permanent magnet itself imparts lens action by the magnetic field produced in its center bore and the magnetic fields produced between the magnet and its confronting pole pieces. Accordingly, since ample space is afforded between the outer cylinder and the internal electron lens as in the examples shown in FIGS. 3, 4 and 5, it is apparent that the outer cylinder can be used as an evacuating pipe.

In one preferred embodiment of the invention as shown in FIG. 7, the above described feature is utilized. In this system, there is provided a permanent magnet 52 which, being disposed to confront upper and lower pole pieces 55 and 56 across non-magnetic gaps 53 and 54, causes lens action to be imparted to an electron beam passing through its center bore by means of the magnetic fields produced in the gaps and in the center bore of the magnet itself, as in the aforescribed examples.

The upper and lower pole pieces 55 and 56 are respectively provided with upper and lower flanges 57 and 58, which are connected to an outer cylinder 59 to form a magnetic circuit. The internal electron lens parts 52-53-54-55-56 are mechanically assembled by a support member 60 made of a non-magnetic material. This lens system is connected coaxially to a succeeding stage lens system with a spacer 61 of a magnetic material or non-magnetic material interposed therebetween.

The succeeding stage lens system has two permanent magnets 62 and 63 disposed coaxially and provided with gaps 64, 65, and 66 consisting of non-magnetic material, gap 65 being interposed between the magnets. The magnets 62 and 63 respectively confront pole pieces 67 and

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68 to effect lens action. In this case, upper and lower flanges 69 and 70 provided on the pole pieces 67 and 68 are connected to the same outer cylinder 59 as mentioned above or to a cylinder constituting an integral part of the vacuum system of the cylinder 59, thereby forming a magnetic circuit.

The flanges 57 and 58, spacer 61, and flanges 69 and 70 are respectively provided with several groups of through holes 71, 72, 73, 74, and 75, etc., for evacuation, each group of said holes being substantially aligned in parallel to the axis of the center bore. Particularly in the spacer 61, there are provided several evacuation holes 76 disposed perpendicularly to the electron beam axis and connecting different evacuation holes 73. In accordance with necessity, the pole pieces also may be provided with similar transverse evacuation holes such as hole 77 shown in the pole piece 68. The outer cylinder 59 of magnetic material constituting a part of a magnetic circuit is not necessarily a structure common to the two adjacent electron lens systems.

Thus, by enclosing individual electron lens systems, spacers, etc., within a single magnetic material cylinder and providing evacuation holes in the flanges of the electron lens systems, spacers, etc., as described above, evacuation can be accomplished. As described above, in the electron lens system according to the present invention, there is no necessity of providing a separate evacuating pipe.

In each of the electron lens systems illustrated in FIGS. 3, 4, and 5, the focal length is constant for constant accelerating voltage. Therefore, in the case where the focal length of a lens such as an objective lens is to be varied slightly, an electromagnetic coil can be used jointly with the system.

In one example of such use of a magnetic coil as shown in FIG. 8, the space 80 between the centrally disposed electron lens system and the outer cylinder is utilized for the installation of an electromagnetic coil 81 disposed concentrically relative to the central electron beam axis. In the case where this space 80 is used for evacuation to establish a vacuum, it is necessary to vacuum seal the coil 81 within a container 82. Furthermore, in accordance with necessity, the coil 81 can be communicated with the outside by means such as a connecting pipe 83 provided with vacuum gaskets 84 and 85.

The focal length can be varied also by adjustably varying the relative positions of the parts of the lens system. For example, in the system shown in FIG. 4, the focal length can be varied over a relatively wide range of adjustment by fixing the positions of the upper and lower pole pieces 34 and 35 and vertically (axially) moving the permanent magnet 31, or by fixing the positions of the permanent magnet 31 and the upper pole piece 34 and vertically (axially) moving the position of the lower pole piece 35.

When it is necessary to vary the focal length over a wider range, as in the case of a projection lens, a magnet interchanging device as shown in FIG. 9 can be used. This device comprises essentially a turntable 89 of disk shape which is made of a non-magnetic material and rotates around a vertical shaft 88, a plurality of permanent magnets 86, 87, etc., disposed in the turntable 89 and differing in dimensions such as outer diameter, inner diameter, and thickness but all having center axes lying on a circle whose center coincides with the axis of shaft 88, and an actuating mechanism consisting of a driven gear 92 fixed to the turntable 89, a driving gear 91, and a knob 90 for turning the gear 92 through a shaft. It will be apparent that, by manipulating the knob 90, the magnets 86, 87, etc., can be selectively changed.

In the case where several permanent magnets are used as illustrated in FIG. 5, the focal length can be varied widely by taking one or more of the permanent magnets out of the electron beam path.

Alignment of the lens axis can be accomplished in a simple manner by fixing the upper and lower opposed pole pieces and moving in two dimensions in a horizontal plane, relative to the electron beam axis, one or more than one magnet from among one or several permanent magnets provided in the center, or, by tilting one or more magnets by an angle of the order of from 10^{-2} to 10^{-4} radians as necessary.

As described above in detail, the electron lens system according to the present invention imparts, on an electron beam passing therethrough, lens action due to a magnetic field produced in the center bore or bores of one or several disk-shaped permanent magnets each having a center bore therein for passage of the electron beam by the one magnet itself or by the several magnets themselves and due to magnetic fields produced in gaps between the magnet or magnets and confronting pole pieces. By this arrangement, accordingly, the pole pieces confronting the magnet or magnets, together with an outer cylinder surrounding the magnet or magnets, form a magnetic circuit. This outer cylinder further functions as a magnetic shield. Therefore, the electron lens system of the invention has the advantage of miniature size and weight in comparison with known electron lens systems of equivalent performance.

Furthermore, the interior space of this outer cylinder can be utilized as a pipe of the evacuating system, whereby separate piping for evacuation, as in known systems, are unnecessary.

Another advantage of the electron lens system of this invention is that changes of focal length and alignment of the axis of the electron lens system can be carried out in a relatively simple manner by adjustably moving only the permanent magnets. A further advantage is that the entire construction is extremely small and conducive to miniaturization.

It should be understood, of course, that the foregoing disclosure relates to only preferred embodiments of the invention and that it is intended to cover all changes and modifications of the examples of the invention herein chosen for the purposes of the disclosure, which do not constitute departures from the spirit and scope of the invention as set forth in the appended claims.

What I claim is:

1. An electron lens system excited by permanent magnet means

comprising at least one permanent magnet having a bore through its center for passage of an electron beam and being axially magnetized; an upper and a lower pole piece above and below said magnet, respectively, of magnetic material with high permeability, both aligned coaxially and radially with said magnet, provided with flanges and having a center bore continuing the bore of said magnet; at least one air space between said magnet and said pole pieces, whereby active magnetic fields are produced substantially in the area of said bores, said space and said pole pieces; and an outer cylinder magnetically connected to said flanges, completely enclosing said magnet and disposed symmetrically with respect to said passage of the electron beam, producing a shielding effect while simultaneously forming a closed magnetic path.

2. The electron lens system according to claim 1, further provided with evacuation holes formed at said flanges which follow the space in said cylinder, whereby said holes and the space are utilized as an evacuating path for establishing a vacuum within said system and other systems related thereto.

3. The electron lens system according to claim 1, further comprising means to vary the focal length of a magnetic lens formed by said magnet and pole pieces.

4. The electron lens system according to claim 1, further comprising means to move adjustably said magnet two-dimensionally in a plane perpendicular to said passage of the electron beam and to vary adjustably the angular orientation of said magnet relative to said passage.

5. The electron lens system according to claim 1, wherein said space provided between said magnet and pole pieces are filled with a non-magnetic material.

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