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LePoole

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[54] **PERMANENT MAGNET LENS SYSTEM**

[76] Inventor: **Jan Bart LePoole,** 5, Nassaulaan, Deleft, Netherlands

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[21] Appl. No.: **339,881**

[30] **Foreign Application Priority Data**

Mar. 10, 1972 Netherlands 7203264

[52] **U.S. Cl.** **250/396,** 313/84

[51] **Int. Cl.** **H01j 37/00**

[58] **Field of Search** 250/396; 313/84

[56] **References Cited**

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Primary Examiner—Archie R. Borchelt
Assistant Examiner—B. C. Anderson
Attorney, Agent, or Firm—Watson, Cole, Grindle & Watson

[57] **ABSTRACT**

A magnetic lens system, in particular for an electron microscope, comprising two thin small disc magnets, provided with small openings and magnetized axially in opposite directions, which are united straight into an electron-optic achromatic as well as rotation-free and distortionfree system that forms lens fields, at a distance that is practically equal to the diameter of the small openings.

5 Claims, 7 Drawing Figures

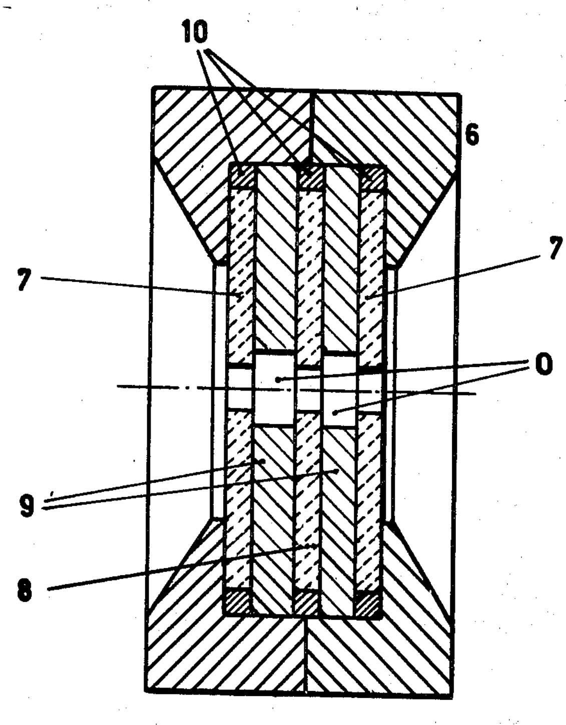


FIG. 1

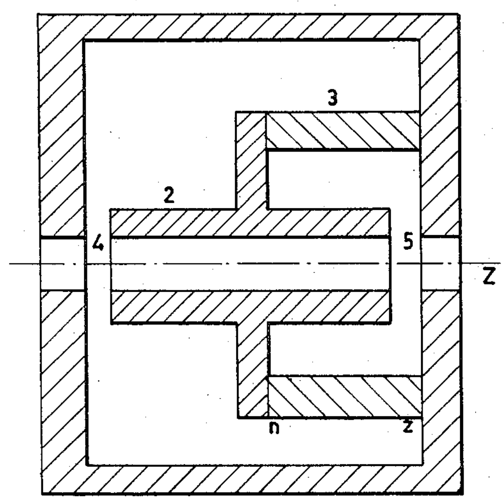


FIG. 4

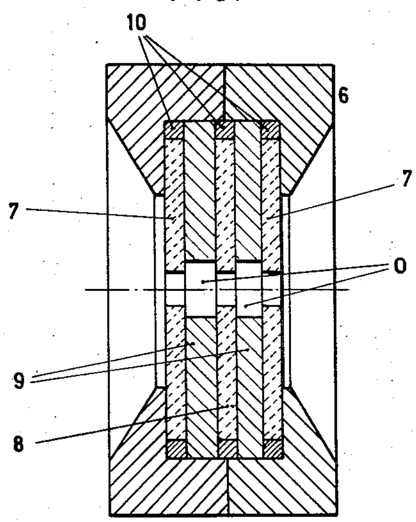


FIG. 2

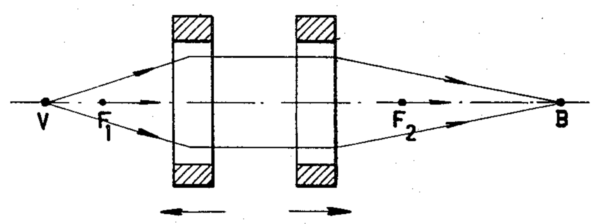


FIG. 3

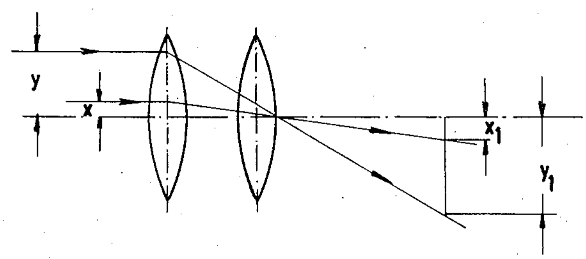


FIG. 5

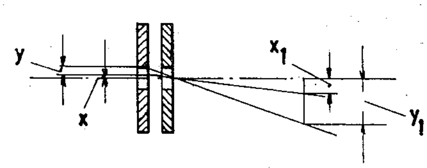


FIG. 6

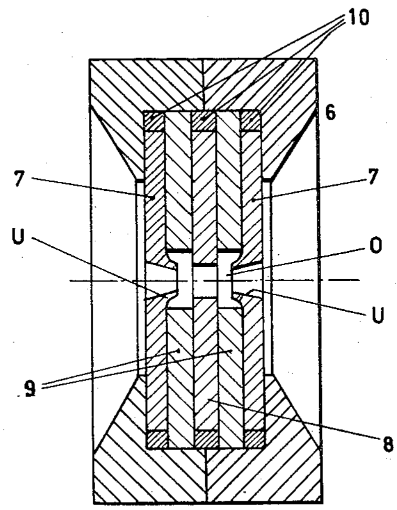
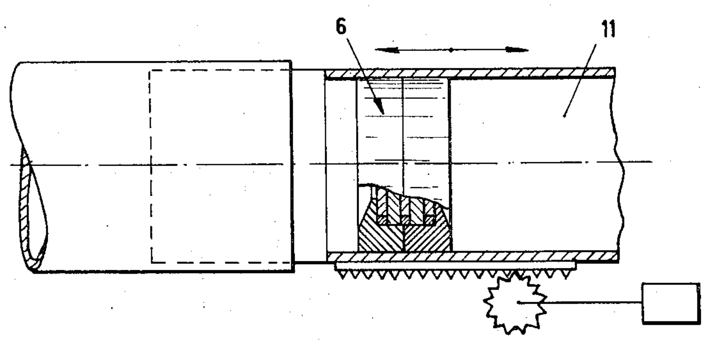


FIG. 7



PERMANENT MAGNET LENS SYSTEM

The invention relates to a magnetic lens system for a flow of charged particles, in particular for an electron beam in an electron microscope, the magnetic field of the lens system having been excited by permanent magnets.

In the technique of electron-optical imaging devices, for the evaluation of the properties of the lens systems applied in them, for instance in an electron microscope, it is usual, analogous to light-optical imaging devices, to distinguish a number of specific lens errors that affect the resolving power of the lens systems or lenses considered. Among these lens errors may be counted i.a. the lens errors indicated by chromatic magnification aberration and image distortion.

For some decades in the development of electron-microscopes a continual strive has been observable aimed at the combatment of above-mentioned lens errors with magnetic lens systems and lenses. In so doing the starting-point was that the chromatic magnification aberration attending the usual rotationally-symmetric lens fields can be combated by reducing the focus of a magnetic lens. As the focus of such a lens in the first instance is in inverse ratio to the integral $\int B^2\,dz$, in which B is the magnetic induction on the axis of the lens field, alongside which z has been chosen as independent variable, it will be clear that so far in many ways it has been tried to affect this magnetic induction and to render a value as great as possible to it.

The above-mentioned starting point of increasing the value of magnetic induction B, in the past has led to innumerable constructions of permanent magnet lens systems, which are characterized by the application of permanent magnets in co-operation with magnetic flux conductivity circuits, in which at the location of suitably formed "air gaps" magnetic lens fields with a relatively great induction value were localized.

On the one hand for this purpose use could be made advantageously of permanent magnetisable materials with a high energy product for the magnets, but on the other hand it was found that there was a limit to the increase of magnetic induction B for a certain desired configuration and for rendering the correct dimensions to the permanent magnet lens system, the permanent magnet lens, respectively, set by the occurrence of a magnetic saturation in the flux conductivity circuits.

A consideration of such a magnetic lens system provided with one or a number of permanent magnets and a flux conductivity circuit teaches that for a certain desirable configuration of this lens system and desirable values of magnetic induction B in the lens fields concerned, a number of ampere windings equivalent to this lens system can be calculated. This number of ampere windings again is determining for the dimensions and, in so far there is freedom as to that, the choice of material for the permanent magnet. By way of example it may serve that magnetic lenses of the type elucidated above have been realized, whose number of ampere windings amounts to 1,000 to 3,000 and for which permanent magnets, manufactured under the name of "Ticonal," "Alnico" and such well-known materials, with a length of 5 to 10 cm, are required.

These prior art magnetic lens systems, lenses, respectively are voluminous and have a great weight as a result of the relatively big permanent magnets required for them and the appurtenant magnetic flux conductivity circuits, to which rendering of correct dimensions a certain minimum limit is set so as to prevent an undesirable magnetic saturation. In this connection it may be observed that weights of some kilograms per lens are by no means unusual.

A more general survey of the prior art magnetic lens systems, lenses, respectively, that have been described so far can be found in "Focussing of charged particles," C.Fert and P.Durandeau, Part I, 1967, Publishers A.-Septier, Academic Press, New York, London.

An other way of approach with respect to combating the chromatic magnification aberration in magnetic lens systems and to increase magnetic induction, B, as a rule in co-operation with the measures mentioned above, is, analogous to the achromatic lens systems applied in light-optical imaging devices, the assembly of an electron-optical equivalent achromatic, magnetic lens system, e.g., an electron-optic equivalent of the Ramsden ocular well-known among those skilled in the art, the focus of the one lens lying in the centre of the other lens.

A magnetic lens system of this type is known from "Proceedings of the fourth international conference on electronmicroscopy", Berlin 1958, pp. 53 to 57 and including, H.Kimura and Y.Kikuchi "Permanent magnet lens systems and their characteristics." In this lens system the magnetic induction values in the lens fields are raised to a high extent by means of permanent magnets magnetized in axial direction with respect to the electron beam, via flux conductivity circuits, provided with a central pole part and two air gaps, formed with the aid of pole shoes, and in the environment of which the lens fields are localized.

In this publication the possiblity of reducing the focus of this so-called double slit lens by diminishing the diameter, the length and the thickness of the central pole part, is referred to, but in it is also emphasized the risk of magnetic saturation of this pole section when its thickness is reduced.

All the above mentioned magnetic lens systems, lenses respectively, are characterized by relatively complicated flux conductivity circuits provided with permanent magnets, the measures for combating or neutralizing the chromatic magnification aberration are chiefly of the same nature.

Again and again the starting point was: effecting a magnetic induction as great as possible in the lens field localized in the environment of "air gaps" of the flux conductivity circuits, for which purpose with these lens systems known in the art a great volume ought to be magnetized, which, as will be known to those skilled in the art, will result in a situation in which practically all magnetic energy lands into the stray field and as a result necessitates again to choosing permanent magnetic materials of which the product of magnetic induction B and magnetic field strength H for the pertinent lens system has a maximum value, in order to take as much advantage of it as possible.

Besides the drawbacks related to the lens system known in the art with respect to volume and weight there is furthermore the drawback that upon assembling them always measures are involved in order to restrict the magnetic stray fluxes attending these systems and in order to make that in the entire magnet volume a uniform induction prevails.

It may be taken for granted that a magentic lens renders a rotation to a picture of an object represented by the electron beam. When for electrons of this beam, which enter the lens at different angles of incidence, a non-isotropic rotation takes place, then a phenomenon occurs indicated by anisotropic image distortion or S distortion, which is reckoned among the previously stated lens errors.

Measures known in the art for combating this image rotation concern the assembly of systems of lenses, of which each lens is of the type already described before and which each time bring about a rotation in the opposite direction. It will be obvious that without adopting new courses, such systems likewise result in constructions that are voluminous and have great weights.

The invention is based on the insight that the ways that so far have been followed for combating or neutralizing the lens errors stated in magnetic lens systems and lenses always have resulted in taking far-reaching measures for improvement of consisting lens systems and lenses, which essentially are of one and the same intention, and that an entire new way results into an exceptionally simple and compact lens system, in which the lens errors stated are simultaneously neutralized.

According to the invention a magnetic lens system of the type stated in the preamble is provided, because two thin small disc magnets, provided with small openings and magnetized axially in opposite directions, are united straight into an electron-optic achromatic as well as rotationfree and distortionfree system that forms lens fields, at a distance that is practically equal to the diameter of the small openings.

Thus the invention provides a surprisingly small and light permanent magnetic lens system without lens errors for an electron microscope that has only some cubic centimeters volume and some grams of weight.

In this connection it is observed that the application of rings permanently magnetized axially in opposite directions in order to affect an electron beam in so-called travelling-wave tubes or transit-time tubes is known in the art, but this application takes place with a quite a different object, viz. keeping parallel of the electron flow in such a tube. Moreover, the application, usual for this purpose, of a series of these rings alongside the tube actually is a solution acceptable only to a certain extent — the somewhat worse electron-optical properties being taken into the bargain — and of the essential problem of the composition of a homogeneous magnetic field, which actually is desirable for these tubes. It will be clear that the series of rings applied in this case misses the aforesaid electron-optical lens action.

In an embodiment according to the invention the disc magnets, the diameter of which amounts to, for instance, approximately 20 mm are united in a very compact way by inserting an iron platelet, while furthermore two iron platelets, that each each time are mounted on the sides of the disc magnets that are turned from the platelets make the system complete, that than can be fixed in a holder or socket.

Thus the distance between the magnets required with a view to the desirable lens action is fixed, while the platelets mentioned, at the same time may neutralize in a favourable way possible magnetic irregularities.

The small disc magnets advantageously each possesses an opening the diameter of which is smaller than the fourth part of the outer diameter, the smallest outer-dimension of the small magnet disc.

Furthermore, this diameter of the opening can be maximally equal or practically equal to the thickness of the small disc magnet.

The small openings in the small disc magnets of the lens system according to the invention see to it that the field in these small disc magnets becomes practically equal to the coercive force and to a far lesser extent is determined by the energy product.

Advantageously the small disc magnets can be made of a material with a high coercive power, for instance of compounds or of alloys of cobalt with rare earths or platinum. Furthermore, this coercive power advantageously can be greater than 1,400 Oersteds.

As follows from the above the lens system according to the invention has a fixed focus. Consequently, for a control of the magnification it is absolutely necessary that this system is mounted in an electron microscope movably in axial direction.

Though the power of the magnetic lens system thus is determined by the construction, the total magnification can be made continuously variable by displacing one or a number of these systems in axial direction. For this purpose the lens system according to the invention is very suitable by its very simplicity and slight size.

A further advantage of the invention is that it provides lens systems that can easily be interchanged.

The invention will be elucidated hereinafter with reference to the drawings added. In it are:

FIG. 1 a cross-section of a magnetic lens system provided with a permanent magnet and assembled according to a technique known in the art,

FIG. 2 a lens system known in the art with two disc magents that for the adjustment of the focus are movable with respect to each other and have been provided with large openings,

FIG. 3 The path of rays in an light-optical lens system of the Ramsden type, ratio x/y being practically equal to x_1/y_1,

FIG. 4 a cross-section of an embodiment of the lens system according to the invention, for the sake of clarity both the proportions and the dimensions not being drawn to scale,

FIG. 5 beams in the lens system according to the invention, ratio x/y, exactly as in the system of the Ramsden type, being practically equal to x_1/y_1,

FIG. 6 a further embodiment of the lens system according to the invention, provided with platelets with flanges, and

FIG. 7 a picture of a lens system according to the invention and displaceable in axial direction in a guiding member.

In FIG. 1 a magnetic lens system is pictured, which is assembled according to the technique known in the art, a magnetic flux conductivity circuit formed out of parts 1 and 2 guiding the field originating from permanent magnet 3 to air gaps 4 and 5. In the environment of these air gaps 4 and 5 the lens fields are situated that focus an electron beam entering alongside axis z. The system pictured in FIG. 1 represents only in principle the construction of one of the innumerable permanent magnet lenses known in the art, which in reality have a far more complicated construction. This does not only concern the magnetic flux conductivity circuits but the location and the shape of the permanent magnets as well, with a view to the curbing of magnetic stray fields. In this connection reference is made to what has already been observed before with respect to these stray fields.

In FIG. 4 the lens system according to the invention, held in a holder or socket **6**, is pictured. This system contains two axially in opposite directions magnetized, thin small disc magnets **9**, provided with small openings O. Between these small disc magnets **9** a small spacer **8** has been inserted, for instance, of iron, which also is provided with a fitting opening for the electron beam and determines the distance between the small disc magnets that is required for a desirable lens action. Two further iron platelets **7** provided with fitting openings and which each each time are provided on to the sides of small disc magnets **9** that are turned from small spacers **8** complete the system, which is fixed in holder **6**.

It has been found that the as yet relatively slight stray of this system can be reduced still further, by choosing the outer diameters of iron platelets **7** and **8** somewhat smaller than the outer diameter of small disc magnets **9**. Thus in a certain configuration a lens system consisting of the same small disc magnets became suitable for a 20 percent higher voltage which means a 10 percent higher value for magnetic field strength H in the magnet material.

In order to fix the system into holder **6** in this case three centering rings **10** have been provided.

It may be observed that for the sake of clarity FIG. **2** has not been drawn to scale and the diameter of small openings O has been shown relatively too great.

In the way as described lens systems have been realized, of which openings O are smaller than the fourth part of the outer diameter or smallest outer dimension of the pertinent small disc magnets and maximally equal to or practically equal to their thickness. These systems proportionally have a slight stray.

When use is made of magnetic materials with no extremely high coercive powers, advantageously end platelets **7** can be provided with flanges U, as FIG. **6** shows. In special cases this also holds good for centre platelet **8**.

In FIG. **7** the lens system according to the invention is shown axially displaceable in a guiding member **11**, as the drawn arrows make clear. This guiding member **11** in turn is provided within the space to be evacuated of an electron microscope.

Furthermore, for the first time it has become possible to assemble a Ramsdon-type lens system of such small dimensions as is indicated by the invention. Moreover, now in an advantageous way new avenues are opened up for the assembly of, for instance, groups of lens systems housed in a revolver head as well as so-called "zoom lenses," which are known in light-optical systems.

I claim:

1. A magnetic lens system for a flow of charged particles, in particular for an electron beam in an electron microscope, comprising a pair of permanent disc magnets each having a central opening therein of a size substantially less than the size of said magnets, said magnets producing a magnetic field for the lens system and each being magnetized axially in opposite directions, said magnets being coaxially aligned and separated by means of a spacer having a thickness substantially equal to the size of each said opening, an iron plate with a central opening coaxial with said magnet opening being in surface contact with the outer surface of each said magnet, and a holder provided within which said magnets, spacer and plates are fixedly mounted, whereby the lens system compensates for any electronoptic, achromatic and the like distortions as well as being rotation-free and distortion-free.

2. The magnetic lens system according to claim **1** wherein said magnets and their opening are respectively circular, the diameter of said magnet openings being less than one-fourth the outer diameter of said magnets.

3. The magnetic lens system according to claim **1** wherein said magnets are of a material having a high coercive power selected from the group consisting of cobalt alloys and cobalt compounds together with materials selected from the group consisting of rare earth metals and platinum.

4. The magnetic lens system according to claim **3** wherein said coercive power is greater than 1,400 Oersteds.

5. The magnetic lens system according to claim **1** wherein said holder is coaxially disposed within a guide member movable in an axial direction.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,812,365 Dated May 21, 1974

Inventor(s) Jan Bart Le Poole

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the drawings, FIGURES 2, 3 and 5, should appear as shown on the attached sheets.

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FIG.2

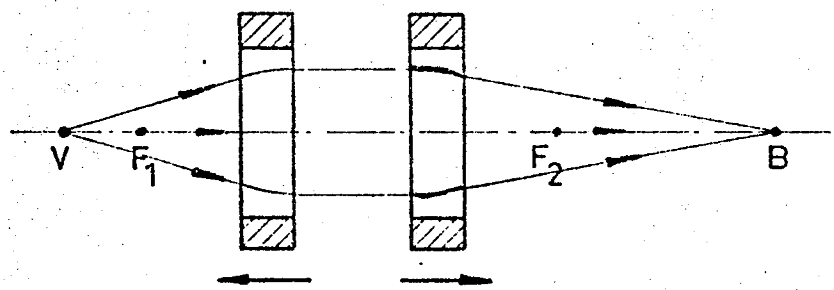


FIG. 3

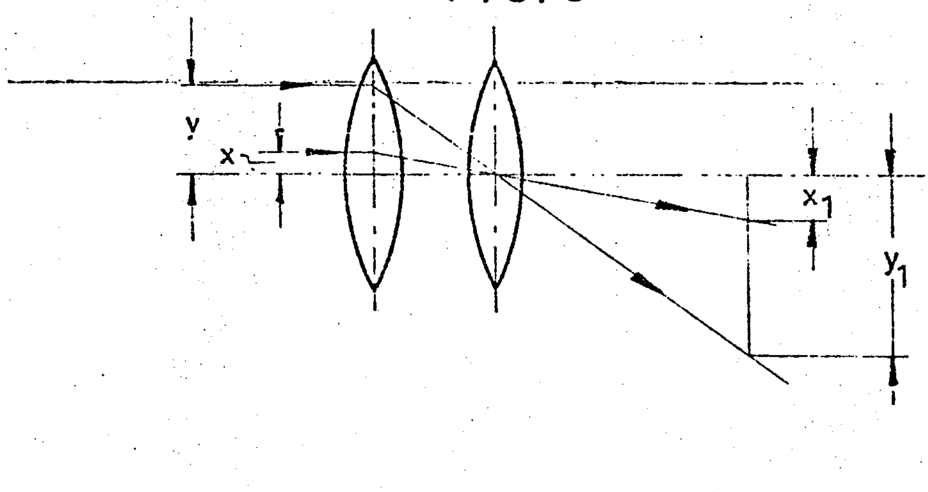


FIG. 5