United States Patent [19]

Katagiri et al.

[11] **3,736,423**

[45] **May 29, 1973**

[54] **ELECTRON LENS OF MAGNETIC FIELD TYPE FOR AN ELECTRON MICROSCOPE AND THE LIKE**

[75] Inventors: **Shinjiro Katagiri; Syozo Kasai,** both of Hachioji, Japan

[73] Assignee: **Hitachi, Ltd.,** Tokyo, Japan

[22] Filed: **May 12, 1971**

[21] Appl. No.: **142,606**

[30] **Foreign Application Priority Data**

May 13, 1970 Japan 45/40630

[52] **U.S. Cl.** ..... **250/49.5 D**

[51] **Int. Cl.** **H01j 37/10**

[58] **Field of Search** ..... 250/49.5 D

[56] **References Cited**

UNITED STATES PATENTS

3,150,258 9/1964 Welska ..... 250/49.5 D

3,046,397 7/1962 Delong ..... 250/49.5 D

Primary Examiner—James W. Lawrence
Assistant Examiner—C. E. Church
Attorney—Craig, Antonelli and Hill

[57] **ABSTRACT**

An electron lens of the magnetic field type, wherein a plurality of compensating coils are installed in a magnetic cover for a lens coil and wherein compensating currents are supplied to said compensating coils, whereby astigmatism appearing in the lens and undesired deflection of an electron beam passing through the lens are compensated by adjusting said currents.

12 Claims, 13 Drawing Figures

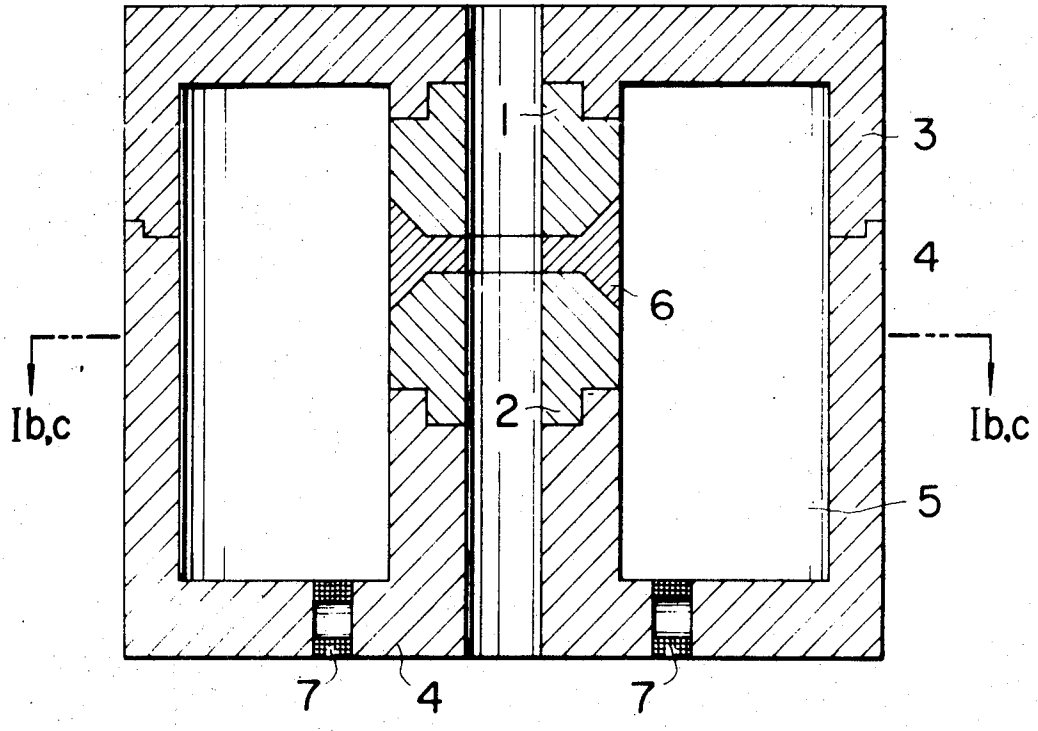


FIG. 1a

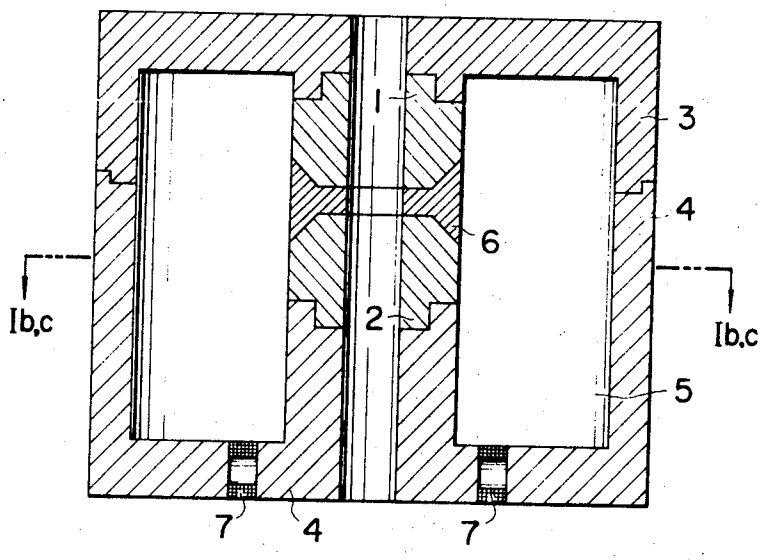
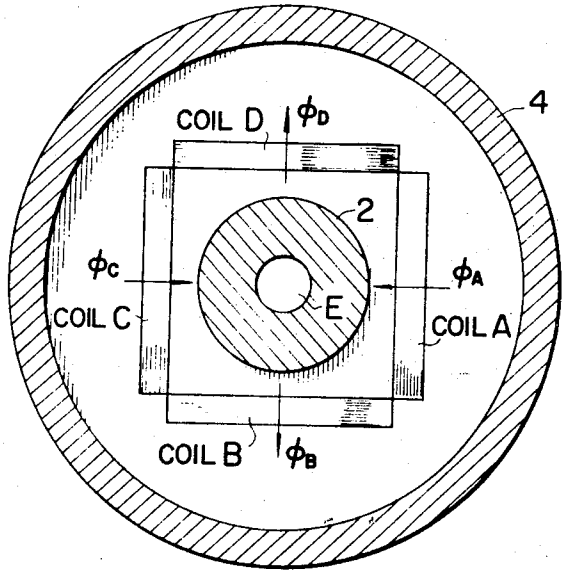


FIG. 1b



INVENTORS
SHINJIRO KATAGIRI and SYOZO KASAI
BY Craig, Antonelli & Hill
ATTORNEYS

FIG. 1c

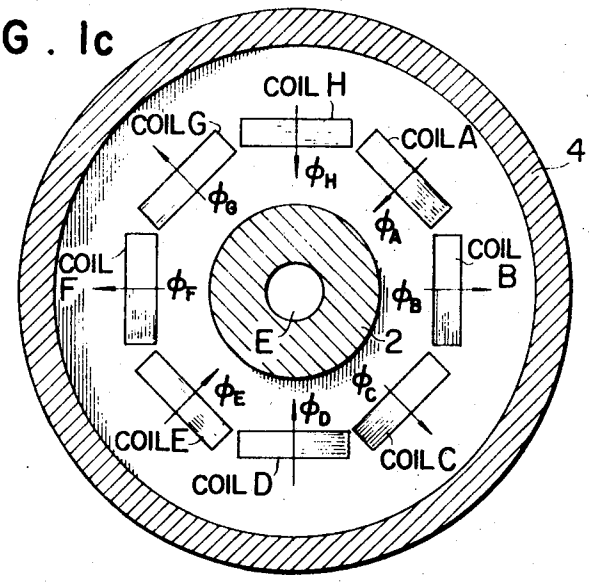


FIG. 2

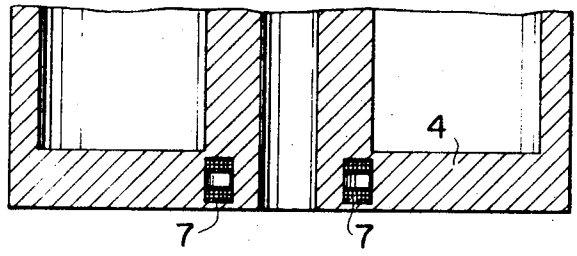


FIG. 3a

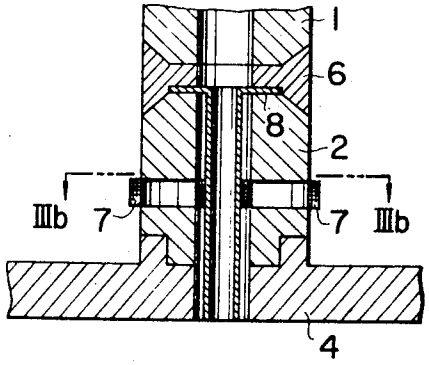
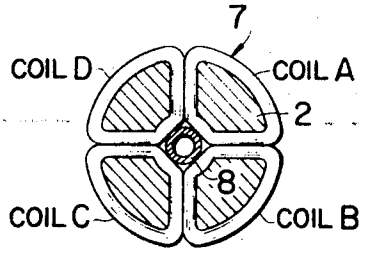


FIG. 3b



INVENTORS

SHINJIRO KATAGIRI and SYOZO KASAI

BY Craig, Antonelli & Hill

ATTORNEYS

FIG. 4a

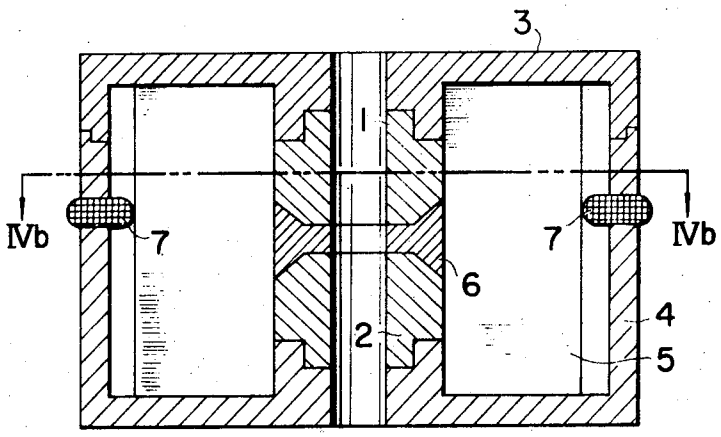
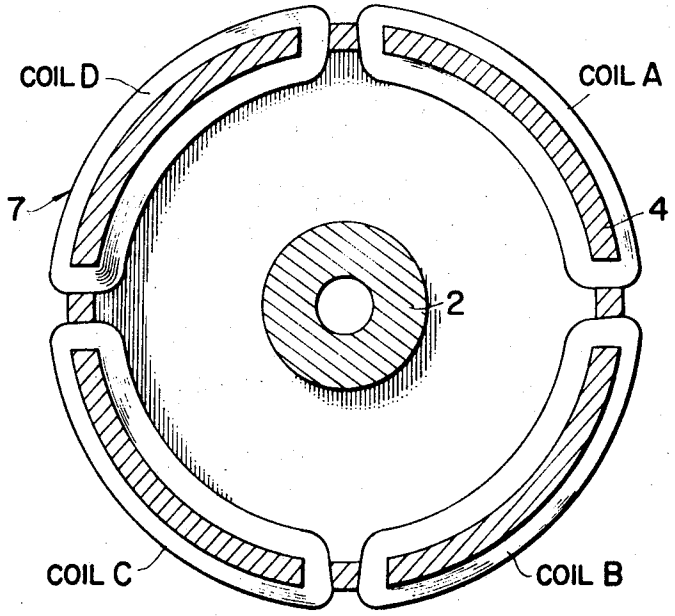


FIG. 4b



INVENTORS
SHINJIRO KATAGIRI and SYOZO KASAI
BY Craig, Antonelli & Hill
ATTORNEYS

FIG. 5a

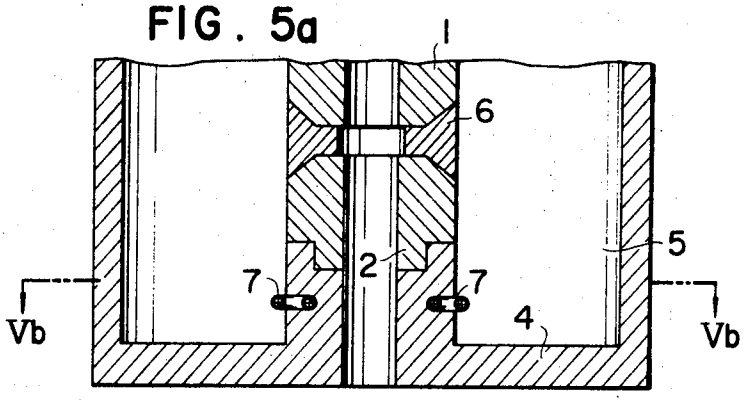


FIG. 5b

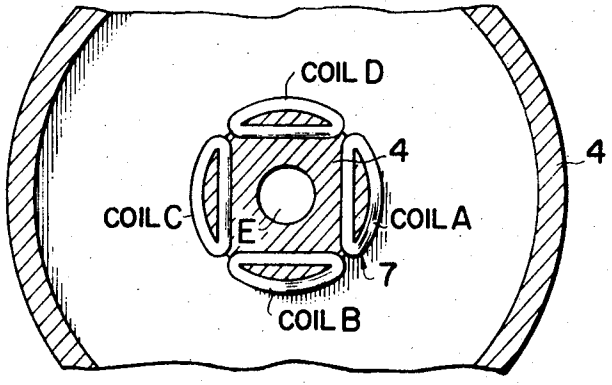
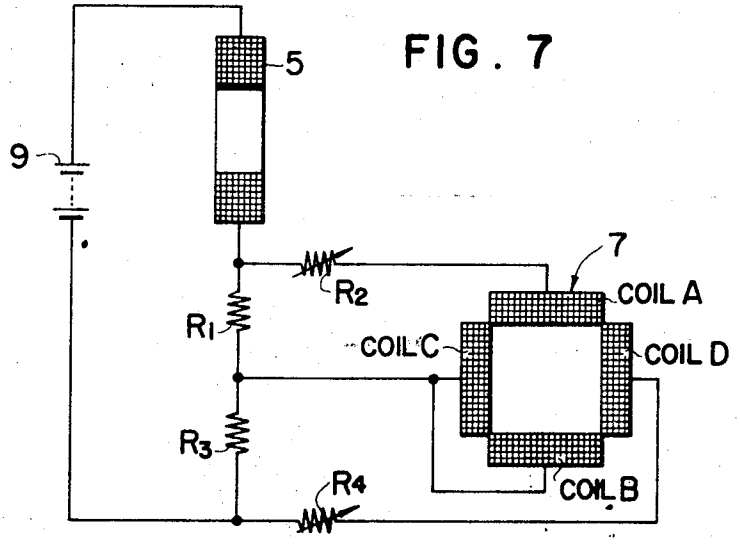


FIG. 7



INVENTORS

SHINJIROKATAGIRI and SYOZO KASA

BY

Craig, Antonelli & Hill

ATTORNEYS

FIG. 6a

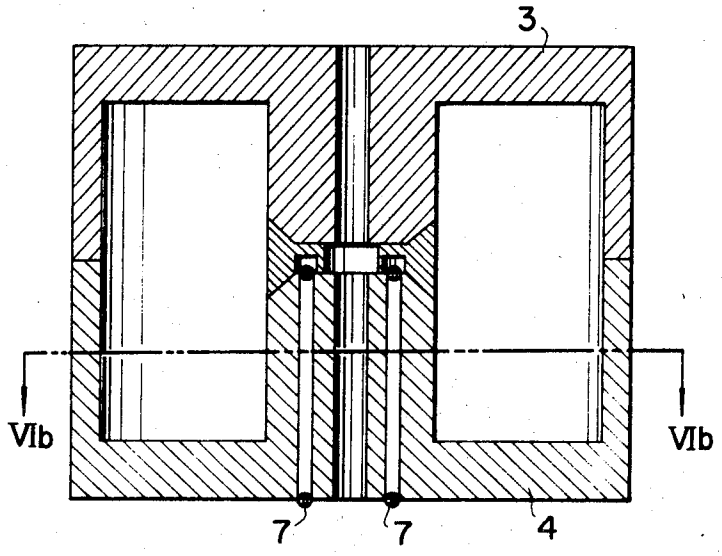
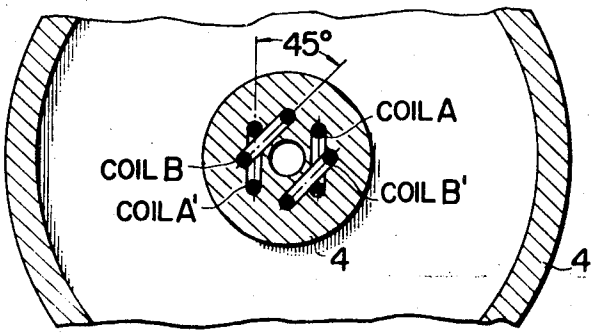


FIG. 6b



INVENTORS
SHINJIRO KATAGIRI and SYOZO KASAI
BY
Craig, Antonelli & Hill
ATTORNEYS

ELECTRON LENS OF MAGNETIC FIELD TYPE FOR AN ELECTRON MICROSCOPE AND THE LIKE

BACKGROUND OF THE INVENTION

This invention relates to an electron lens of the magnetic field type for an electron microscope and the like, and more particularly to an electron lens having means for compensating for astigmatism and undesirable deflection of an electron beam therein.

As is well known, in an electron lens of the magnetic field type which is commonly used in an electron microscope and the like, astigmatism occurs on account of the asymmetry of the mechanical construction and magnetic characteristic thereof.

Moreover, undesirable deflecting magnetic fields occur in the area of contacting portions between the pole pieces and magnetic path members in said lens to deflect an electron beam therein.

Due to such astigmatism and undesirable deflection of the electron beam, the image produced by the beam is distorted, and further it is impossible to observe said image within a constant viewing field since the image is shifted therefrom so that the ability of an electron microscope and the like using said lens to produce an acceptable image is unsatisfactory and manipulation thereof becomes complicated.

In a conventional electron lens, compensating coils are disposed in the vacuum space of the pole piece opening or beam passage in said lens so as to eliminate said astigmatism and undesirable deflection of the electron beam. However, such an arrangement is undesirable since the lead lines of said compensating coils must be taken out from said vacuum space without producing leakage and it is required to insulate between said compensating coils and the magnetic circuit of said lens.

Therefore, such an arrangement requires a complicated construction to attain the above requirements so that the production costs of said lens becomes prohibitive. Moreover, since the compensating coils are disposed in the vacuum space, the reluctance with respect to the magnetic flux produced by said compensating coils is very large, and thus the compensating currents supplied to said compensating coils must be increased.

SUMMARY OF THE INVENTION

An object of this invention is to provide an electron lens so constructed that astigmatism and undesirable deflection of the electron beam are compensated efficiently.

Another object of this invention is to provide an electron lens having compensating coils whose reluctance is very small. A further object of this invention is to provide an electron lens having compensating means whose construction is simple and compact.

The electron lens in accordance with this invention is characterized in that compensating coils are installed in a magnetic cover disposed around an exciting lens coil so as to efficiently compensate astigmatism and undesirable deflection of the electron beam.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* is a longitudinal section showing an embodiment of this invention;

FIGS. 1*b* and 1*c* are cross sections of respective embodiments of compensating coil arrangements taken along line I*b*, *c* — I*b*, *c* in FIG. 1*a*;

FIG. 2 is a partial sectional view showing the location of compensating coils in another embodiment of this invention;

FIG. 3*a* is a partial sectional view showing the main part of a further embodiment of this invention;

FIG. 3*b* is a section taken along line III*b* — III*b* in FIG. 3*a*;

FIG. 4*a* is a longitudinal section showing a still further embodiment of this embodiment;

FIG. 4*b* is a cross section taken along line IV*b* — IV*b* of FIG. 4*a*;

FIG. 5*a* is a longitudinal section showing the main part of a still further embodiment of this invention;

FIG. 5*b* is a cross section taken along line V*b* — V*b* of FIG. 5*a*;

FIG. 6*a* is a longitudinal section showing still another embodiment of this invention;

FIG. 6*b* is a cross section taken along line VI*b* — VI*b* of FIG. 6*a*; and

FIG. 7 is a circuit diagram showing a circuit for supplying a compensating current to said compensating coils.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1*a*, an electron lens includes an upper magnetic pole piece **1**, a lower magnetic pole piece **2**, an upper magnetic path member **3**, a lower magnetic path member **4**, an exciting lens coil **5** wound in an annular shape to surround the electron beam passage, and a spacer **6** made of non-magnetic material. The upper and lower magnetic pole pieces **1** and **2** and the upper and lower magnetic path members **3** and **4** constitute a magnetic cover disposed to cover the exciting lens coil **5**. These are well known elements which constitute a conventional electron lens structure of magnetic field type. In such an electron lens, the spacer **6** is not always used.

In accordance with the invention, the electron lens further includes a compensating coil device **7** having four coils A to D, as shown in FIG. 1*b*, which are wound on the lower magnetic path member **4** through holes formed therein. In this case, the respective coils are disposed to have an angle of 90° formed between two transverse center axes of said coils adjoining each other, as shown in FIG. 1*b*. As also shown, the compensating coils may be recessed in the cover body so as not to protrude therefrom.

The coil A is connected to coil C with an opposite sense thereto in series and the coil B is connected to coil D in the same manner. Compensating currents are supplied to said coils in such a manner that magnetic flux ϕ_A and flux ϕ_C produced by said coils A and C are in the direction of an electron beam axis E, and magnetic flux ϕ_B and flux ϕ_D produced by said coils B and D are in the opposite direction thereof so as to compensate for astigmatism and undesirable deflection of the electron beam.

As is well known, with the above-mentioned compensating coil device, only the astigmatism appearing in a specific direction may be corrected. In order to make it possible to correct astigmatism in whichever direction it occurs, the compensating coil device may be

constructed by eight coils A to H, e.g., as shown in FIG. 1*c*.

The respective coils are wound on the lower magnetic path member **4** through holes formed therein as in the foregoing, and they are disposed in such am manner that the angle defined by the central axes of the adjacent two coils is 45°.

The coils A, C, E and G are connected in series with the sense of alternate coils being the same. Thus, they are energized in such a manner that, as in the above description, ϕ_A and ϕ_E, which are among the magnetic fluxes produced by the respective coils opposing each other, are directed towards the electron beam axis E; whereas, ϕ_C and ϕ_G are directed away from the axis. Similarly, the coils B, D, F and H are connected in series, and are energized as described above.

As apparent from the above description, the compensating coil device in FIG. 1*c* comprises in combination two sets of the one in FIG. 1*b*. The compensating current which is caused to flow through one set of the coils A, C, E and G is made so as to differ in phase by 90° with respect to the compensating current which is caused to flow through the other set of the coils B, D, F and H. In other words, if the current through one set of the coils is varied in accordance with the cosine of the angle, so that the resultant magnetic field may rotate by 360°. In this manner, in whichever direction astigmatism appears, it may be corrected.

Even if eight coils are not used, astigmatism generated in any direction may be corrected with only four coils A, A′, B and B′ insofar as they are arranged as illustrated in FIG. 6*b*. In FIG. 6*b*, the mutually opposing coils A and A′, and B and B′ are connected in series, respectively, while they are disposed in such a manner that the central axes of the coils of the set consisting of A and A′ and those of the coils of the set consisting of B and B′ define an angle of 45°, respectively.

The same result as achieved in the previous embodiment is obtained with the exciting currents varying in accordance with the sine and cosine of the angle being supplied to the respective sets of the coils. These coils are assembled into a magnetic cover with the pole piece and the magnetic path member formed integrally, e.g., as illustrated in FIG. 6*a*.

The embodiment shown in FIG. 2 is a modification of the embodiment in FIG. 1*a*, and has the deflecting coil embedded in the lower magnetic path member **4**. The feature of this embodiment is that the leakage magnetic field from the magnetic cover may be reduced.

Since the deflecting coil **7** is wound into the iron core in each of the embodiments shown in FIGS. 1*a* and **2**, the magnetic reluctance through which the magnetic flux permeates is low, and the correcting effect is strong. Therefore, even when the deflecting coil **7** is provided at that part of the lower magnetic path member **4** which is considerably distant from the electron lens gap, its effect may be sufficiently utilized.

FIGS. 3*a* and 3*b* illustrate a further embodiment with the deflecting coil **7** mounted on the lower pole piece **2**. In the figures, numeral **8** designates a protecting tube. The feature of this embodiment resides in that, since the compensating coil device **7** is assembled in the vicinity of the electron lens gap, the correcting effect is strong and hence it may accomplish the object of the invention satisfactorily even in case where only a small amount of excitation is provided.

A still further embodiment shown in FIGS. 4*a* and 4*b* has the deflecting coil **7** installed at that part of the magnetic path member which is at a position as distant from the electron beam axis as possible. Although the figures illustrate a structure wherein four coils A, B, C and D constituting the deflecting coil **7** are provided so as to enable the correction of incorrect deflection of an electron beam and astigmatism in a specific direction, it is also possible to construct the deflecting coil so as to correct astigmatism in any direction by providing eight coils, as seen in FIG. 1*c*.

In an embodiment illustrated in FIGS. 5*a* and 5*b*, the compensating coil device **7** is assembled in the magnetic cover in the vicinity of the electron lens gap, and yet, it is disposed so as not to appear within the vacuum space of the electron beam path.

As shown in FIG. **7** by way of example, the compensating coil device A to D in FIG. 1*b* may be connected to the lens coil **5** through resistors R_1 and R_3 and variable resistors R_2 and R_4, thereby to supply predetermined currents from an exciting power source **9** to both of the coils.

With such construction, the excitation of the respective coils varies in proportion to each other. Therefore, once the exciting currents of the respective compensating coils are adjusted by means of the variable resistors R_2 and R_4 so as to enable the correction of astigmatism and undesired deflection, it is unnecessary to again adjust the compensating currents even if the excitation of the electron lens is changed.

While we have shown and described several embodiments in accordance with the present invention, it is understood that the same is not limited thereto but is susceptible of numerous changes and modifications as known to a person skilled in the art and we therefore do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are obvious to one of ordinary skill in the art.

What is claimed is:

1. In an electron lens of the magnetic field type for an electron microscope and the like, comprising an exciting lens coil wound in an annular shape, a magnetic cover disposed to cover said lens coil and composed of an upper magnetic path member, a lower magnetic path member and upper and lower magnetic pole pieces, the improvement which comprises a plurality of compensating coils each being wound on different portions of said magnetic cover through holes provided therein, supply means for supplying compensating currents to said compensating coils and adjusting means for adjusting said compensating currents whereby astigmatism and undesired deflection of an electron beam passing through said lens can be eliminated.

2. An electron lens according to claim **1**, characterized by eight compensating coils, which are respectively arranged such that the central axes of adjacent coils define an angle of 45° therebetween.

3. An electron lens according to claim **1**, characterized in that said compensating coils are embedded in said magnetic cover.

4. An electron lens according to claim **1**, characterized by four compensating coils, the central axes of one pair of coils opposing each other defining an angle of 45° with those of the other pair of coils opposing each other.

5. An electron lens according to claim 1, wherein said compensating coils are provided in said lower magnetic path member.

6. An electron lens according to claim 5, wherein said compensating coils are disposed symmetrically about said lower magnetic pole piece.

7. An electron lens according to claim 1, wherein said compensating coils are disposed around said lower magnetic pole piece.

8. An electron lens according to claim 7, wherein said upper and lower magnetic pole pieces define a central passage and an insulating tube is disposed in said central passage formed by said lower pole piece to protect said compensating coils.

9. An electron lens according to claim 1, wherein said upper and lower pole pieces form a magnetic lens gap therebetween, said compensating coils being disposed in said lower magnetic path member in a plane substantially passing through said lens gap.

10. An electron lens according to claim 9, wherein four compensating coils are provided in said lower magnetic path member so as to occupy a respective quadrant about said lens gap.

11. An electron lens according to claim 1, wherein said compensating coils are wound in planes parallel to the axis of said lens coil adjacent a passage through said upper and lower pole pieces.

12. An electron lens according to claim 11, characterized by four compensating coils, the central axes of one pair of coils opposing each other defining an angle of 45° with those of the other pair of coils opposing each other.

* * * * *