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A. DELONG ETAL
 DEVICE FOR COMPENSATING AXIAL ASTIGMATISM
 OF ELECTRON-OPTICAL SYSTEMS

3,046,397

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2 Sheets-Sheet 1

Fig. 1

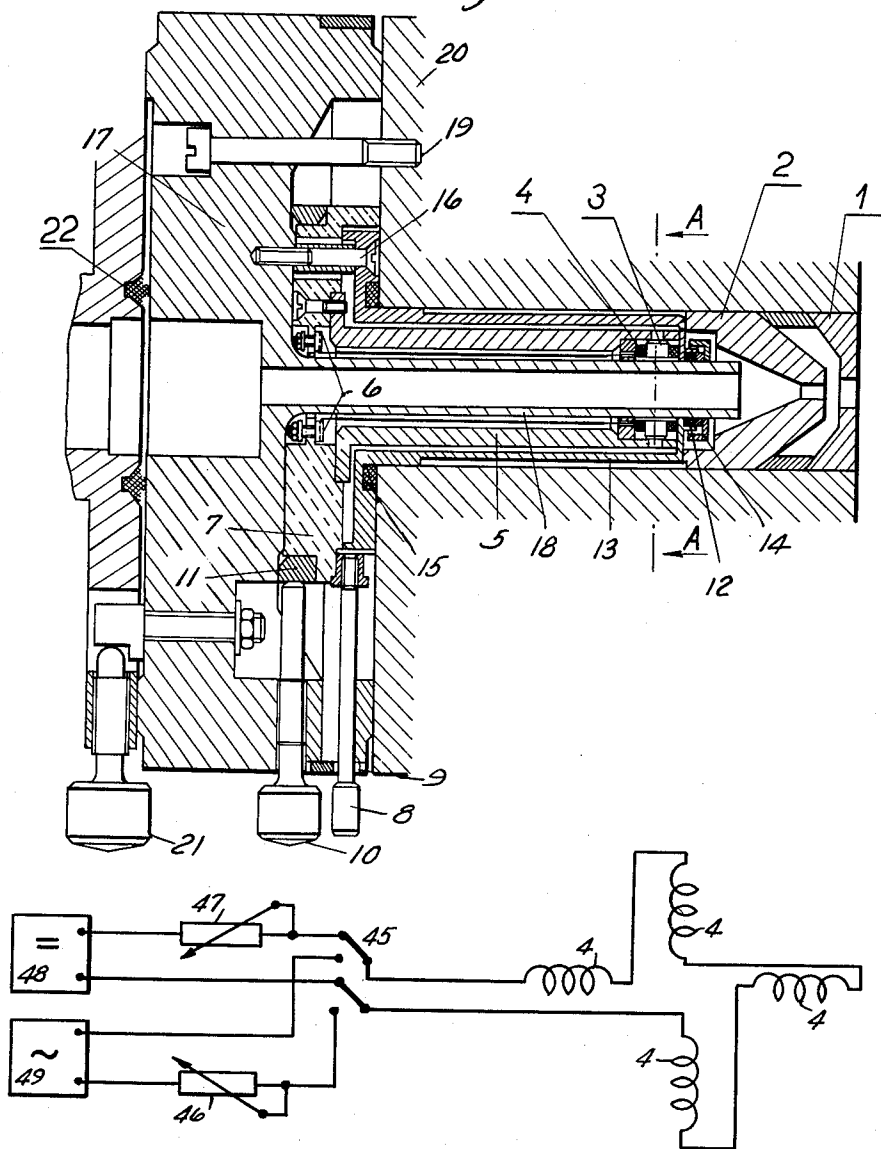


Fig. 4

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Fig. 2

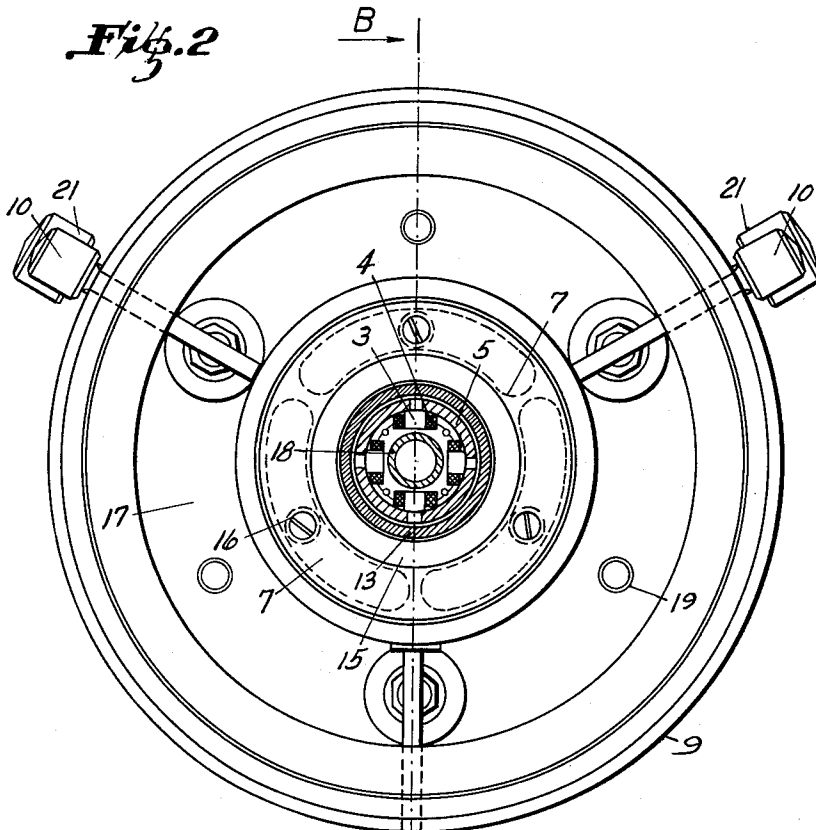
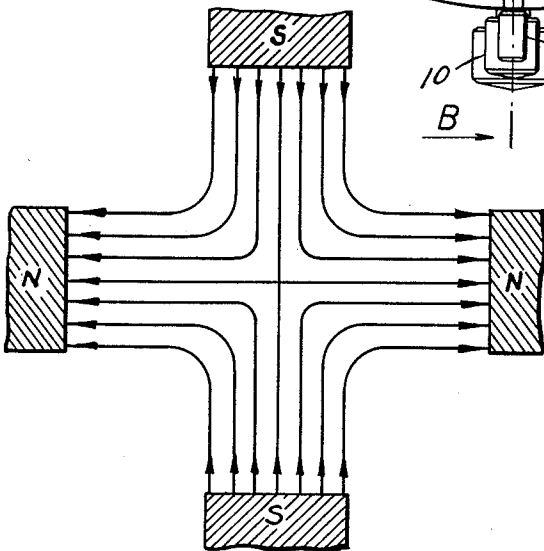


Fig. 3

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DEVICE FOR COMPENSATING AXIAL ASTIGMATISM OF ELECTRON-OPTICAL SYSTEMS

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This invention relates to a device for compensating axial astigmatism of electron-optical systems, particularly of electron microscopes.

The pole pieces or electrodes of the magnetic or electrostatic lenses used heretofore in electron-optical devices cannot be manufactured with such accuracy as is necessary to produce an exactly rotationally symmetrical magnetic field. This is the cause of an optical defect called axial astigmatism, which defect decreases the resolving power of electron microscopes. In order to correct this optical defect it is known to use so called stigmators located under the objective. They either directly compensate the unsymmetry of the magnetic field of the lens or they compensate the astigmatic picture. The known devices of this kind used heretofore comprise electrostatic systems or permanent magnets and have a complicated mechanism and uneasy handling.

The invention removes these inconveniences by a novel device for compensating axial astigmatism of electron-optical systems with the aid of a magnetic field working as a cylindrical lens. The device according to the invention is arranged in such manner that the correcting system comprising at least four pole pieces of an electro-magnet is arranged in the immediate neighbourhood of the corrected system, outside the evacuated space, is displaceable by mechanical means towards the optical axis of the corrected system and is electrically centerable by feeding the exciting windings with alternating current.

An embodiment of the invention is shown in the accompanying drawings, in which:

FIG. 1 shows a magnetic stigmator in an axial longitudinal sectional view,

FIG. 2 depicts the same stigmator in a cross-sectional view,

FIG. 3 shows the arrangement of four pole pieces of a magnetic stigmator with an outline of the magnetic field, and

FIG. 4 shows a circuit diagram of a direct-current power source and an alternating-current signal source and the interconnecting means by which the series-connected windings of the four pole pieces may be connected to one or the other of the two sources.

An example of a device according to the invention and adapted to compensate for axial astigmatism of electron-optical systems is the magnetic stigmator shown in FIGS. 1 and 2. Under the pole pieces 1 and 2 is arranged a correcting system comprising four pole pieces 3 provided with field coils 4 fixed within a tube 5 of a ferromagnetic material. The tube 5 forms a part of the magnetic circuit and also serves as a screen for the electron beam. The field coils 4 are connected in series and are fed by a direct current supplied to terminals 6. The tube 5 is joined with a flange 7 of insulating material. The main member 17 contains the stigmator consisting of the parts 3, 4, 5, 6, 7, 8 joined to form a unit which is rotatable round the optical axis within a range of $\pm 50^\circ$ and controllable by a rod 8 linked with a graduated dial 9. With the aid of three set-screws 10 engaging a ring 11 the stigmator may be displaced in a plane perpendicular to the optical axis. The correcting system is separated from the evacuated space within the optical system by an elastic packing 12 provided in a tubular member 13, the packing 12 being pressed by a screw-nut 14 and a packing ring

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15 towards the surface of the tubular member 13. The tubular member 13 is manufactured of a non-magnetic material and is fixed by three screws 16 to the main member 17 provided with a projecting tube 18. The system of the stigmator is joined by three screws 19 with the body 20 of the objective. The system may be displaced with the aid of set-screws 21 in respect to the projecting system by movements in a plane perpendicular to the optical axis, a vacuum-tight connection with the optical system being secured by a packing ring 22.

The essential parts of the above described stigmator are four pole pieces 3 arranged symmetrically round the optical axis. The magnetic flux is produced by four field coils 4 arranged on the pole pieces 3. If the direction of the current in the field coils is chosen in such a manner that the pole pieces represent in succession north and south poles, the magnetic field induced between said pole pieces has a form shown by field lines in FIG. 3. This magnetic field works like a combination of two cylindrical lenses, a condensing lens and a diverging-lens. The field is given by the following equations:

$$H_x = kx$$

and

$$H_y = -ky$$

wherein:

H_x is the component of the magnetic field in the direction of the axis of x ,

H_y is a component of the magnetic field in the direction of the axis of y ,

k is a constant coefficient.

The above described stigmator shown in FIGS. 1 and 2 corrects the picture produced by the objective. The correcting field between the pole pieces 3 should be as near as possible to the objective in order to limit the additional distortion to a minimum. The intensity of the correcting field may be varied by changing the current in the field coils 4. The desired direction of the correcting field is adjustable by the lever 8 which carries with it the dial 9 provided with a scale for reading the angle of rotation of the stigmator. The accuracy of reading is better than $\pm 1^\circ$. In order to reach a perfect correction it is desirable to shift the center of the correcting field so as to make the center coincide with the optical axis of the objective. Such position may be achieved by a mechanical centering of the stigmator by the set-screws 10. As an auxiliary measure for centering the stigmator it is possible to feed the field coils by alternating current.

FIG. 4 shows a circuit diagram of a direct-current power source 48 and an alternating-current signal source 49 and interconnecting means including a switch 45 by which the series-connected coils 4 may be connected to one or the other of the two sources 48 and 49. Variable resistors 46 and 47 are provided to permit adjustment of the source voltages to any desired values.

The stigmator according to the invention may be located between the pole pieces thus making it possible to correct directly any unsymmetry of the field of the objective instead of correcting only the astigmatic picture. Even in such case the device may be arranged substantially in the same manner as described above.

The stigmator may also correct the ellipticity of an illuminating beam or a distortion of dimensions of the picture in reflection electron microscopy.

It is an advantage of the invention that the system of the field coils is located outside the evacuated space so that it is not necessary to arrange complicated vacuum bushings. The angle of correction is easily adjustable by mechanical rotation of the whole system round the optical axis and the intensity of the correcting field may be adjusted by changing the exciting current. The arrange-

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ment of the system off the path of electrons avoids the formation of dirt whose electric charge disturbs the symmetry of the field. The system is mechanically centerable in order to achieve an ideal correction the manufacture of the device is simpler than with the stigmators known heretofore.

What we claim is:

1. In combination in an apparatus for correcting the axial astigmatism of an electron-optical system which includes an evacuated chamber, magnetic lens means having a main axis along which an electron beam is to be projected, said magnetic lens means establishing an asymmetrical magnetic field configuration with respect to said main axis, means positioned adjacent to said magnetic lens means for correcting the asymmetrical configuration of the magnetic field of said magnetic lens means, said correction means including four series-connected electromagnets disposed outside the evacuated spaced of the electron-optical system in approximate quadrature relation with said main axis, said electromagnets having windings which are connected in series in such a manner that

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the poles of said electromagnets which face said axis and are opposite each other have identical magnetic polarities, variable direct-current power source means for energizing said four series-connected electromagnets, means for mechanically rotating said four series-connected electromagnets with respect to said main axis, and centering means for moving said four series-connected electromagnets in a plane perpendicular to said main axis.

2. A combination as in claim 1 wherein said centering means further includes an alternating-current power source means, and means for interrupting the energization of said four series-connected electromagnets by said variable direct-current power source means and four energizing said electromagnets by said alternating-current means.

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