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SLOT STIGMATOR

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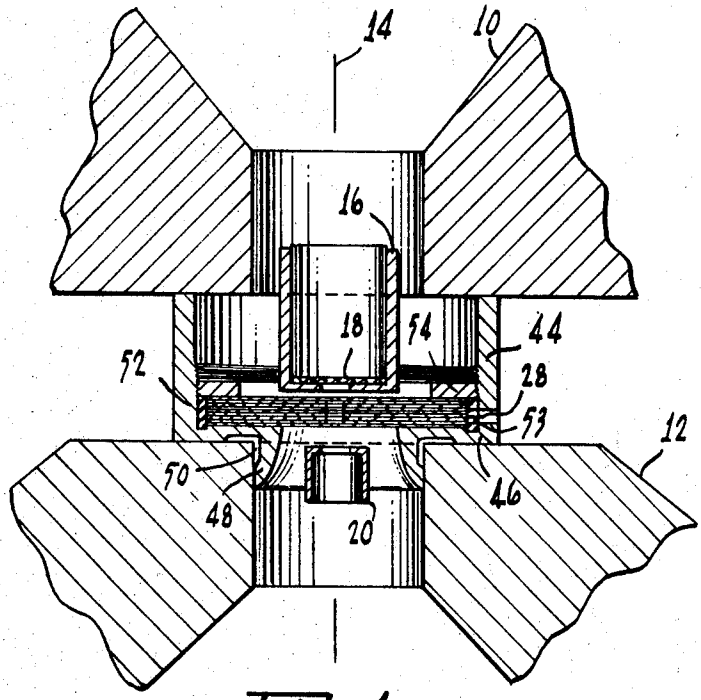


Fig. 1.

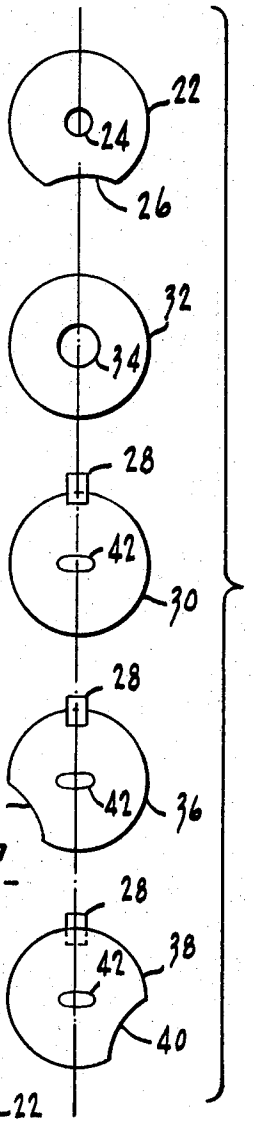


Fig. 2.

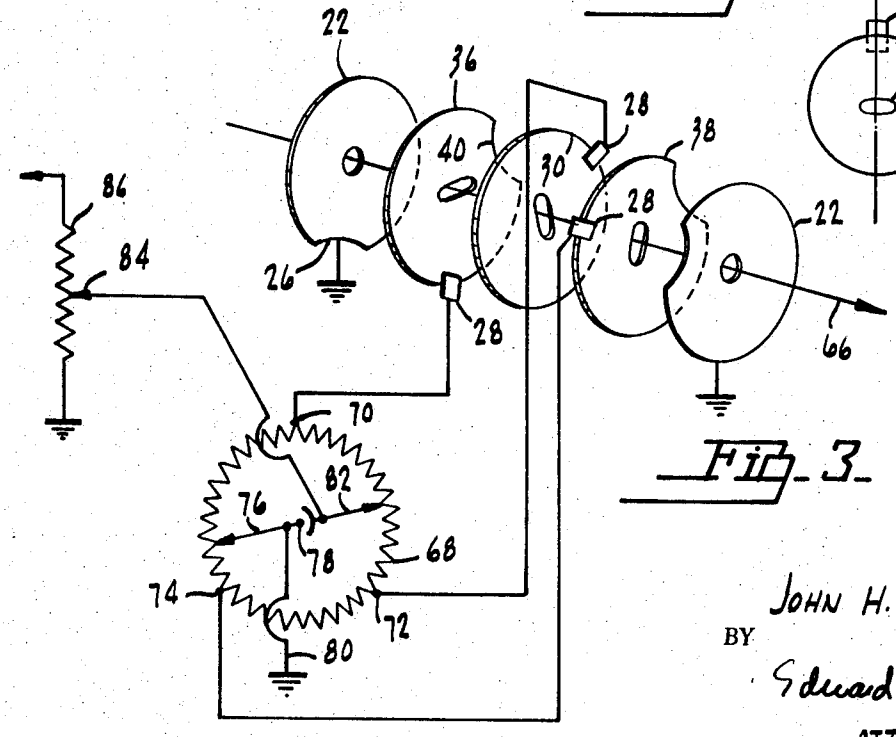


Fig. 3.

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SLOT STIGMATOR

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ABSTRACT OF THE DISCLOSURE

Disk means are disclosed to overcome the defocusing effect of a non-symmetrical magnetic electron lens in an electron microscope. The disk means is thin enough to fit between the pole pieces of the magnetic lens and still leave room for the specimen to be inserted between the pole pieces of the magnetic lens. The disk means includes a plurality of disks so constructed and arranged as to produce a plurality of different and distinct electron lenses.

This invention relates to electron apparatus and more particularly to lens compensating means for electron beam apparatus such as an electron microscope.

In an electron optical apparatus such as an electron microscope, a beam of electrons is formed by an electron gun. The electrons are projected through a specimen to be examined and then through a magnetic electron lens which focuses an image of the object on a viewing plate. If the magnetic field provided by the magnetic lens is not symmetrical about its central axis, the effect on the beam will be to cause distortion of the image. Asymmetry in the magnetic field is usually caused by anisotropy of the magnetic material from which the pole pieces comprising the magnetic lens are made, and by mechanical imperfections in the construction and adjustment of the lens. The asymmetry causes a type of image distortion that is called anisotropic astigmatism. Means for correcting field asymmetry, or stigmators, are known. However, the known stigmators are relatively long, about 0.15 of an inch, in the direction of the electron beam. In working with high energy electron lenses whose focal lengths are about 0.083 of an inch, where for proper focusing the specimen must be inserted between the pole pieces of the lens, a known stigmator cannot be successfully fitted into a lens of such short focal lengths since the distance between the pole pieces of such a lens does not allow space for both the specimen and a known stigmator. If the stigmator is positoned outside of the pole pieces along the electron beam, more voltage must be applied to stigmator to cause it to correct for anisotropic astigmatism.

It is an object of this invention to provide an improved anisotropic astigmatism correction means or stigmator.

It is another object of this invention to provide a stigmator which is short in the direction of the beam of electrons that pass therethrough compared to known stigmators.

It is still another object of this invention to provide a stigmator which is sufficiently short in the direction of the electron beam that passes trerethrough to be mounted in a short focal length magnetic lens.

In accordance with this invention, a plurality of flat conductive disks, each having a hole therethrough, are provided. The disks are so stack that the flat sides of each disk, except the outside ones, are separated only by insulation from the flat sides of other disks and the centers of the holes throught he disks are aligned. The holes through the outside disks are round and the holes through the intermediate disks are elongated and are symmetrical with respect to their respective centers whereby the holes

in the intermediate disks each have a long and a short axis perpendicular to each other. The intermediate disks in the stack are so arranged that hte long axes of the holes are at an angle with each other. The stack of disks may be placed between the pole pieces of an electron lens in such a position that the electron beam which has passed through the specimen also passes through the holes in the stack of disks. Ground or a reference potential is applied to the outside disks and adjustable voltages are applied to the inner disks with respect to the outside disks. The voltage applied to the inner disks may be adjusted to correct for anisotropic astigmatism of the beam whereby the stack of disks so stacked and so energized acts as a stigmator.

The invention may be better undestood from reading the following description in connection with the accompanying drawing in which:

FIG. 1 is a diagrammatic showing of a stigmator in accordance with this invention in place in a magnetic electron lens,

FIG. 2 is a plan view of the individual disks making up the stigmator of FIG. 1, and

FIG. 3 is a circuit diagram of a means for energizing the stigmator of FIG. 1, showing the relative angular and spacial positions of the conductive disks comprising the stigmator.

Turning first to FIG. 1, portions of the upper and lower magnetic pole pieces **10** and **12**, as viewed in this figure, are shown in sections. As understood, the pole pieces **10** and **12** are symmetrical about the electron beam **14** which goes down along the axis thereof. A cup-like specimen holder **16** is also arranged symmetrically with respect to the beam **14**. The specimen holder **16** is supported on the upper pole piece **10** by conventional means not shown. A hole in the bottom of the specimen holder **16** is closed by a finely meshed screen **18** on which the specimen, not shown, may be laid. The specimen holder **16** and the screen **18** are both so positioned that the specimen will be positioned between the pole pieces **10** and **12**. An aperture means **20**, which may be supported by the lower pole piece **12**, is provided, the aperture through the top of the aperture means **20** being at about the level of the upper surface of the lower pole piece **12**. The electron beam **14** is produced by an electron gun, not shown, and passes downward through the pole pieces **10** and **12**. After the electrons comprising the beam pass through the specimen and the objective lens comprising the pole pieces **10** and **12** and the aperture means **20**, which intercepts electron beams that are scattered by the specimen or by the screen **18**, the beam is focused on a viewing plate (not shown) to give a magnified image of the specimen. However, as noted above, due among other things, to anisotropy of the magnetic material from which the pole pieces **10** and **12** are made and due to mechanical misadjustments, anisotropic astigmatism of the image occurs. This astigmatism is minimized or cured by the stigmator to be described.

In passing through the lens comprising the pole pieces **10** and **12**, the beam is rotated in a helical manner through an angle of about 120°. The stigmator should operate to correct the astigmatism within a distance during which the beam is rotated less than 90°, because otherwise, the corrections made by the stigmator would be averaged out along all the directions perpendicular to the direction of travel of the beam, whereby the stigmator would not correct the astigmatism. Optimum operation of the stigmator would result if its length were zero whereby all the correction would be applied to the beam before it had a chance to rotate, however, this is mechanically impossible. To be useful for its purpose, a stigmator must be provided whose length in the direction of travel of the

beam is not more than the distance through which the beam rotates about 60°. When the distance between the lower edge of the upper pole piece and the upper edge of the lower pole piece **12** is only about 0.41 of an inch, as in the case of a short focal length magnetic lens, and when the maximum rotation of the beam while passing through the sigmator is 60°, it is seen that the thickness of the stigmator to be described cannot exceed about 0.2 of an inch. However, when the specimen is also positioned between the pole pieces **10** and **12**, as is necessary, the space left between the pole pieces for the stigmator may not exceed about 0.08 of an inch. A stigmator has been built having a thickness of less than about 0.033 of an inch, the stigmator including nine disks such as those illustrated in FIG. 2.

The disk **22** shown in plan view at the top of FIG. 2 is an end disk of which two are required. This disk **22** is made of a conductive non-magnetic material and is about $\frac{5}{1,000}$ of an inch thick and has a round hole **24** through the center thereof having a diameter of about $\frac{3}{100}$ of an inch. An edge of the disk **22** is cut away at **26** to provide clearance for a tab **28** on another conductive disk, as will be explained.

Four circular disks **32** of insulating material about $\frac{3}{1,000}$ of an inch thick and having a hole **34** therethrough having a diameter of about $\frac{8}{100}$ of an inch are provided. These insulating disks will be placed between stacked conducting disks as will be explained.

A further conductive circular disk **30** is provided having a thickness of about $\frac{3}{1,000}$ of an inch. A slot-like hole **42** having rounded ends is provided through the disk **30**. The longer dimension or axis of the hole **42**, which is not critical in length, is at least two and a half times as great as its smaller dimension or axis, the two axes being perpendicular to each other. The smaller dimension of the hole **42** is at least as great as the diameter of the hole **24**. The diameter of the hole **34** is at least as great as the larger dimension of the hole **42**. A tab **28** is electrically connected to the disk **30**, as by welding, in a position such that the extended shorter axis of the hole **42** passes through the tab **28**.

Two further disks **36** and **38** are provided. The disks **36** and **38** are identical and they differ from the disk **30** only in that a portion of the disk **36** is cut away as at **40** through about a 60° arc starting at the left, as viewed in FIG. 2, at the line through the larger axis of the hole **42** therethrough, the cut away portion extending downward in a counterclockwise direction. The disk **38** is merely the disk **36** rotated 180° about an axis through the smaller axis of the hole **42**. The stigmator which comprises the disks of FIG. 2 is assembled and positioned between the pole pieces **10** and **12** in FIG. 1 as will be described.

Turning to FIG. 1, a non-magnetic conductive cylinder spacer **44**, which is internally threaded along a portion of its length is provided between the pole pieces **10** and **12** and is coaxially arranged with respect thereto. The bottom part of the spacer **44** is partially closed by a closure member **46** having a hole therethrough. A conical flange **48** extends around the hole in the member **46** and projects downward and outward to contact the inner periphery of the lower pole piece **12**. The member **46** and the flange **48** may be cut away as at **50** for ease of assembly of the spacer with the pole piece **12**, if desired. The upper surface of the closure **46** acts as a support for the lower outside disk of the stigmator as will be explained. A ring-like spacer **52** of insulating material, having three radial holes **53** therethrough, only one of which is shown, is provided within the cylinder **44**. The stigmator disks are mounted on the closure member **46** within the spacer **52**, as will be explained, and a conductive ring-like top clamp plate **54**, which is threaded on its external cylindrical periphery, is screwed down on the top disk of the assembled stigmator.

In FIG. 3, the conductive disks or electrodes **22, 36, 30, 38** and **22** are shown in their relative spacial and also in

their relative angular positions when assembled (as explained below) between the pole pieces **10** and **12** of a magnetic electron lens, the insulating disks **32** (one of which appears between each two conductive disks) being omitted for clarity. The arrow **66** in FIG. 3 represents the electron beam of the microscope in which the described stigmator is to be mounted. For clarity of illustration, the disks of FIG. 3 are shown as being widely separated but they are assembled as close together as they can be placed and still be insulated from each other.

The stigmator is assembled by laying an end disk **22** (the left one as viewed in FIG. 3) on the support member **46**. Then an insulator disk **32** is laid on the disk **22**. Next, the disk **36** is laid on the disk **32** in such a manner that the tab **28** of the disk **36** is above the cut away portion **26** of the disk **22**, the tab **28** extending through a hole **53** in the insulator ring **52**. The next step is to lay an insulator disk **32** on the disk **36**. Then lay the disk **30** on the disk **32** with the tab **28** of the disk **30** over the cut away portion **40** or the disk **36** and with the tab **28** extending through another hole **53** in the insulator **52**. Then an additional insulator disk **32** is laid on the disk **30**. The disk **38** is then laid on this disk **32** with the tab **28** of the disk **38** extending in such a manner that the tab **28** of the disk **30** is under the cut away portion of the disk **38**, the tab **28** of the disk **38** extending through the third hole **53** in the insulator **52**. An additional insulator disk **32** is laid on the disk **38** and a second end plate **22** is laid on the disk **38** in such a manner that the cut away portion of the disk **22** is above the tab **28** of the disk **38**. All the disks are coaxially positioned. Therefore, a thin stigmator having five conductive electrodes or disks that are insulated from each other is provided. The long axes of the holes **42** through the disks **30, 36** and **38** are at 60° angles with each other. The distance between the end plates **22, 22** is about equal to the smaller axis of the holes **42** through the disks **30, 36** and **38**, whereby each disk **30, 36** and **38** acts with the end disks **22** as an electron lens, three electron lenses thereby being provided by the assembled stigmator. The distance between any two alternate ones of the conductive disks **22, 30, 36, 38**, or **22** however, is smaller than the small axis of the hole **42** in an intermediate conductive disk whereby three adjacent conductive disks do not act as an electron lens.

Energization of the disks comprising the stigmator is accomplished as follows: The clamping of the disks comprising the stigmator together by the clamping plate **54** connects the upper and the lower disks **22** to the pole pieces **10** and **12** which are kept at a constant reference potential. The tabs **28** on the disks **30, 36** and **38** extend through respective holes **53** in the insulator **52** and are accessible through registering holes in the cylindrical spacer **44**, only one hole through the spacer **44** being shown in FIG. 1. The disks **30, 36** and **38** are energized by applying direct voltages thereto with respect to ground through conductors (see FIG. 3, not shown in FIG. 1) connected to the respective tabs **28**.

The tab **28** on a disk **36** is connected to a point **70** on a circular potentiometer resistor **68**. The tab **28** on the disk **30** is connected to a point **72** on the resistor **68**, 120° away from the point **70**, and the tab on the disk **38** is connected to a point **74** which is 120° away from both of the points **70** and **72**. A radially positioned rotating contactor **76** rotates about the center **78** of the resistor **68** and the contactor **76** is connected to ground or reference potential by a conductor **80**. Another radially positioned rotating contactor **82**, which is held in line with the contactor **76** and is insulated therefrom, is connected to a slider **84** on a potentiometer **86**. The potentiometer **86** is connected across a voltage source (not shown) which may be of either polarity with respect to ground or to a reference potential. By rotating the contacts **76** and **82** as a unit, the voltages, on the disks **30, 36** and **38** may be varied with respect to each other and with respect to

ground. In this manner, energization of the three electrostatic lenses comprising each one of the intermediate disks **36, 30** and **38** taken individually with the two end disks **22,** is adjusted to apply deflecting voltages to the beam **66** in a direction perpendicular to the direction of the beam and at 60° with each other and in such a manner as to minimize or cure the anisotropic astigmatism of the beam passing therethrough.

As noted above, in the described stigmator, the individual slotted disk electrodes **30, 36** and **38** act almost independently of the other slotted electrodes. That is, each of the slotted electrodes **30, 36** and **38,** and the end elctrodes **22, 22** complete a different and distinct lens. This is due to the fact that the long dimensions or axes of the slots **42** in the slotted disks **30, 36** and **38** are more than two and a half times the short dimensions or axes thereof, whereby the several lenses comprising the disks **30, 36** and **38** are almost completely cylindrical and whereby the several lenses do not shield each other in the plane of action thereof, and due to the fact the separation of the slotted electrodes **30, 36** and **38** is small compared to the small dimension of the slot **42.** For example the separation of the slotted electrodes **30, 36** and **38** is about one-fifth of the small dimension of the slot **42.** The described stigmator provides a plurality (three in the embodiment described) of separate cylindrical lenses, which are axially close together compared with the focal lengths in which the effect of the several lenses is vectorially addable without substantial interaction between the several lenses. Such action of the stigmator is necessary to correct for anisotropic astigmatism.

While the stigmator is described as being mounted in a magnetic lens, it may be mounted at any desired location along an electron beam.

Many modifications of the stigmator described will be evident to a person skilled in the art. For example, instead of providing insulating disks **32,** each of the intermediate disks **30, 36** and **38** may be coated with insulation over the contacting surfaces thereof. Other methods of clamping the disks comprising the stigmator are evident such as the provision of an upper and a lower clamping ring held together by bolts extending therebetween which are insulated from the intermediate disks **30, 36** and **38.** With such a clamping means, an insulating spacer **52** may not be necessary. Also, the stigmator may be used in cathode ray apparatus other than microscopes that do or do not include magnetic lenses. Therefore, the above illustration is to be considered as illustrative and not in a limiting sense.

What is claimed is:

1. The combination of a short focal length magnetic lens and a stigmator, said stigmator being arranged between the pole pieces of said lens, said stigmator comprising

a stack of at least four conductive disks,

said conductive disks each having a hole therethrough,

the holes through the end disks of said stack of disks being round and the holes through the intermediate disks of said stack of disks each having a long and a short axis, said long axis being at least two and one-half times said short axis,

the centers of the holes through the disks being aligned and the long axes of the holes in the intermediate disks being at an angle with each other,

the distance between each two alternate disks being less than the short axis of the holes in the intermediate disks, and

means for insulating said disks from each other,

said holes being positioned to pass the electron beam of said magnetic lens.

2. The combination of claim **1,** said stigmator comprising three intermediate disks, the angles between the long axes of the holes in the intermediate disks being substantially 60°.

3. The combination of claim **1,** said stigmator comprising three intermediate disks, the angle between the long axes of the holes in the intermediate disks being substantially 60°,

the distance between said end disks being substantially equal to the small axis of the holes through the intermediate disks.

4. A combination of claim **1** including

means for electrically connecting said end disks to said pole pieces, and

means to apply voltages to said intermediate disks with respect to said end disks.

5. The invention as expressed in claim **4** in which there are three intermediate disks and in which the angle between the long axes of the holes through the intermediate disks is substantially 60° with respect to each other.

References Cited

UNITED STATES PATENTS

2,884,559 4/1959 Copper et al. ------ 315—31TV

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