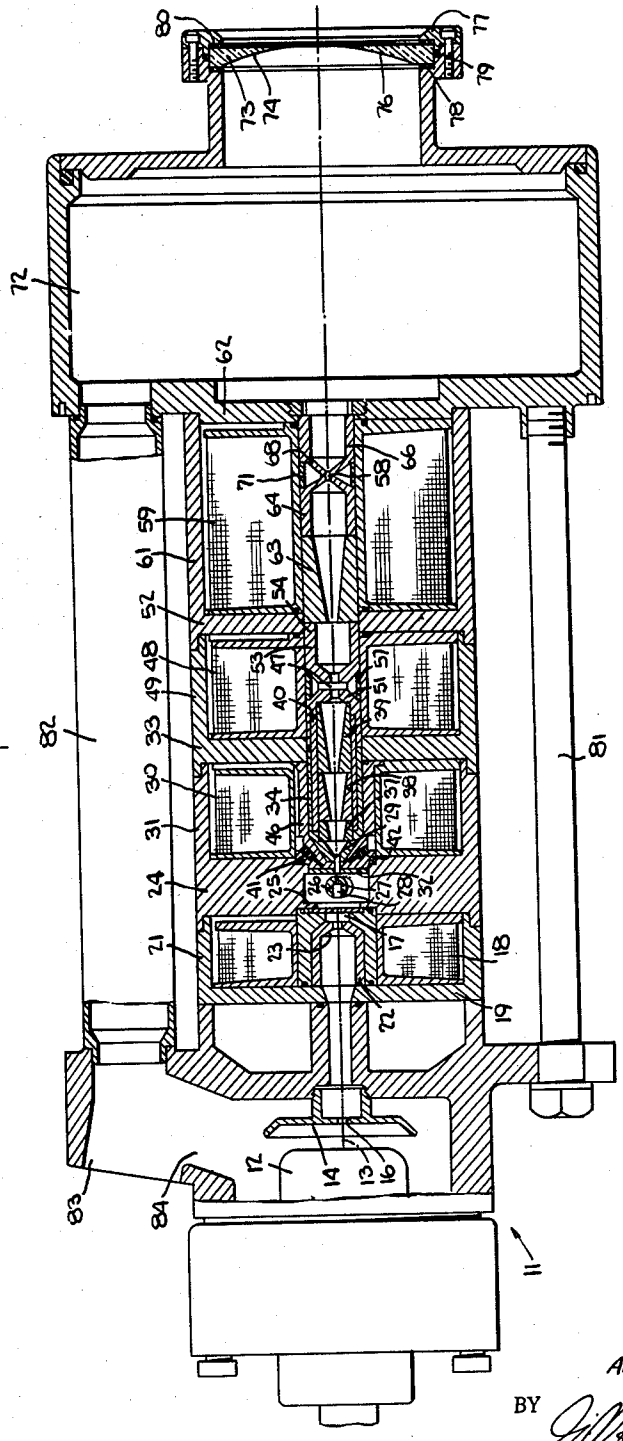
Sept. 22, 1964 A. P. WILSKA 3,150,258

ELECTROMAGNETIC STIGMATORS FOR CORRECTING ELECTRON-OPTICAL DEFICIENCIES IN THE LENSES OF ELECTRON BEAM INSTRUMENTS

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Fig. 1.



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Fig. 2.

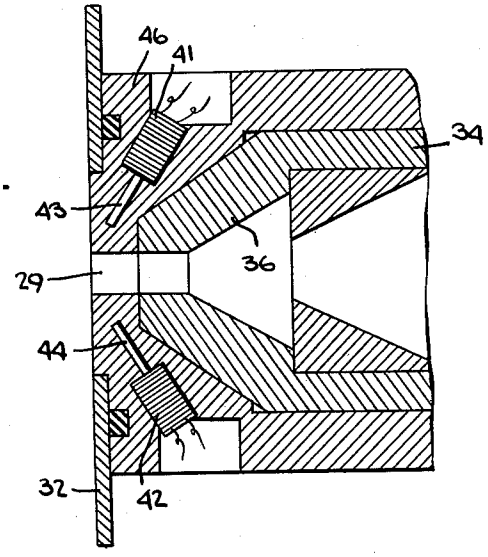
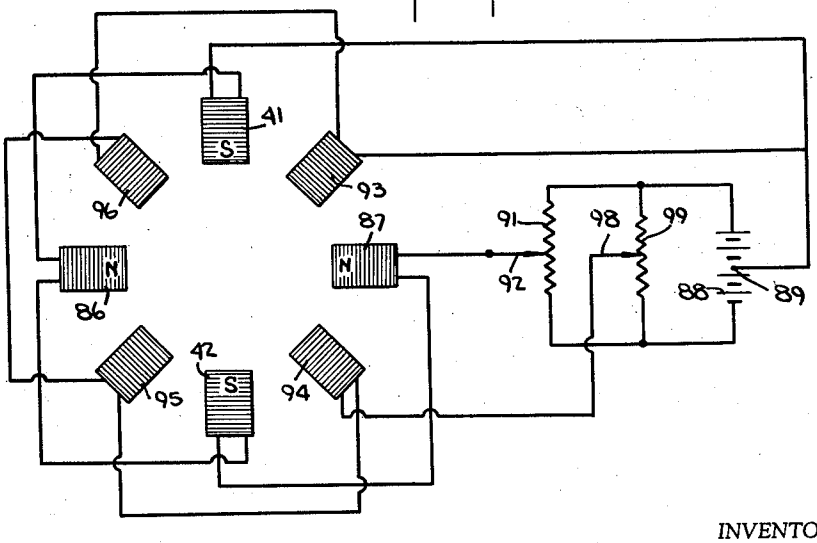


Fig. 3.



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ELECTROMAGNETIC STIGMATORS FOR CORRECTING ELECTRON-OPTICAL DEFICIENCIES IN THE LENSES OF ELECTRON BEAM INSTRUMENTS

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This invention relates to electron microscopes and particularly to electromagnetic means known as stigmators for correcting certain electron-optical deficiencies in the lenses of electron microscopes and other electron beam instruments.

In electron beam instruments such as electron microscopes, it is essential that the lenses which focus the electron beam be as nearly rotationally symmetric as is possible in order to reduce aberrations in the image formed, particularly spherical aberration. Of all of the lenses in a microscope the most critical is the objective lens which is closest to the object to be studied. The present invention comprises an arrangement of a plurality of coils spaced around an electron lens area in an electron beam instrument and connected together by a circuit which permits controlled currents to be directed through the coils in order to produce desired correctional electromagnetic fields located as nearly to the lens area as possible.

The invention will be discussed in greater detail in connection with the drawing in which:

FIG. 1 is a cross-sectional side view of an electron microscope including two of the aberration-correcting coils of a stigmator constructed according to the present invention;

FIG. 2 is an enlarged view of the coils in FIG. 1; and

FIG. 3 shows an electrical circuit in which the coils of FIGS. 1 and 2 are connected.

The microscope in FIG. 1 is indicated by reference character 11 and comprises at one end an electron source 12 which may be of conventional nature. Electrons from the source 12 emerge in a beam which travels along an axis 13 under the force of attraction of an anode 14 which is connected to the positive terminal of a power supply (not shown) the negative terminal of which is connected to the source 12. As described in my copending patent application entitled "Column for Electron Microscopes" and filed concurrently herewith, the magnitude of the voltage difference between the source 12 and the anode 14 is of the order of about 5,000 volts to about 50,000 volts, which is smaller than has generally thought to be desirable hereinbefore but which I have found to permit greatly increased contrast ratios to be obtained in the image in comparison with the contrast ratios of previous microscopes.

The electron beam passes through a central aperture 16 in the anode 14 and then enters the lens region 17 of an electromagnetic condensing lens comprising a coil of wire 18 and a ferromagnetic structure that shapes the electromagnetic field in the region 17. This ferromagnetic structure consists of an annular disc 19 terminating at its outer periphery in a cylindrical wall 21 and at its inner perimeter in a smaller cylinder 22. Both of these cylinders are of ferromagnetically soft material and the latter cylinder is provided with a somewhat conically shaped, inwardly extending, apertured end 23. A second annular disc 24 having an annular inset disc 25, both of the latter discs being of ferromagnetically soft material, joins the end of the cylinder 21 to form a part of the low reluctance flux path that shapes the field in the lens region 17.

The annular disc 24 also serves as a part of the structure for holding an object to be studied. The object is

placed in a specimen support rod 26 and specifically on a specimen support surface 27 located in an aperture 28 through the rod so as to be struck by electrons of the beam travelling along the axis 13, as described in greater detail in my co-pending patent application entitled "Specimen Holder" and filed concurrently herewith.

Immediately after passing through the object on the specimen support surface 27 the electron beam enters the region 29 of a focusing lens which is commonly known as an objective lens. The objective lens comprises a magnetic coil 30 and certain ferromagnetically soft members substantially surrounding the coil 30 except for a small gap in the lens region 29. These members include the annular disc 24 and a cylindrical extension 31 thereof, together with another small inset annular disc 32, another large annular disc 33, and a hollow cylinder 34. The latter cylinder is provided with a frusto-conical end 36 having a central aperture coaxial with the axis 13 and so shaped that the edges of the end 36 cooperate with the inwardly directed edges of the disc 32 to define the shape of the electromagnetic objective lens field in the region 29. The hollow cylinder 34 has within it a plurality of hollow, ferromagnetically soft cylinders 37, 38 and 39, each of which has a frusto-conical bore, the included angle of each bore in each of the latter cylinders being such as to remove the frusto-conical surface of each cylinder out of the line of sight of the specimen support surface 27. Between the cylinders 37 to 39 and the cylinder 34 is a nonmagnetic tube 40.

The delicate nature of the electron beam in the objective lens region 29 requires that means be provided to compensate for any anomalous electromagnetic effects in that region. Of course, great care must be used in constructing the parts described, particularly the ferromagnetic parts, but in addition I have found it desirable to provide stigmator coils arranged in a novel manner and in close proximity of the lens region 29. In particular, I have found that eight coils equally spaced around the region permit excellent correction and that these coils, when connected in accordance with this invention, facilitate making the electromagnetic field correction so that the time for arriving at a proper field correction is greatly reduced over what has been the practice heretofore.

Only two of the coils indicated by reference characters 41 and 42 are shown in the drawing. Each of these coils comprises several hundred turns, for example 400 turns of exceedingly fine wire wound on a mandrel of small dimensions, for example approximately 2 mm. in diameter and 2 mm. in length. Each of the coils is provided with a slender ferromagnetically soft core, that of the coil 41 being indicated by reference character 43 and that of the coil 42 being indicated by reference character 44. The stigmator coils are securedly held within a non-magnetic structure 46, which serves also as a spacer between the ferromagnetic disc 25 and the conical end 36 to fix the location of the objective lens region 29. The structure 46 is of thermally conductive material to carry away the heat produced by current flowing in the stigmator coils. Each of the eight coils may produce in the neighborhood of 3 watts of heat within a very small area, and in order to prevent destruction or excessive thermal expansion of the parts, this heat must be drained off efficiently. I have found that the structure 46 may be made of brass, and when so made has both the proper heat conduction and rigidity necessary for successful operation.

A magnifying electron lens region 47 is formed by a coil 48 and is shaped by a plurality of ferromagnetic members including a hollow, cylindrical extension 49 from the outer periphery of the disc 33, an inner hollow cylinder 51 from the inner perimeter of the disc 33, another annular disc 52 and a hollow cylinder 53 extending from the inner perimeter of the disc 52 toward the cyl-

inder 51. Both of the latter inner cylinders have frusto-conical, apertured ends facing each other to define the field region 47, the end of the cylinder 51 being identified by reference character 54 and the end of the cylinder 53 being identified by reference character 56. The cylinders 51 and 53 are spaced apart by a non-magnetic hollow cylinder 57.

A projection lens region 58 is formed by another coil 59 which, as in the case of the other lenses, is surrounded by ferromagnetically soft members and define the shape of the field region. These members include the annular disc 52, a cylindrical, hollow extension 61 from the periphery thereof, another annular disc 62 at the end of the cylinder 61 and three inner ferromagnetic cylinders along the center of the column of the microscope. The first of these cylinders is indicated by reference character 63 and is provided with a conical inner bore, the included angle of which is determined by the same law that governs the angles of the cylinders 37 to 39, except that the apex of the angle of the bore 63 lies between the end of that cylinder and the center of the lens region 47 which is nearest to it. The other two ferromagnetic members are cylinders 64 and 66 with facing, somewhat conical, apertured ends 67 and 68, respectively. These cylinders are spaced apart by a hollow, non-magnetic cylinder 71 to define the projection lens region 58.

Beyond the projection lens is a large chamber 72 within which may be placed a photographic film holder. At the end of the chamber 72 directly on the axis 13 is a viewing window 73, which is described in detail in my co-pending patent application entitled "Viewing Window for Electron-Optical Devices" and filed concurrently herewith. The window has a concave inner surface 74 to which a thin layer 76 of fluroescent material is applied in order to transform the electron beam image into a light image. The window is held in place by a clamping ring 77 and is sealed by gaskets 78 to 80.

The whole assembly is aligned and clamped together by one or more bolts 81 and by a hollow pipe 82 which connects the chamber 72 to an evacuating channel 83. The latter is also connected to a channel 84 in the base region of the microscope to permit rapid evacuation of the microscope from both ends of the column.

FIG. 2 shows a cross-sectional view of an enlarged fragment of FIG. 1 with the objective lens region 29 and the various parts of the microscope in the immediate vicinity of this lens region. As may be seen, the member 46 serves not only to hold the coils 41 and 42 but also as a spacer between the ferro-magnetic disc 32 and the conical end portion 36 of the hollow cylinder 34. Thus, the spacing between the latter two elements is rigidly fixed and does not vary with any vibration to which the microscope may be subjected.

Although only two of the coils 41 and 42 are shown, I have found it desirable to provide more than two coils and to divide them up into diametrically opposite pairs to control the electromagnetic field produced by them in the lens region 29. The coils 41 and 42 would constitute one such pair and at right angles to this pair I have found it desirable to provide another pair of similar coils similarly inserted into recesses in the member 46. The ferromagnetically soft, slender cores, such as cores 43 and 44, with which each of the coils is provided, are all aimed at a common point on the axis 13 and all make an equal acute angle with respect to this axis. For the best results I have found it desirable to provide eight such coils equally spaced apart around the axis 13.

FIG. 3 shows an electrical circuit for connection of the eight coils. Coils 41 and 42 are shown as being diametrically opposed to each other as they are in FIGS. 1 and 2. Midway between these two coils are two other coils 86 and 87. These four coils are connected electrically in series and in such fashion that when the same electrical current passes through the four of them, the ends of the coils 41 and 42 closer to the center of the circle of coils

become magnetically polarized with one polarity and the corresponding ends of the coils 86 and 87 become magnetically polarized with the opposite polarity. As a result, the electron beam passing through the center of the space between the proximal ends of the coils is subjected to astigmatic distortion but this distortion is actually controlled so as to correct astigmatic distortion that already exists in the other elements making up the electron lens in the region 29. In order to produce the electrical current to traverse the four coils connected electrically in series, an electric current source 88 having a centertap 89 is used. The centertap 89 is connected to one end of the series circuit and a potentiometer 91 is connected across the end terminals of the source 88. By connecting the other end of the series circuit to the movable arm 92 of the potentiometer, electrical current of varying magnitudes may be forced to flow through the series circuit in either direction, depending upon whether the arm 92 is on one side or the other of the center point of the potentiometer 91 and how far the arm is removed from this center point. Thus, while the letters N and S have been applied to the four coils 41, 42 and 86, 87, it is to be understood that these magnetic polarities exist only when the arm 92 is on one side of the center point of the potentiometer and that when the arm is on the opposite side the letters S and N will be reversed.

I have found it desirable to provide two such series circuits, the second being made up of coils 93 to 96. One end of the second series circuit is connected to the centertap 89 of the current source, and the other end of the second series circuit is connected to the movable arm 98 of a potentiometer 99 which is connected directly in parallel with the potentiometer 91 across the end terminals of the current source 88. This second series circuit is independent of the first series circuit, but by using the two circuits together it is a simple matter to correct the astigmatism in the objective lens region 29 within a matter of twenty seconds, or thereabouts, which permits the astigmatism of the image to be corrected for each image without taking up an excessive amount of time.

While this invention has been described in terms of a specific embodiment and in particular as the correction is applied to the objective lens of a microscope, it is to be understood that modifications are possible within the true scope of the invention as defined by the following claims and, in particular, but without limitation thereto, the correctional features may be applied to other lenses of the microscope.

What is claimed is:

1. A structure for defining and correcting an electron lens field, said structure comprising: a first ferromagnetic member having an aperture on an axis; a second ferromagnetic member having an aperture aligned with the aperture in said first member and spaced from said first member along said axis; means for oppositely magnetically polarizing said first and second ferromagnetic members; a heat conductive spacer member located in the space between said first and second ferromagnetic members and in contact therewith and having an aperture aligned with the apertures in said first and second ferromagnetic members; and a plurality of coils held within said heat conductive spacer member and in heat conductive relationship therewith to supply correctional electromagnetic fields to the space between said first and second ferromagnetic member along said axis.

2. The structure of claim 1 in which said coils are uniformly distributed around said axis.

3. The device of claim 2 in which there are at least two pairs of coils connected electrically in series to conduct the same electrical current and polarized so that the two diametrically opposite coils of each pair are similarly polarized to produce flux of the same magnetic polarity in the region of said axis, and the two coils of the second pair, physically displaced by 90° from the first pair, pro-

duce flux of the opposite magnetic polarity from the first pair in the region of said axis.

4. The structure of claim 2 in which each of said coils is provided with a slender central core of ferromagnetically soft material pointed toward said axis.

5. The structure of claim 4 in which all of said central cores point toward a common point on said axis and make an acute angle with said axis.

6. A structure for defining and correcting an electron lens field, said structure comprising: a first ferromagnetic member having an aperture on an electron beam axis; a second ferromagnetic member having a frusto-conical end with an aperture therein aligned with the aperture in said first member and spaced from said first member along said axis; means for oppositely magnetically polarizing said first and second magnetic members; a non-ferromagnetic metallic spacer member located in the space between said first and second ferromagnetic members and in contact therewith and having an aperture aligned with the apertures in said first and second ferromagnetic members; eight coils located in recesses in said metallic member and in heat conductive relationship with said metallic members, said recesses being equally spaced around the aperture therein; a slender central core of ferromagnetically soft material extending through each of said coils, all of said cores pointing to a common point on said axis and making equal acute angles with respect to said axis; a first series electrical circuit comprising alternate ones of said coils, said alternate coils being divided into two pairs of diametrically opposite coils and connected so that each of the coils of a diametrically opposite pair produces magnetic flux of the same polarity when current flows through the coil, and the flux produced by one pair of diametrically opposite coils is opposite to the flux produced by the other pair of diametrically opposite coils at right angles to the first-named pair; a second series circuit comprising the remaining coils divided into two opposite pairs and connected so that each of said last-named opposite pairs produces magnetic flux of the same polarity on said axis and flux of the opposite magnetic polarity from that produced by a diametrically opposite pair of coils at right angles thereto; a source of direct current having a centertap; a direct connection from said centertap to one end of each of said series circuits; a pair of potentiometers connected in parallel across the end terminals of said source of current; a direct connection from the movable tap of one of said potentiometers to the other end of one of said series circuits; and a direct connection from the movable tap of the other of said potentiometers to the other end of said second series circuit.

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