United States Patent [19]

Hirata

[11] **3,749,964**

[45] **July 31, 1973**

[54] **ELECTRON BEAM DEVICE**

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[73] Assignee: **Nihon Denshi Kabushiki Kaisha**, Akishima, Tokyo, Japan

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[21] Appl. No.: **101,613**

[30] **Foreign Application Priority Data**

Dec. 25, 1969 Japan 44/104540

[52] **U.S. Cl.** .... **315/18**, 250/49.5 A, 313/76, 315/27 TD

[51] **Int. Cl.** **H01j 29/76**

[58] **Field of Search** .... 315/18, 27 TD; 313/75, 76; 250/49.5 A

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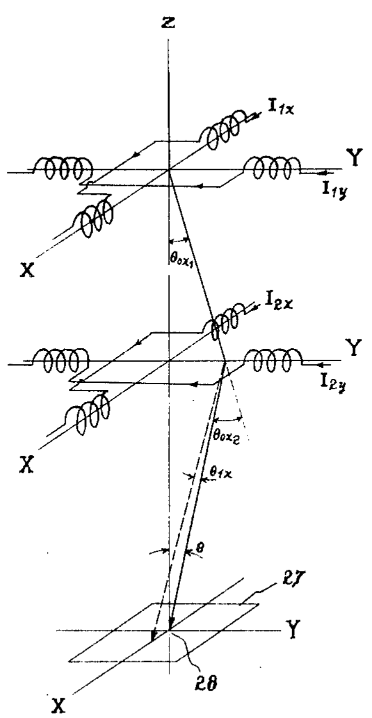
Primary Examiner—Carl D. Quarforth
Assistant Examiner—E. E. Lehmann
Attorney—Webb, Burden Robinson & Webb

[57] **ABSTRACT**

An electron beam deflecting apparatus incorporating two deflecting stages, each of said deflecting stages being provided with two pairs of deflecting coils for generating two directional magnetic fields, the said fields being at right angles to each other and perpendicular to the optical axis. The electron beam deflecting apparatus also incorporates a circuit for supplying current for deflecting the electron beam, the said current supply circuit being sufficient to supply the total current required for independently actuating the individual coils constituting the two deflecting stages.

3 Claims, 9 Drawing Figures



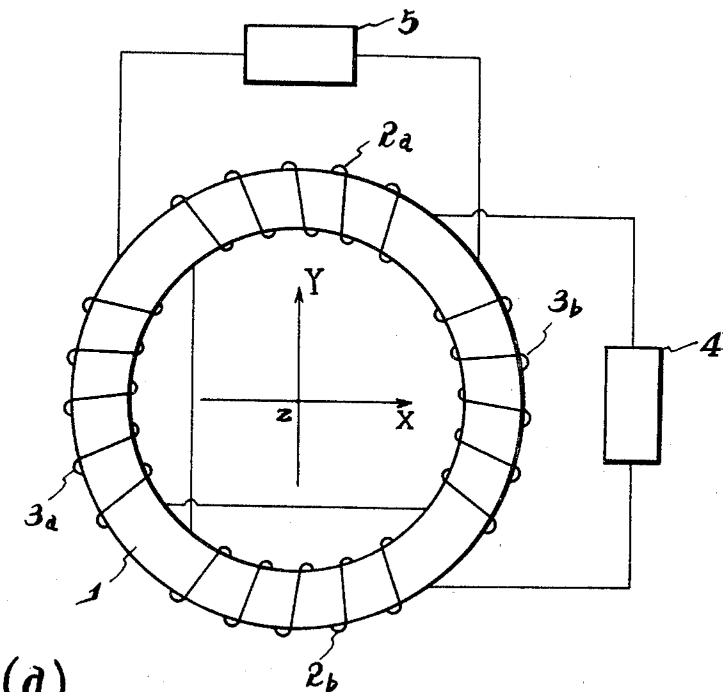


Fig. 1(a)

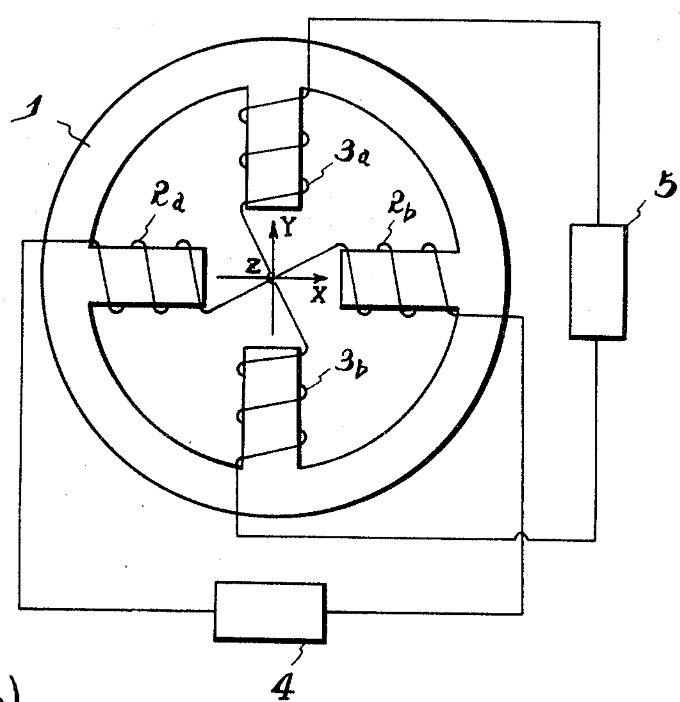
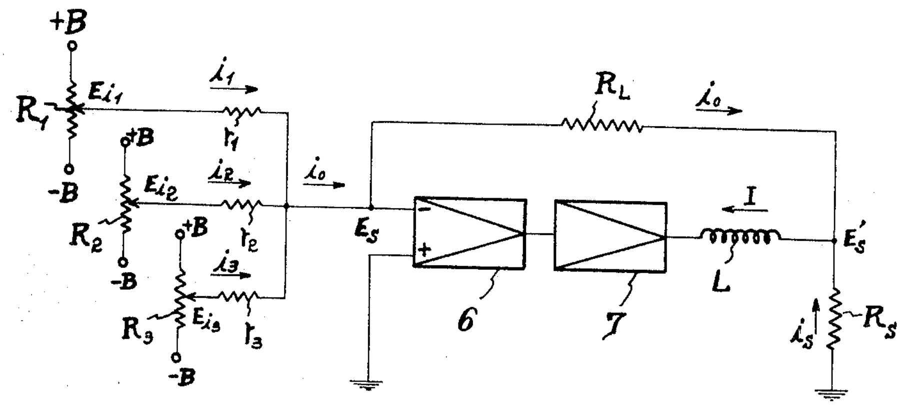


Fig. 1(b)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R_1
-B
+B
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R_2
-B
+B
R_3
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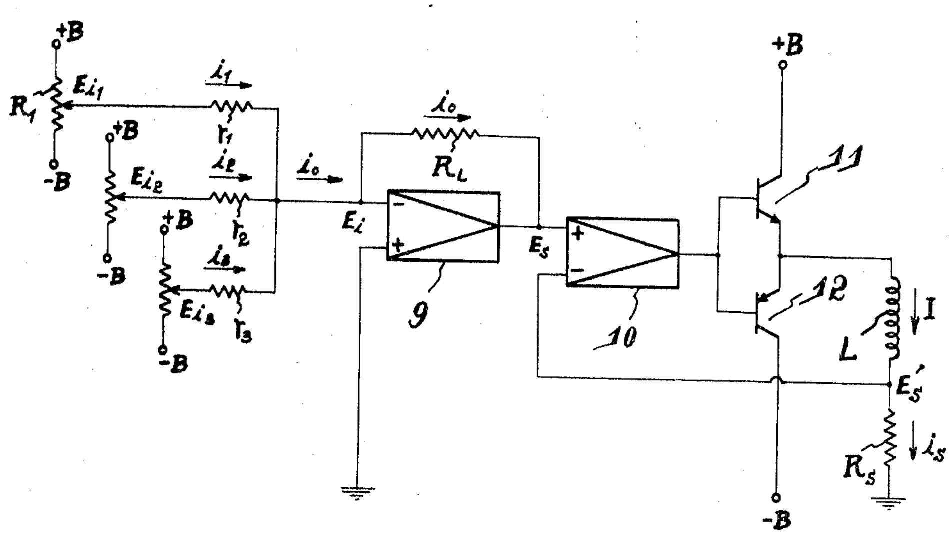
-B
i_1
r_1
i_2
r_2
i_3
r_3
i_o
E_S
R_L
i_o
I
L
E_S'
i_S
R_S
6
7

Fig. 2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-B
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E_{i_3}
-B
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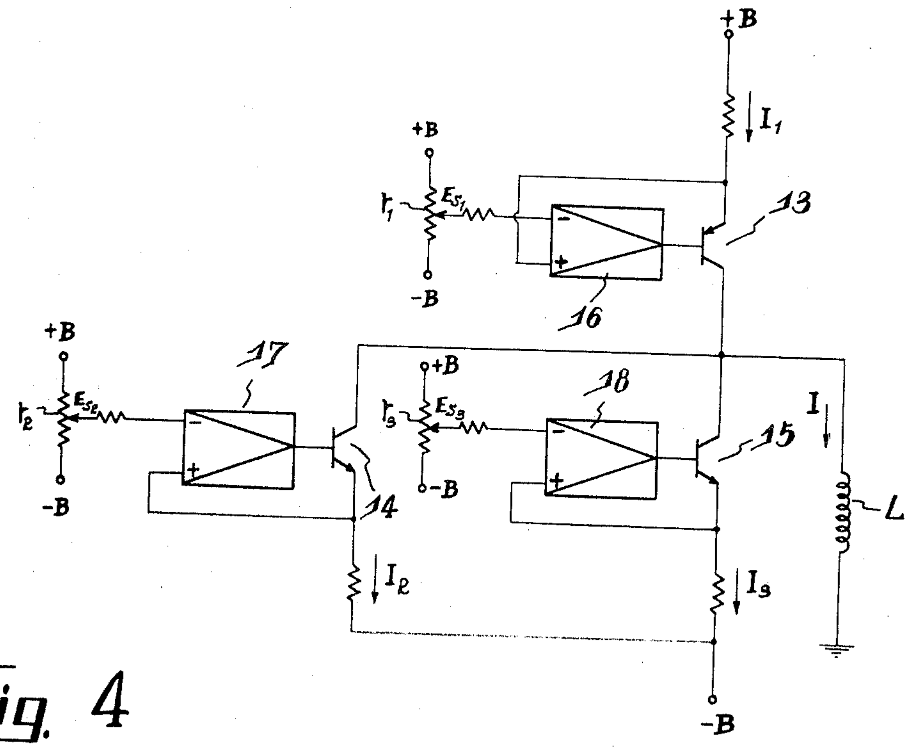
i_2
r_2
i_3
r_3
i_o
i_o
R_L
E_i
E_S
9
10
+B
11
12
L
I
E_S'
R_S
i_S
-B

Fig. 3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13
16
17
18
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L
I_2
I_3
-B

Fig. 4

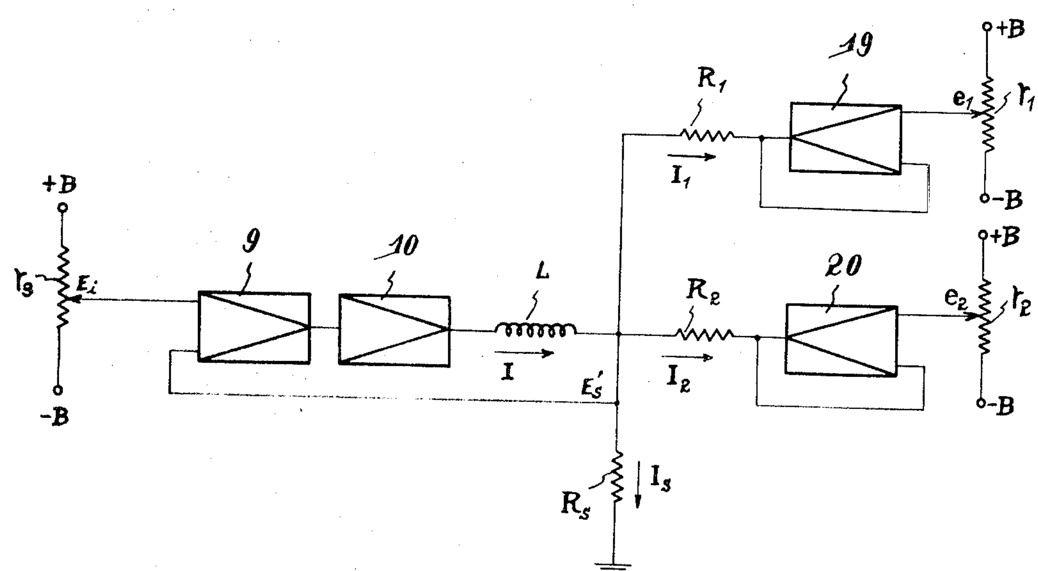

19
20
9
10
L
I
R_1
R_2
I_1
I_2
R_s
I_s
e_1
e_2
E_i
+B
-B

Fig. 5

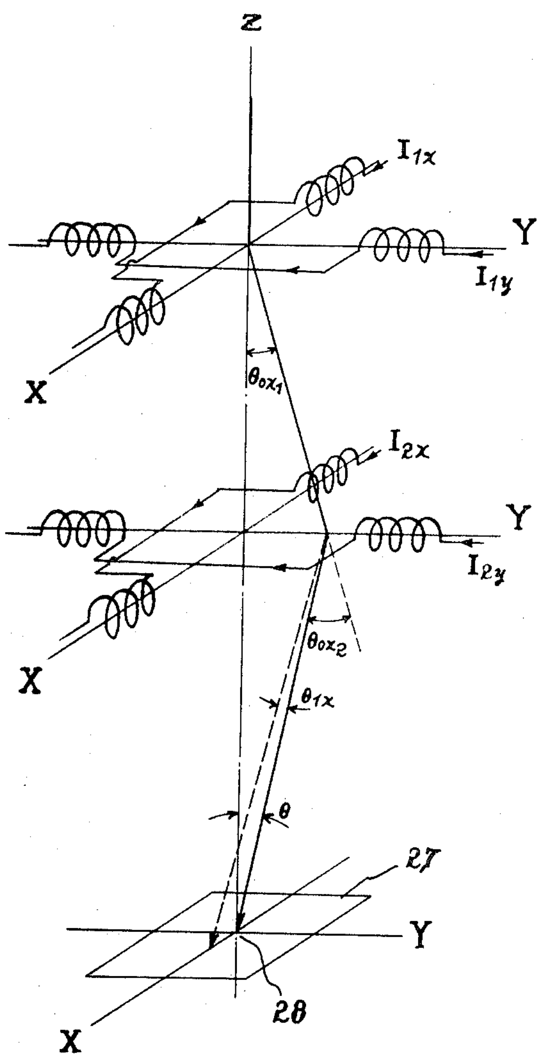

z
I_{1x}
Y
I_{1y}
X
θ_{ox_1}
I_{2x}
Y
I_{2y}
X
θ_{ox_2}
θ_{1x}
θ
27
Y
28
X

Fig. 6

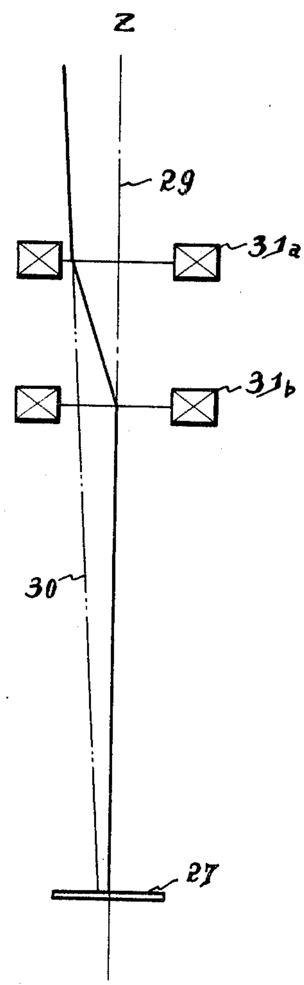
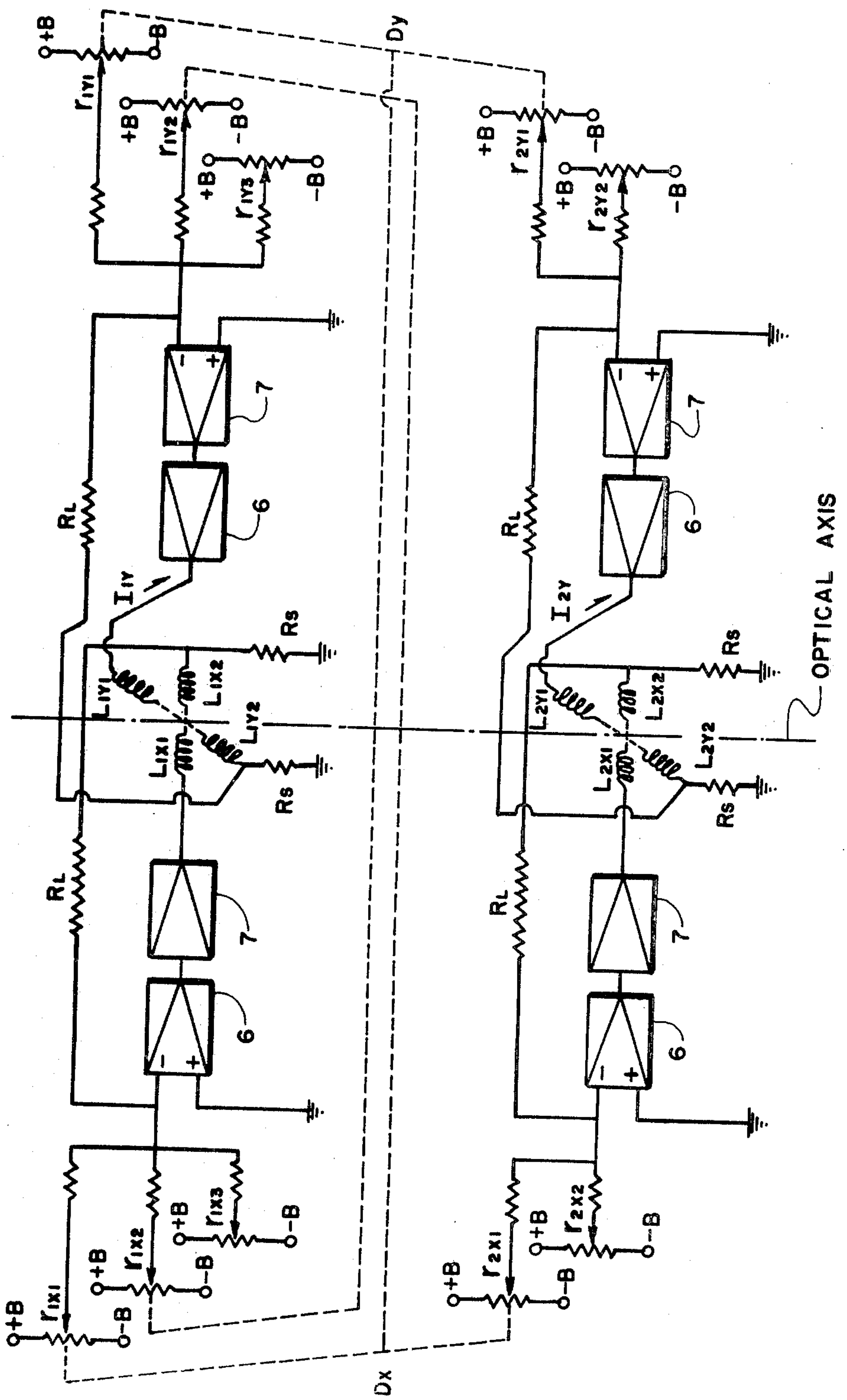

z
29
31a
31b
30
27

Fig. 7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-B
r1Y1
r1Y2
r1Y3
r2Y1
r2Y2
r1X1
r1X2
r1X3
r2X1
r2X2
RL
Rs
I1Y
I2Y
L1Y1
L1X2
L1X1
L1Y2
L2Y1
L2X2
L2X1
L2Y2
6
7
Dy
Dx
OPTICAL AXIS

Fig. 8

ELECTRON BEAM DEVICE

In order to observe a dark field image and an electron diffraction pattern by means of an electron microscope, it is necessary to irradiate the specimen with the electron beam at various angles of inclination or azimuth. To this end, electron beam deflecting devices incorporating two deflecting stages, each stage being provided with two pairs of deflecting coils have been used. Further, in this arrangement, the respective magnetic fields produced by each pair of coils are perpendicular to the optical axis and at right angles to each other. Utilizing this electron beam deflecting apparatus, the electron beam generated by the electron beam gun is deflected through an angle α by the first electron deflecting stage and through an angle β, which is proportional and opposite to α, by the second electron deflecting stage. The specimen is thus irradiated at an inclination equal to the difference between angles α and β. It should be noted that tan α is proportional to tan β. However, in a conventional electron microscope, since both angles α and β are very small, the angles themselves are substantially proportional.

A drawback of this arrangement, however, is the difficulty in producing coils whose magnetic fields are exactly at right angles to each other and deflecting stages which are accurately parallel with respect to each other. As a result, it is extremely difficult during specimen observation to prevent the irradiation spot from shifting. One attempt to overcome the above defect is described, for example, in German Pat. specification (Auslegeschrift) 1,299,088 where additional deflecting coils have been incorporated as compensators in the deflecting stages. Operation of this apparatus is facilitated by controlling the deflecting current of the compensation coils in accordance with the deflecting current of the regular coils. However, in this arrangement, as a result of resorting to the provision of additional coils in order to surmount the original defect, secondary defects have ensued. These are mainly in connection with the increased size of the deflecting stages, plFs the added difficulty of manufacturing this more complicated deflecting means with sufficiently precision orientation. In short, the above embodiment is feasible in theory but not in practice.

It is an advantage of electron beam deflection devices according to this invention that they overcome the shortcomings inherent in conventional apparatus and at the same time are easy to manufacture. Further, they are easy to operate, whereby the deflection current is automatically controlled, in accordance with the variable incident angle, so as to fix the position irradiated by the electron beam. Still further, the present invention provides a deflecting device which facilitates comparison of the dark field image and bright field image in the same area of an elcectron miscroscope specimen.

The full advantage and novelty of the present invention will be more readily understood by reading the following detailed description in connection with the appended drawings wherein:

FIG. 1*a* and FIG. 1*b* are diagrammatic views of the deflecting stages in accordance with the conventional apparatus;

FIGS. 2,3,4 and 5 are block schematics showing the deflecting current supply according to the present invention;

FIG. 6 is an explanatory diagram of the irradiating electron beam path in the deflecting apparatus according to the present invention;

FIG. 7 is a diagram ilustrating alignment of the irradiating electron beam by the deflecting apparatus; and,

FIG. 8 is a schematic diagram showing a preferred circuit incorporating the elements shown in FIGS. 2 and 6 for controlling the beam deflection of an electron microscope.

Referring to FIGS. 1*a* and 1*b* (showing different but analogous embodiments of this invention), four coils 2*a*, 2*b*, 3*a* and 3*b* are wound onto a core 1 whose center axis Z aligns with the optical axis. Coils 2*a* and 2*b* generate a magnetic field in the direction of the x-axis and coils 3*a* and 3*b* generate a magnetic field in the direction of the *y*-axis.

FIG. 2 is a circuit diagram of the deflecting current supply according to this invention. Coil L through which current I flows represents any one of the coils 2*a*, 2*b*, 3*a* and 3*b* shown in FIG. 1. Current I is equal to the sum of the current i_s flowing through resistor Rs and the current i_o flowing through resistor R_L. However, since i_o is normally quite negligible, current I is substantially equal to i_s.

Current i_o is equal to the sum of the currents i_1, i_2, and i_3, flowing through resistors r_1, r_2, and r_3, respectively. By means of the operational or differential amplifiers 6 and 7 (power supplies not shown for simplicity) the following relationships were established:

$$I \approx i_s = E's/R_s \tag{1}$$

$$E's = - R_L \cdot i_o \tag{2}$$

Hence,

$$\begin{aligned} I &= -(R_L/R_s) \cdot i_o \\ &= - (R_L/R_s) \cdot i_1 - R_L/R_s \cdot i_2 - R_L/R_s \cdot i_3 \\ &= - (R_L \cdot Ei_1/R_s) \cdot (1/r_2) - (R_L \cdot Ei_2/R_s) \cdot (1/r_2) - (R_L \cdot Ei_3/R_s) \cdot (1/r_3) \end{aligned} \tag{3}$$

It is apparent from equation (3) that the deflecting current I is independently determined by the variable resistors R_1, R_2, and R_3.

FIG. 3 shows another embodiment of the deflecting current supply incorporating two current control transistors 11 and 12. Here, the input voltage E*i* of the operational or differential amplifier 9 is substantially equal to voltage E'*s*. Accordingly, the following relationships were established:

$$I = i_s = E's/R_s = Es/R_s \tag{4}$$

$$Es = - R_L \cdot i_o \tag{5}$$

Now, since current i_o, is equal to the sum of the currents i_1, i_2, and i_3, flowing through resistors r_1, r_2, and r_3, respectively, the following relationship is established:

$$I = -(R_L/R_s) \cdot i_o$$
$$= -(R_L/R_s)\, i_1 \cdot (R_L/Rs)\, i_2 - (R_L/Rs)\, i_3$$
$$= -(R_L \cdot Ei_1/R_S) \cdot (1/r_1) - (R_L \cdot Ei_2/R_s) \cdot (1/r_2) - (R_L \cdot Ei_3/R_s) \cdot (1/r_3) \text{ ta} \quad (6)$$

It is thus apparent from equation (6) that the circuit described in FIG. 3 can substitute for that described in FIG. 2.

FIG. 4 shows yet another embodiment of the deflecting current supply this time incorporating three current control resistors **13, 14** and **15.** Here, currents I_1, I_2, and I_3 flowing through transistors **13, 14** and **15** respectively, produce current I flowing through coil L. Expressed algebraically:

$$I = I_1 - I_2 - I_3 \quad (7)$$

Thus, by controlling input voltages Es_1, Es_2 and Es_3 of the operational or differential amplifiers **16, 17** and **18,** the deflecting current I can be controlled in the same way as in FIG. 2.

FIG. 5 shows a further embodiment of the deflecting current supply incorporating operational or differential amplifiers **19** and **20.** Here current I_1 and I_2, flowing through resistors R_1 and R_2, respectively, produce current I flowing through coil L, expressed algebraically, equation (7) can be expressed as:

$$I = Ei \cdot [1/Rs) + (1/R_1) + (1/R_2)] - (e_1/R_1) - (e_2/R_2) \quad (8)$$

Thus, by controlling variable resistors r_1, r_2 and r_3, voltages Ei, e_1 and e_2 are controlled thereby determining the deflecting current I the same way as in FIG. **2.**

In the case of the deflecting current supplies described with reference to FIGS. **2** to **5,** there are three independent currents. This number, however, can be easily increased or decreased as required.

The method of deflecting an irradiating electron beam by means of the deflecting apparatus as described in the aforegoing will be apparent in the following.

Referring to FIGS. **6** and **8,** the deflecting current I_1 x for generating the magnetic field in the x-axis direction in the first deflecting stage is expressed as follows:

$$I_1\, x = i_1\, x_1 + i_1\, x_2 + i_1\, x_3 \quad (9)$$

Similarly, the deflecting current $I_1\, y$ for generating the magnetic field in the y-axis direction in the first deflecting stage, the deflecting current $I_2\, x$ for generating the magnetic field in the x-axis direction in the second deflecting stage, and the deflecting current $I_2\, y$ for generating the magnetic field in the y-axis direction in the second deflecting stage are expressed as follows:

$$I_1\, y = i_1\, y_1 + i_1\, y_2 + i_1\, y_3 \quad (10)$$

$$I_2\, x = i_2\, x_1 + i_2\, x_2 \quad (11)$$

$$I_2\, Y = i_2\, Y_1 + i_2\, Y_2 \quad (12)$$

In the conventional type deflecting apparatus as used with an electron microscope, the irradiating electron beam is deflected in the amount θox**1** by the first deflecting stage and is the amount θox**2** by the second deflecting stage, so as to irradiate a point **28** where the optical axis intersects the plane of specimen **27.** By so doing, the irradiation angle θ is controlled. However, since the magnetic field generated by the first deflecting stage in the x-axis direction and the magnetic field generated by the second deflecting stage in the x-axis direction are not absolutely parallel, a component of the magnetic field in the y-axis direction is inadvertently generated, resulting in the irradiating electron beam being deflected in the amount θ_1x in the said direction. Such being the case, it is extremely difficult to prevent the irradiation spot from shifting without the aid of either one or both y-axis magnetic fields to act as shift compensators.

Since θox_1, θox_2, θ_1x and θ are proportional to each other, it is possible to determine the proportional coefficient existing between θox_1, θox_2 and θ_1x and that existing between $i_1\, x_1$, $i_2\, x_1$ and $i_1\, y_2$. The deflecting current supply circuit is designed to satisfy the relation between $i_1\, x_1$, $i_2\, x_1$ and $i_1\, y_2$ by, for example, interlocking variable resistors r_1, r_2 and r_3 in FIG. **2.**

By designing the deflecting current supply circuit as described above, the irradiating electron beam in the x-axis direction is fully controlled. Similarly, by controlling i_1, y_1, $i_2\, y_1$ and $i_1\, x_2$, the irradiating electron beam in the y-axis direction is also fully controlled. As a result, the irradiating electron beam in any azimuth is fully controlled.

Referring to FIG. **8,** in order to control the deflecting current component $i_1\, x_1$, it is necessary to control variable resistor $r_1\, x_1$. Similarly, to control $i_2\, x_1$, it is necessary to control $r_2\, x_1$, and to control $i_1\, y_2$, $r_1\, y_2$ must be controlled.

The deflecting angle θox_1 as shown in FIG. **6** is controlled by $i_1\, x_1$ in turn controlled by $r_1\, x_1$. Similarlyy, θox_2 and θ_1x are controlled by $i_2\, x_1$ and $i_1\, y_2$ respectively, in turn controlled by r_2x_1 and $r_1\, y_2$ respectively.

A plurality of individually adjustable potentiometers provides current to the individual deflection coils because $r_1\, x_1$, $r_2\, x_1$ and $r_1\, y_2$ (interlocked to form control Dx) must be controlled proportionally, in order to satisfy the proportionally of θox_1, θox_2, θ_1x and θ whose said proportionality is necessary to prevent the irradiation spot from shifting.

Similarly, $r_1\, y_1$, $r_2\, y_1$, and $r_1\, x_2$ (interlocked to form control Dy) are used to deflect the irradiation electron beam in the y-axis direction.

Variable resistors $r_1\, x_3$, $r_1\, y_3$, $r_2\, x_2$ and $r_2\, y_2$ are utilized to control the alignment deflecting current. Normally, these four resistors are controlled individually.

Thus far, it has been assumed that the irradiating electron beam aligns with the optical axis. If not, the beam must be either aligned mechanically by shifting the position of the electron beam generator or deflected electromagnetically. In the case of the latter, two deflecting stages are necessary.

Referring to FIG. **7,** the irradiating electron beam is deflected by the first deflecting stages **31**a so as to intersect the cross point between the optical axis and the second deflecting stages **31***b*. It is then further deflected by **31***b* so as to align with the optical axis.

In order to effect the above alignment, the conventional deflecting apparatus requires additional deflecting coils. This is not so in the deflecting apparatus according to this invention, the deflecting currents $i_1\ x_3$, $i_1\ y_3$, $i_2\ x_2$ and $i_2\ y_2$ refer to equations (9), (10), (11) and (12) being used in lieu.

In order to observe a bright field image with the apparatus according to this invention, the deflecting current i_1x_1, $i_1\ x_2$, $I\ y_2$, $i_1\ y_1$, $i_2\ x_1$ and $i_2\ y_1$ are set to zero and the deflecting currents $i_1\ x_3$, $i_1\ y_3$, $i_2\ x_2$ and $i_2\ y_2$ are used for alignment purposes. Again, in order to observe a dark field image, the deflecting currents $i_1\ x_3$, $i_1\ y_3$, i_2x_2 and $i_2\ y_2$ are used for alignment purposes and the deflecting currents $i_1\ x_1$, $i_1\ x_2$, $i_1\ y_1$, $i_1\ y_2$, $i_2\ x_1$ and $i_2\ y_1$ are used for controlling the inclination of the irradiating electron beam. irradiating electron beam.

Accordingly, by incorporating deflecting current changeover switches, comparison of the bright and dark field images with the same areas of the specimen will be appreciably facilitated.

Sometimes, an electron deflecting apparatus incorporating only one deflecting stage is used for alignment. In such cases, it is possible to facilitate alignment by incorporating the deflecting current supply according to this invention since the two directional magnetic fields can be accurately orientated at right angles to each other by supplying compensating curent to one of the two deflecting coils for generating the said two directional magnetic fields by the said deflecting current supply.

Having thus described my invention with the detail and particularity as required by the Patent Laws, what is desired protected by Letters Patent is set forth in the following claims.

I claim:

1. In an electron microscope or the like having an electron optical axis, an apparatus for deflecting an electron beam to irradiate a location on a specimen at different easily selectable azimuthal angles of incidence comprising:

A. a deflection stage being equipped with deflecting coils L_{1x} and L_{1y} for generating magnetic fields substantially at right angles to each other and perpendicular to the optical axis;

B. a second deflection stage being equipped with deflecting coils L_{2x} and L_{2y} for generating magnetic fields substantially at right angles to each other and perpendicular to the optical axis, said magnetic deflecting fields of said second stage being substantially aligned with the magnetic deflecting fields of the first stage;

C. a deflecting current supply for supplying individual coil currents I_{1x}, I_{1y}, I_{2x} and I_{2y} to each of said deflecting coils L_{1x}, L_{1y}, L_{2x} and L_{2y} respectively, said individual coil currents being the total of a plurality of individually variable analog currents, such that

$$I_{1x} = i_{1x1} + i_{1x2} + i_{1x3}$$
$$I_{1y} = i_{1y1} + i_{1y2} + i_{1y3}$$
$$I_{2x} = i_{2x1} + i_{2x2}$$
$$I_{2y} = i_{2y1} + i_{2y2}$$

means for varying simultaneously and proportionally at least some of the analog currents controlling coil current to both first and second stages, such that the means for controlling i_1, i_{2x1} and i_{1y2} are interconnected and means for controlling i_{1y1}, i_{2y1} and i_{1x2} are interconnected, such that the one deflection stage redirects the electron beam deflected by the other stage to the location on the specimen thus changing the azimuth angle of incidence without moving the location on the specimen on which the beam is incident notwithstanding slight misalignment of the deflection stages and slight deviation from right angles between the fields of the separate stages.

2. An apparatus according to claim **1** in which the i_{1x3}, i_{1y3}, i_{2x2} and i_{2y2} analog currents are used for aligning the irradiating beam.

3. In an electron microscope or the like having an electron optical axis an apparatus for deflecting an electron beam to irradiate a location on the specimen comprising:

A. a deflection stage equipped with deflecting coils L_{1x} and L_{1y} for generating magnetic fields, said fields being substantially at right angles to each other and perpendicular to the optical axis;

B. a deflecting current supply for supplying individual coil currents I_{1x} and I_{1y} to coils L_{1x} and L_{1y} respectively, said individual coil currents being the total of a plurality of individually controlled analog currents, such that $I_{1x} = i_{1x1} + i_{1x2}$ and $I_{1y} + i_{1y1} + i_{1y2}$ and means for varying the analog currents i_{1x1} and i_{1y1} to control coil currents and vary the deflection of the electron beam.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,749,964 Dated July 31, 1973

Inventor(X) Yoshihiro Hirata

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

In the equation in Column 3 Line 5 delete the letters --ta--. Column 5 Line 12 --1-- should read --i_1--. Claim 3 Column 6 Line 46 --$I_{1y}+$ -- should read --$I_{1y}=$ --.

Signed and sealed this 20th day of November 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

RENE D. TEGTMEYER
Acting Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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