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TADAO TAKIZAWA
ELECTRON BEAM APPARATUS HAVING COMPENSATING MEANS
FOR TRIANGULAR BEAM DISTORTION
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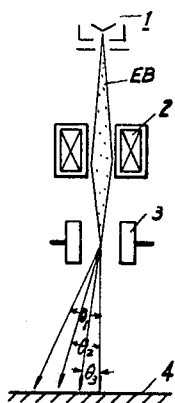


FIG. 1

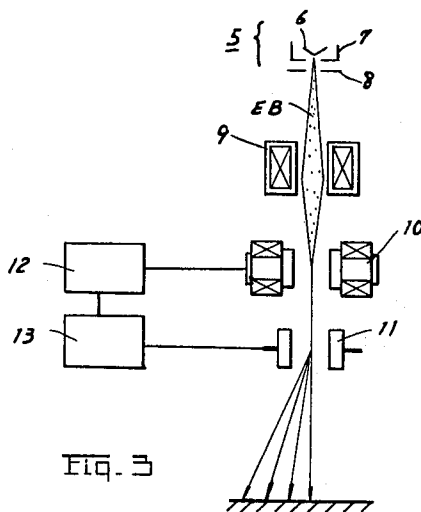


FIG. 3

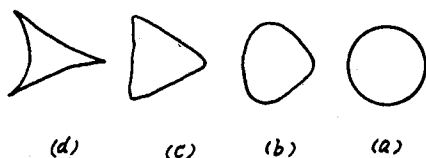


FIG. 2

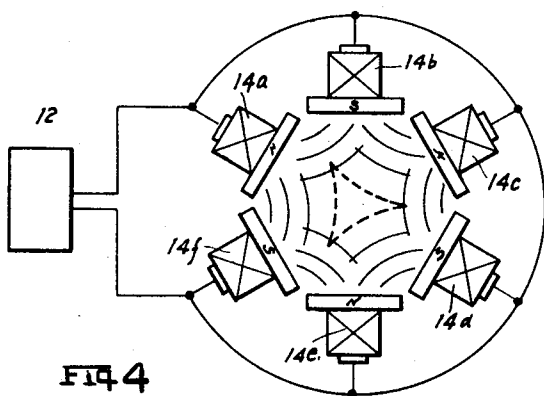


FIG. 4

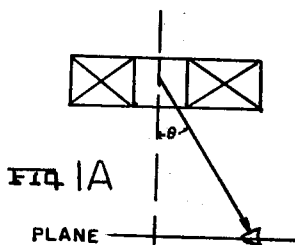


FIG. 1A

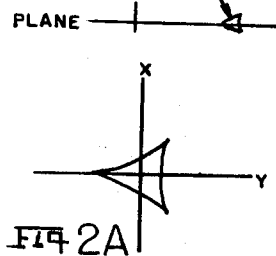


FIG. 2A

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ELECTRON BEAM APPARATUS HAVING COMPENSATING MEANS FOR TRIANGULAR BEAM DISTORTION

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4 Claims. (Cl. 250—49.5)

ABSTRACT OF THE DISCLOSURE

An apparatus for irradiating a workpiece with an electron beam having a beam source and means for focusing the beam and also having a magnetic deflection system and a compensator positioned between the deflection system and focusing means to compensate for triangular image distortion introduced by the deflection system.

This invention relates to an improved method and apparatus for treating a workpiece with a charged electron beam.

In the conventional electron beam apparatus, the beam is focused onto the surface of the workpiece by a magnetic lens and also passes through a magnetic deflection field which is a variable magnetic field that is disposed to cause the beam to bend so as to change its position along the workpiece surface. The problem generally arises that when an electron beam is deflected by such a field, it is undesirably distorted resulting in astigmatism and coma of the focused beam on the workpiece surface. The distorted image on the workpiece in general takes on a star-like pattern and accordingly the area of the image becomes larger and the energy density of the beam is lowered.

The above-mentioned aberrations seriously limit the use of charged electron beams for such applications as boring, milling, melding and welding.

The usual steps for eliminating such image distortion in conventional apparatus has been to position a slit member under the deflector. This practice provides a means for obtaining a circular beam spot on the surface of the material by eliminating the outer part of the distorted star-like pattern. However, by doing this, the energy density and the efficiency of the application are inevitably lowered.

The present invention provides a method and apparatus for making a circular beam spot or image on the surface of the material during magnetic deflection without lowering the energy density of the beam. Our apparatus is automatically controlled in conjunction with the deflector. Thus, our invention overcomes the difficulties of beam distortion.

Our invention completely eliminates beam aberration by a compensating device, such as is depicted by FIGURE 4 of the drawings.

In the drawings, I have illustrated a preferred embodiment of my invention in which:

FIGURE 1 is a schematic diagram showing the prin-

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ciples of electron beam deflection as accomplished by conventional means;

FIGURE 1A is a diagram showing a deflection lens deflecting an advancing electron beam and casting its image on a plane;

FIGURE 2 is an illustrative plan view of electron beam images from the device of FIGURE 1 as projected on a workpiece during four positions of the beam;

FIGURE 2A is an illustrative plan view of an electron beam image deflected onto an ordinate x and an abscissa y ;

FIGURE 3 is a schematic diagram similar to that of FIGURE 1 but showing the application of the apparatus of the present invention; and

FIGURE 4 is a plan view of a compensator device that embodies the principles of the present invention.

Referring to FIGURE 1, there is illustrated the principles of a conventional charged beam apparatus. The apparatus of FIGURE 1 is described in advance of a detailed description of the present invention so that the principles of operation of the present invention are more fully understood.

An electron beam EB is emitted from an electron gun 1 and is focused by a condenser lens 2, and then deflected by a deflector lens 3 prior to irradiating the workpiece 4 that is being treated. The said beam is controlled to a fixed angle with respect to the axis of the beam, such as angle θ_1 , θ_2 or θ_3 as shown by FIGURE 1. The angle of deflection is dependent upon the intensity of the magnetic field. The stronger the intensity of the magnetic field, the more the deflection angle of the beam will be.

Additionally, the image of the beam that is formed on the workpiece varies in its shape according to the angle of the beam or the intensity of the magnetic field posed by the deflection device.

In FIGURE 2, (a) shows the image when the beam irradiates the workpiece perpendicularly with respect to its surface. (b), (c), and (d) of FIGURE 2 show the images formed on the surface of the material or the workpiece when the beam is progressively deflected through angles, such as angles θ_1 , θ_2 and θ_3 . As the intensity of the deflection field increases, the image is gradually distorted and finally appears as a star-like pattern as shown by (d) of FIGURE 2.

In FIGURE 3, an electron gun 5 is shown which is identical to that conventionally employed. This gun is composed of a cathode 6, an anode 7, and a grid 8. The electron beam EB focused by the focusing lens 9 is affected by the magnetic field of a compensator 10 which is positioned between the focusing lens 9 and the deflector 11. This compensator is operated by means of an electric source 12, and the deflector is provided with an electric source 13.

The compensator is energized in accordance with the intensity of the electric current used in the deflector and is preset or adjusted so that it effects an electron beam image that is conversely symmetrical to the one formed by the deflector.

The value of the resistance to electric current flow in the compensator is adjusted so that current flow will not take place when the deflector has no effect on the advancing beam.

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FIGURE 4 illustrates a compensator which embodies the principle of the present invention in obtaining a conversely symmetrical image to the distorted image that is created by the deflection lens. In this embodiment, coils 14a, 14b, 14c, 14d, 14e and 14f are connected in series to an electric source 12 and are arranged symmetrically around the beam passage so that their respective polarities oppose one another. With this arrangement, a substantially triangular magnetic field is created (see dotted outline in FIG. 4) which is imposed by the magnetic interaction between the poles.

As shown above, magnetic deflection of the electron beam creates a substantially triangular shaped image. Accordingly, the compensator is constructed in such a manner that its magnetic influence shapes the electron beam so that it is conversely symmetrically triangular to the shape created by the deflector distortion. This results in a beam spot or image on the face of the material that is substantially circular shaped because of the two different influences of the deflector and the compensator lenses.

The beam image on the workpiece which is distorted when deflected by an ordinary deflector as shown in FIGURE 1A is illustrated in FIGURE 2A in conjunction with an ordinate x and an abscissa y . The junction of x and y intersects the nondistorted center point of the image. The respective relationship between a given deflection angle θ and x and y are illustrated by the following equation:

$$(1) \quad \begin{aligned} x &= f_1(\theta) \\ y &= f_2(\theta) \end{aligned}$$

where f_1 and f_2 are the abbreviations of function.

In greater detail, the above distortion relationships are given by the following general distortion formulae:

$$(2) \quad \begin{aligned} x &= \left\{ rs + \frac{q}{l}(rs - ro) + \frac{1}{2}\theta^2(rs - ro) \right\} \cos x + \frac{\theta l}{2b^2} r^2 o \sin 2X \\ y &= \theta l + \frac{1}{4}\theta^3 l + \left\{ rs + \frac{q}{l}(rs - ro) - \theta^2 \left(\frac{5}{2}ro - \frac{3}{2}rs \right) \right\} \sin X \\ &\quad + \frac{\theta l}{2b^2} r^2 o \cos 2x \end{aligned}$$

where:

ro = the beam radius on the principal plane of the deflector
 rs = the beam radius on the perpendicular plane
 l = the distance from the deflector's principal plane
 θ = the deflection angle
 q = defocusing, i.e., the distance in centimeters of the shifting of the focusing point by the deflection of the beam
 $2b$ = a half width along the z axis (the direction of the incident beam).

In my investigations, I presumed that distortion was caused by both elements of

$$\frac{\theta l}{2b^2} r^2 o \sin 2X$$

in the formula introduced by x and

$$\frac{\theta l}{2b^2} r^2 o \cos 2X$$

in the formula introduced by y .

When employing a cylindrically coordinated six-pole magnetic deflector such as that depicted by FIGURE 4, the following correlation is possible.

$$(3) \quad \psi(r_o, \theta_1) = Cr_o^3 \cos 3X$$

where r_o = the beam radius on the principal plane of the deflector, θ_1 = the angle between the point on the cross-section of the beam on the principal plane of the de-

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flector and the y axis, the cylindrical beam passing through is influenced as shown by the following ratio:

$$(4) \quad \begin{aligned} \Delta x &= -A \left(\frac{rs}{ls} \right)^2 \sin 2X \\ \Delta y &= -A \left(\frac{rs}{ls} \right)^2 \cos 2X \end{aligned}$$

where ls is distance from the six pole magnetic field to the image plane and A is a constant.

Accordingly, distortion for any given angle of deflection may be eliminated by selecting and properly determining the constant C in Formula 3 above. The constant C in actuality involves such factors as electric current and mechanical factors. However, if the mechanical factors are constant, then C is substantially proportional to the electric current.

The electric current flow to the compensator is not proportional to the electric current flow to the deflector. However, as shown above, a relationship exists between the electric current flow into the compensator and into the deflector.

Consequently, current flow into compensator 10 may be regulated by any conventional current flow apparatus such as a rheostat and a current flow established for any given current flow into deflector 11 to compensate for any given distortion for any given angle of deflection.

Thus, by employing our invention, the resulting electron beam image on the surface of the material is circular in shape or identical to the shape created when the beam is perpendicularly irradiated with respect to the surface of the material.

Although in the present invention the embodiment of FIGURE 4 shows a six-pole compensator utilized for compensating beam distortion, it is possible to employ a compensator having more than six poles and, additionally, it is possible to employ an electrostatic field in place of the magnetic fields and a combination of magnetic and electrostatic field can be used without changing the principles of the present invention.

The following data is typical of an operation of the above described apparatus:

- Accelerating voltage of the electron gun—25KV.
- Deflection angle of the beam in respect to the beam axis—30°.
- Current supplied to the deflector 11—0.018 ampere.
- Coil turns in the deflector 11—10,500.
- Number of poles of deflector 11—2.
- Current supplied to the compensator 10—0.3 ampere.
- Number of coil turns in compensator 10—150.
- Number of poles in compensator 10—6.

While I have described the presently preferred embodiments of my invention, it is to be understood that it may be otherwise embodied within the scope of the following claims.

- I claim:
1. An apparatus for irradiating the surface of a material with an electron beam comprising:
 - (a) an electron beam source;
 - (b) focus means for directing the beam onto the surface of the material;
 - (c) magnetic deflection means for subjecting the electron beam to magnetic influences to change the position of the beam on the material, said deflection means causing the beam to be distorted in a substantially triangular manner; and
 - (d) compensator means having at least six poles and positioned between the focus means and the deflection means, said poles shaping the beam in a complementary manner to the distortion created by the deflection means by means of at least one influencing factor selected from the group consisting of magnetic fields and electrostatic fields.
 2. An apparatus as set forth in claim 1 wherein said 75 poles influence said beam by means of a magnetic field

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and wherein said poles are arranged so that each opposite and adjacent pole is antipodal.

3. An apparatus as set forth in claim 1 wherein said poles influence said beam by means of an electrostatic field and wherein said poles are arranged so that each opposite and adjacent pole is antipodal.

4. An apparatus as set forth in claim 1 including means for supplying an electric current to the compensator means that is substantially proportional to the current supplied to the deflection means so that the compensator means will effect the field at substantially the correct strength to create the complementary influence.

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