# United States Patent

[11] 3,629,577

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[21] Appl. No. **859,791**
[22] Filed **Sept. 22, 1969**
[45] Patented **Dec. 21, 1971**
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[32] Priority **Sept. 23, 1968**
[33] **Germany**
[31] **P 17 89 019.6**

[54] **METHOD AND APPARATUS FOR PRODUCING A STEREO IMAGE BY ELECTRON MICROSCOPY**
**11 Claims, 3 Drawing Figs.**

[52] **U.S. Cl.** .......... **250/49.5 A,** 250/61
[51] **Int. Cl.** .......... **H01j 37/26**
[50] **Field of Search** .......... 250/49.5 R, 49.5 A, 49.5 B, 60, 61

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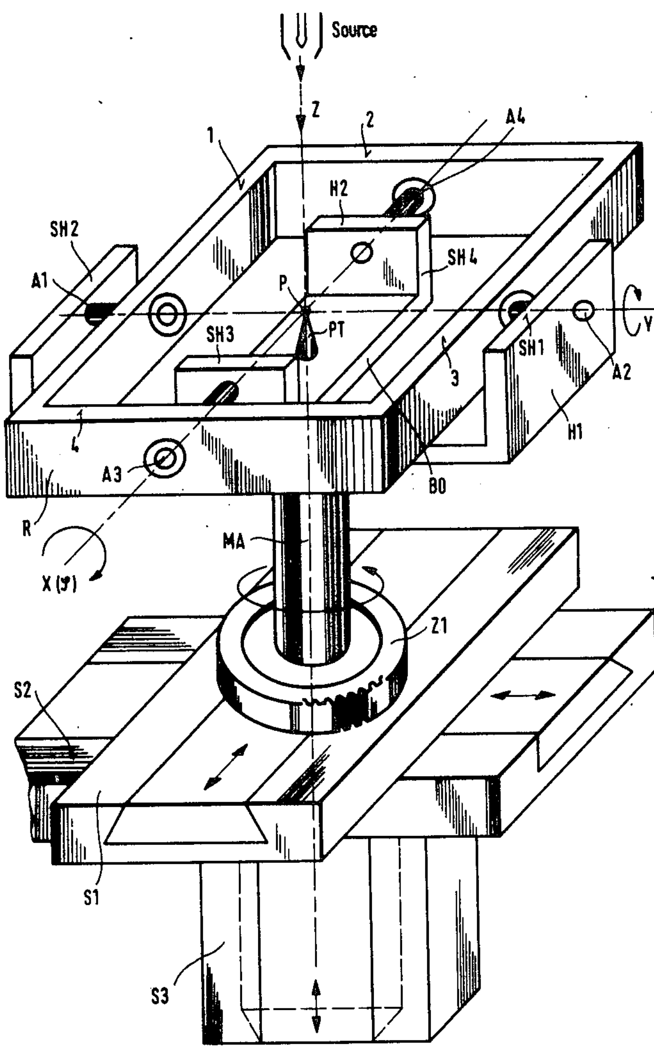
**ABSTRACT:** For producing a stereo image, for example of a crystalline object, by electron beam microscopy, any chosen surface area of the object is rotated about a central axis defined by the direction of the electron beam. The amount of rotation is such that after a subsequent tilting of the object about a second axis intersecting the central axis, the image intensity of the surface area is the same in the starting position as in the end position of the tilting displacement. Respective individual pictures are taken in these two object positions.



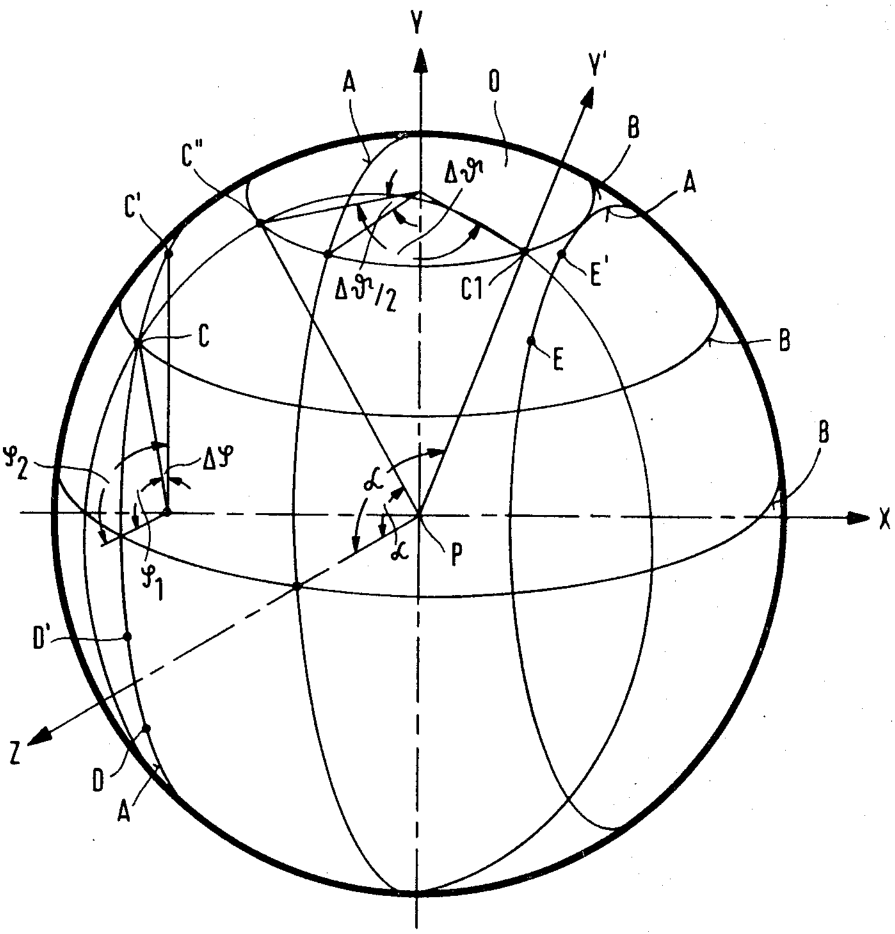
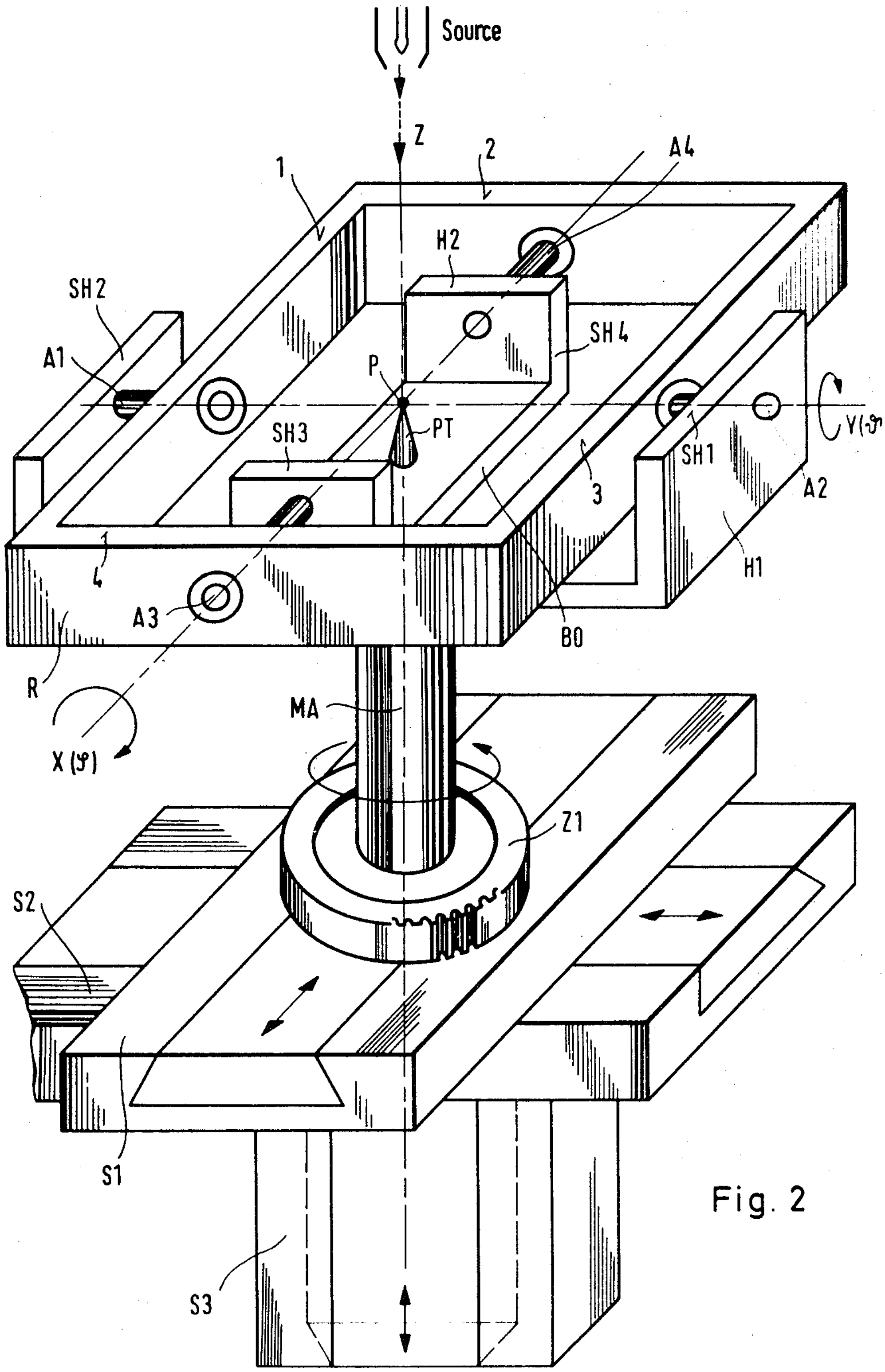



Fig. 1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H2
SH2
SH4
A1
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PT
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SH3
SH1
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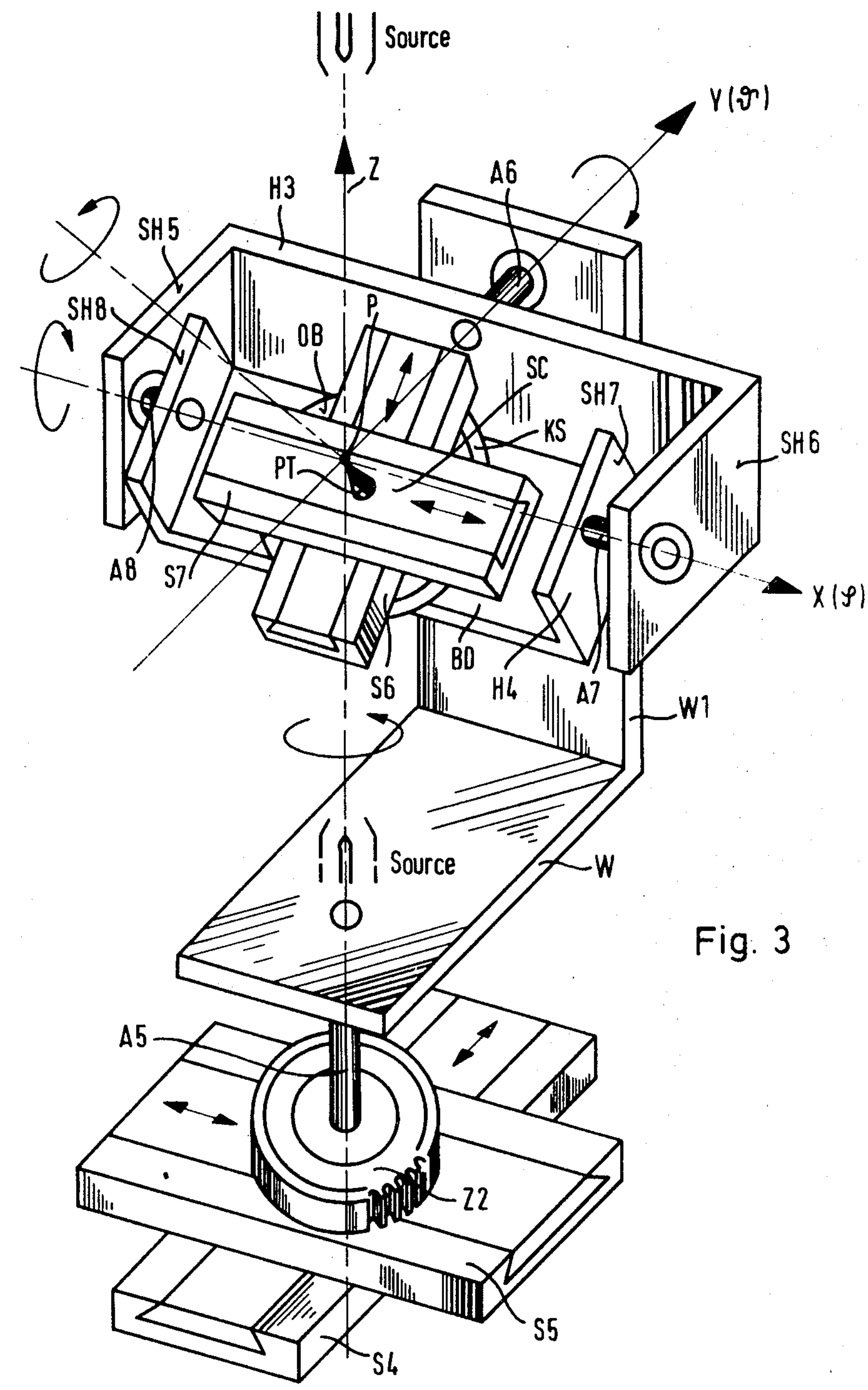
H1
4
A3
B0
R
MA
X(ϑ)
Z1
S2
S1
S3

Fig. 2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H3
SH5
SH8
OB
P
SC
SH7
KS
SH6
PT
A8
S7
X (φ)
BD
S6
H4
A7
W1
Source
W
A5
Z2
S5
S4

Fig. 3

## METHOD AND APPARATUS FOR PRODUCING A STEREO IMAGE BY ELECTRON MICROSCOPY

Our invention relates to a method for producing a stereo image whose individual images, for example of a crystalline object, are produced by means of electron microscopy.

It is known that devices for producing stereo image pairs of crystal specimens by scanning electron microscopes must be equipped with devices which permit displacing each point of the specimen with respect to its distance from the electron beam, and which also permit tilting the specimen surface about an axis which is nearly or precisely perpendicular to the electron beam direction. It is further known that pairs of stereo images to be viewed with known optical equipment, can be combined to a stereo image only if the stereo angle remains limited in accordance with physiological optics, for example the Lüscher-parallax condition. The production of stereo images further requires that the image brightnesses of the object surfaces in the two individual images be not, or only slightly, different from each other. The change in image brightness when tilting the object is due to the fact that the number of secondary electrons released by the primary electron beam out of a specimen surface, and consequently the image brightness of the object surface, greatly depends upon the inclination angle of the surface normal of the object relative to the direction of the primary electron beam. It may happen, therefore, that a stereo effect of interesting object structures cannot, or only very deficiently, be attained if at the mutually corresponding localities of the individual images produced, the image intensities differ so greatly from each other that no genuine stereo effect will result. For the same reason, it may be difficult to measure the local object height.

It is an object of our invention to provide a method and means for the production of stereo images by electron microscopy which minimize or virtually eliminate the above-mentioned difficulties. More specifically, it is an object of the invention to readily afford producing electron-optical stereo images which secures substantial constancy of the image brightness with respect to given object surfaces in the two individual images of a stereo pair.

According to our invention, we first rotate the chosen surface area or face of the object about a central axis defined by the direction of the electron beam, whereafter we tilt the object about a second axis intersecting the central axis, the tilting being in an amount corresponding to the stereo angle; and the rotation about the central axis being such that the image brightness of the surface is substantially the same in the starting position and in the end position respectively of the tilting displacement. The individual pictures of the stereo pair are taken as the object is in these two positions respectively.

Preferably, the cented axis and the second axis are perpendicular to each other, and the point of intersection is situated within the object or specimen.

According to another feature of our invention, a third axis may be provided which passes through the intersection of the first and second axes and which extends perpendicularly or at a different angle to each of these two axes, the specimen being rotatable about the third axis for maintaining a given surface brightness intensity of the object.

According to a further, alternative method of the invention, any chosen surface of the object is rotated about an axis which is noncoincident with the beam direction; and adjustable so as to be parallel to, or identical with, the normal direction of the surface (i.e., the direction perpendicular to the surface), the amount of rotation, constituting the stereo angle, being dependent upon the angle between the adjustable axis and the central axis defined by the beam direction.

As a consequence of the object movements performed in accordance with the above-described method of the invention, noninteresting object faces or surface areas can be uniformly suppressed as regards their brightness intensity on the corresponding localities of the stereo image pair, thus more clearly imaging and emphasizing the other structural features of the object. This is tantamount to having the possibility of varying and/or improving the image contrasts. For example, the intensity of a planar crystal surface can be uniformly suppressed for more clearly imaging any individual small etch pits located on the surface.

The invention will be further elucidated with reference to the accompanying drawing in which:

FIG. 1 is an explanatory diagram;

FIG. 2 is a schematically perspective view of apparatus embodying the invention by way of example; and

FIG. 3 is a schematically perspective view of another apparatus also embodying the invention by way of example.

The diagram shown in FIG. 1 serves to permit a comparison of the method according to the invention with those heretofore available. The perspective representation indicates various axes. Among these is the Z-axis (central axis) shown with an arrowhead opposed to the direction of the primary beam of electrons. Also apparent is an axial direction X which is perpendicular to the primary electron-beam direction (Z-direction) and about which the specimen surface, in the heretofore customary manner, was tilted in opposition to the beam direction $z$ about the angles $\Phi_1$ in order to first obtain a given image brightness of the surface, and thereafter is tilted through the stereo angle $\Delta\Phi$ to the angular position $\Phi_2$. Also indicated in FIG. 1 is an axis Y which is assumed to be perpendicular to the X-axis and to the Z-axis, although it may also intersect these two axes at a different angle. The Z-, Y- and X-axes are shown to intersect in a single point P although this is not an indispensable requirement. Further represented is a spherical surface O about the common intersection P of the three axes with latitude circles A and B concentric to the X-direction and Y-direction respectively.

For simplification, assume that the surface structure of the specimen is composed of three areas conjointly forming a triple-edged pyramid represented in central projection. The surface normal (not shown) passes through the intersection point P of the axes and intersects the surface O of the sphere at C, D and E.

In the conventional method for producing a stereo image, the two individual images of the stereo pair differ from each other in that the tilting angle $\Phi$, denoting the angular displacement about the X-axis, after first taking a picture at an angle $\Phi_1$, is changed by the stereo angle $\Delta\Phi$ to assume the angular position $\Phi_2$, this being represented at point C. Relative to this tilting displacement, the $\Phi$-tilting axis perpendicular to the cented axis Z is designated as the X-axis. Due to the tilting displacement, the surface normal directions passing through C, D, E change to directions passing through C′, D′, E′ respectively. The Y-direction which is assumed to be fixed with the specimen, changes along the latitude circles A to the Y′-direction. In the following, the points C, C′, C″, $C_1$, $C_2$, D, D′, E, E′ where the surface normal directions passing through the sphere center point intersect the surface O of the sphere, are used to denote the surface normal directions as well as the surfaces C, D and E themselves.

As a consequence of the tilting displacement, the corresponding surfaces C and C′, D and D′, E and E′ in the two individual pictures are imaged in respectively different sizes and also with different image brightnesses. Thus, for example, it may happen that the increased inclination of the surfaces C′ and E′ will result in a higher image intensity relative to C and E, whereas the brightness at the surface D in the second picture D′ is reduced. For similar reasons, an inversion in contrast of the area brightness may take place and may weaken or obviate the stereo effect.

The method according to the invention minimizes or eliminates these difficulties at least with respect to any surface area of interest to the observer. In lieu of the additional tilting about the X-axis by the angle $\Delta\Phi$, we provide for other displacing movements of the specimen. That is, we provide for a rotary displacement about the central axis and tilting movement about the Y-axis which extends at an angle, for example perpendicularly, to the Z-beam direction (central axis) as well as to the X-axis. For explaining the method steps, let it be assumed that the surface area denoted by C is the one which, with respect to image structure, intensity and characteristic limitation, is of particular importance. This arbitrarily selected surface area C is inclined by the tilting angle $\Phi_1$ relative to the beam direction Z. It is not necessary that the surface C be first rotated about the X-axis an angular amount $\Phi_1$, since the surface structure of the specimen object is almost always such that from the outset the surfaces occupy a given angle relative to the plane defined by the Z- and X-axes.

One of the applicable ways of turning the face C to the positions C'' or $C_1$ for taking the stereo pictures is as follows. The face C is rotated about the Z-axis into a second position C'' in such a manner that a subsequent tilting to the position $C_1$ about the Y-axis by the stereo angle $\Delta\theta$ does not cause a change in image brightness intensity for the face C''. The face direction C'' is determined by the fact that, upon tilting the face C'' one half of the stereo angle $\Delta\theta/2$, it no longer possesses a component in the X-axis direction. When displacing the face C to C'' and taking the electron-optical pictures, no stereo effect is at first produced since the face normals C and C'' do not change the angle relative to the beam direction Z, i.e., their projections in the beam direction remain unchanged. Consequently, their image intensity also remains unchanged. With this rotation, the other faces of the specimen P likewise do not change their intensity.

The subsequent $\Delta\theta$ tilting about the Y-axis, which transfers the face C from the position C'' to the position $C_1$, does not change the image brightness, at least of the face C, because the directions C'' and $C_1$ of the face normals form the same angle $\alpha$ relative to the Z-axis as the face normal direction C.

The face positions C'' and $C_1$ differ from each other, with respect to tilting about the Y-axis, by the stereo angle $\Delta\theta$ and result in obtaining a pair of stereo pictures on which the face C has the same brightness intensities respectively.

The second method according to the invention provides as a first step that an axis be moved in such a manner that it becomes identical with or parallel to the face normal direction on the chosen face of the specimen. Thereafter the chosen face is rotated about this axis and brought into two positions differing from each other by the stereo angle which is now dependent upon the angle defined by the central axis, i.e., the electron-beam axis on the one hand, and the adjustable axis on the other hand. The latter angle can be computed or the positions can be determined experimentally.

The embodiments of apparatus according to the invention illustrated in FIGS. 2 and 3 are designed for performing the first-described method according to the invention.

The device shown in FIG. 2 comprises three sliders S1, S2 and S3 arranged one above the other and serving to impart translatory displacements to the specimen P shown situated on the central axis Z in the path of the electron beam. The slider S1 is used for the first horizontal translatory motion of the specimen, the slider S2 for the second horizontal specimen motion perpendicular to that of the slider S1, and the slider S3 permits a vertical translatory movement of the specimen in the direction of the electron beam which is along the central axis Z. Mounted on the slider S1 is a fixed axle MA which can be turned by means of a spur gear Z1. Seated on top of the axle MA is a cardanic joint assembly of several gimbal members. One of these members, a U-shaped bracket member H1, is fastened to the axle MA and has its lateral legs SH1 and SH2 provided with inwardly directed journal pins A1, A2. A frame R is secured to the ends of the pins A1 and A2. The frame is composed of four lateral parts 1, 2, 3, 4 of which the parts 1 and 3 are connected with the pins A1 and A2. Each of the lateral parts 2 and 4 carries in its middle another axle pin A3 or A4 which protrudes inwardly in the plane defined by the frame R. Another U-shaped gimbal member H2 has its lateral legs SH3 and SH4 joined with the pins A3 and A4 respectively. The bottom BO of member H2 carries the specimen support PT on whose point the specimen P itself is fastened. The member H1, the frame R and the member H2 are angularly displaced 90° from each other so as to jointly form a cardanic or universal-joint suspension for the specimen P. The electron-beam direction identical with the Z-axis passes through the specimen P and the axle MA. The X-axis for the angular rotation about the angle $\Phi$ (see FIG. 1) extends through the journal pins A3 and A4; and the Y-axis extends through the pins A1 and A2 of the gimbal member H1.

Before a stereo picture of the specimen P can be taken, the specimen P must be brought into the focal point of the electron beam by applying translatory displacements with the aid of the sliders S1, S2, S3. For taking a stereo picture with the imprecise known method, it suffices to tilt the member H2 about the X-axis, i.e., about the journal pins A3 and A4. For taking stereo pictures by the method according to the invention, the $\Phi$ tilting is first used alone for adjusting a desired brightness of the image, and is not changed once this adjustment is made. After suitable rotation of the specimen P about the beam direction (Z-axis) the stereo tilting is performed by tilting the specimen about the Y-axis. The rotation about the Z-axis is transmitted to the specimen P through the axle MA and the gimbal member H1 fastened to that axle. The tilting about the Y-axis is effected by the journal pins A1 and A2 whose rotation is transferred to the specimen P through the frame R and the member H2.

The apparatus shown in FIG. 3 resembles that of FIG. 2 in comprising two sliders S4 and S5 which are fastened one above the other and are displaceable at an angle of 90° relative to each other. An axle A5 is mounted on the slider S5 and rotatable by means of a spur gear Z2. A mounting structure W-shaped as an angle piece is fastened to the top end of the axle A5. The sliders S5 and S4 serve to shift the object P into the center axis Z. A gimbal bracket member H3 is fastened by a pivot pin A6 to the upper end of the leg W1 of the angle piece W. The lateral legs SH5 and SH6 of the likewise U-shaped member H3 carry coaxial pins A7 and A8 between which a U-shaped gimbal bracket H4 is attached. The pins A7 and A8 engage the lateral legs SH7 and SH8. The bottom BD of member H4 carries on a further axle (not visible) a circular disc KS whose surface OB is perpendicular to the common axis of pins A7 and A8. A slider S6 mounted on the disc surface carries another slider S7 displaceable perpendicularly to the sliding direction of slider S6. The displacement of slider S7 is along the common axis of pins A7 and A8. The specimen carrier PT with the specimen P is fastened on the sliding member SC of the slider S7.

The sliders S6 and S7 and the disc KS serve to place selected localities of the specimen P into the focal point of the electron beam Z without requiring each time a new focusing of the electron beam onto the specimen P situated parallel to the plane SC. The two sliders S4 and S5 serve to bring the specimen P into the electron beam Z. The coarse displacement of the specimen P in the direction of the central axis (coincident with the direction of the electron beam Z) is effected by means of the sliders S4 to S7.

For taking stereo pictures in accordance with the conventional imprecise method, a rotation of the specimen about the X-axis coincident with the common axis of the pins A7 and A8 may be used. This possibility of rotation is also applicable for the purpose of the method according to the invention, namely for improving the inclination of individual crystal faces of the specimen P relative to the center axis Z and hence relative to the electron beam direction. In this manner the brightness of these faces can be varied. The tilting of the specimen about the Z-axis is effected by turning the angle piece W with the aid of the axle A5 fastened on the slider S5. The subsequent tilting about the Y-axis, important for taking stereo pictures, is effected with the aid of the bracket members H3 and the pivot pin A6.

We claim:

1. The method of producing electron-microscopic stereo images by sequentially taking pairs of stereoscopically coordinated individual pictures, which comprises exposing the object to be imaged to a beam of electrons whose direction defines a central axis, rotating the object surface area to be photographed about said central axis, then tilting the object an

angular amount equal to the stereo angle about a second axis intersecting said central axis, the rotation about said central axis being in an angular amount at which the image brightness of said area is the same in the starting and end positions respectively of the tilting, and taking first and second pictures of the object when said electron-irradiated surface area is in said two positions respectively.

2. The method of producing electron-microscopic stereo images by sequentially taking pairs of stereoscopically coordinated individual pictures, which comprises exposing the objects to be imaged to a beam of electrons whose direction defines a central axis, adjusting an adjustable axis to be parallel to or in coincident relation with the normal of the object surface area to be photographed, said adjustable axis being noncoincident with said central axis, and rotating said object surface area about said adjustable axis an angular amount equal to the stereo angle, said angular amount corresponding to the angle formed between said central and said adjustable axes.

3. The method according to claim 1, which comprises rotationally adjusting the object about a third axis for obtaining a surface brightness intensity, sufficient to permit said pictures to record a stereoscopic image before said object surface area is rotated about said central axis, said third axis passing through the intersection of said central and second axes and extending transversely to each of said latter two axes.

4. The method according to claim 1, wherein said central axis and said second axis are perpendicular to each other.

5. The method according to claim 4, which comprises mounting said object on the intersection of said central and second axes.

6. The method according to claim 1, which comprises rotationally adjusting the object about a third axis for obtaining a desired surface brightness intensity, sufficient to permit said pictures to record a stereoscopic image before said object surface area is rotated about said central axis.

7. In apparatus for producing electron-microscopic stereo images by sequentially taking pairs of stereoscopically coordinated individual pictures having means for producing an electron beam in a direction defining a central axis, a device for holding a specimen object on said central axis, and means for photographically taking individual pictures of the electron-illuminated object, the improvement according to which said device comprises a cardanic joint assembly, of gimbal structures, having three cardanic journal axes of which one is coincident with said central axis, said three axes having a common intersection on said central axis, an object support mounted on said assembly near said intersection for holding the object on said intersection, whereby said device permits rotating any chosen surface area of the object about said central axis and then tilting the object through the stereo angle about one of said other axes between two picture-taking positions in which the chosen area has substantially the same brightness, said gimbal structures comprising a quadrangular frame at whose center point said intersection is located, said frame having two coaxial pivot pins protruding from opposite frame sides, a first U-shaped gimbal member on whose two legs said respective pivot pins are mounted to permit rotation of said frame about one of said cardanic journal axes, two further pivot pins protruding from the other two sides respectively of said frame and defining another one of said journal axes, a second U-shaped gimbal member fastened to said other pivot pins for rotation about said other journal axis, said object support being fastened to said second gimbal member, a slider displaceable transversely of said central axis, an axle mounted on said slider and having an axis perpendicular to the slider displacement direction, said axle being rotatable about its axis, said first gimbal member being fastened to said axle to rotate together therewith, a second slider on which said first slider is displaceable, and a third slider on which said second slider is displaceable, the displacement directions of said three sliders extending at an angle of 90° to each other, whereby respective translatory adjustments are applicable to said object support relative to said central axis.

8. In apparatus for producing electron-microscopic stereo images by sequentially taking pairs of stereoscopically coordinated individual pictures having means for producing an electron beam in a direction defining a central axis, a device for holding a specimen object on said central axis, and means for photographically taking individual pictures of the electron-illuminated object, the improvement according to which said device comprises a cardanic joint assembly of gimbal structures, having three cardanic journal axes of which one is coincident with said central axis, said three axes having a common intersection on said central axis, an object support mounted on said assembly near said intersection for holding the object on said intersection, whereby said device permits rotating any chosen surface area of the object about said central axis and then tilting the object through the stereo angle about one of said other axes between two picture-taking positions in which the chosen area has substantially the same brightness, two sliders displaceable in respective directions perpendicular to each other, one of said sliders carrying said object support and being mounted and displaceable upon the other slider, a rotatable circular disc structure to which said other slider is fixedly attached to be rotationally adjustable together therewith, said rotatable discs being mounted on said cardanic assembly, said cardanic assembly comprising a first U-shaped bracket on whose bottom said rotatable disc structure is mounted, a second U-shaped bracket having two leg portions with respective coaxial pivot pins, said first bracket having two leg portions connnected with said respective pivot pins to be rotatable about their common axis, and an angle piece (W) and a pivot pin protruding from one leg of said angle piece and having a pivot axis coincident with one of said two cardanic journal axes other than said central axis, said second bracket (H3) being journaled on said latter pivot pin to be rotatable about said one journal axis.

9. In apparatus for producing electron-microscopic stereo images by sequentially taking pairs of stereoscopically coordinated individual pictures having means for producing an electron beam in a direction defining a central axis, a device for holding a specimen object on said central axis, and means for photographically taking individual pictures of the electron-illuminated object, the improvement according to which said device comprises a cardanic joint assembly of gimbal structures, having three cardanic journal axes of which one is coincident with said central axis, said three axes having a common intersection on said central axis, an object support mounted on said assembly near said intersection for holding the object on said intersection, whereby said device permits rotating any chosen surface area of the object about said central axis and then tilting the object through the stereo angle about one of said other axes between two picture-taking positions in which the chosen area has substantially the same brightness, two sliders displaceable in respective directions perpendicular to each other, one of said sliders carrying said object support and being mounted and displaceable upon the other slider, a rotatable circular disc structure to which said other slider is fixedly attached to be rotationally adjustable together therewith, said rotatable discs being mounted on said cardanic assembly, said cardanic assembly comprising a first U-shaped bracket on whose bottom said rotatable disc structure is mounted, a second U-shaped bracket having two leg portions with respective coaxial pivot pins, said first bracket having two leg portions connected with said respective pivot pins to be rotatable about their common axis, a mounting structure, and a pivot pin connected with said mounting structure and having an axis defining one of said cardanic journal axes other than said central axis, said second bracket (H3) being journaled on said pivot pin for rotation about said one journal axis.

10. Apparatus according to claim 9, comprising slider means displaceable in a direction transverse to said central axis, an axle (A5) mounted on said slider means and extending therefrom in a direction parallel to said central axis, said axle being adjustable by said slider means to a position coaxial with said central axis, said mounting structure being connected to said axle so as to be rotatable about said central axis.

11. An apparatus according to claim 10, said slider means comprising a top slider (S5) carrying said axle, and a bottom slider (S4) on which said top slider is displaceable in a direction perpendicular to the displacement direction of said top slider, said bottom slider being operable to impart translatory displacements to said axle (A5) relative to said central axis (Z).

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