May 13, 1969 A. ASMUS 3,444,367

SPECIMEN TILTING DEVICE FOR PARTICLE BEAM APPARATUS

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Fig. 1

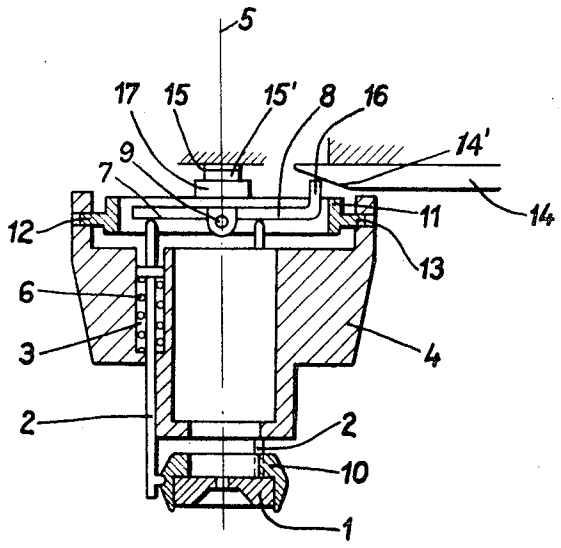
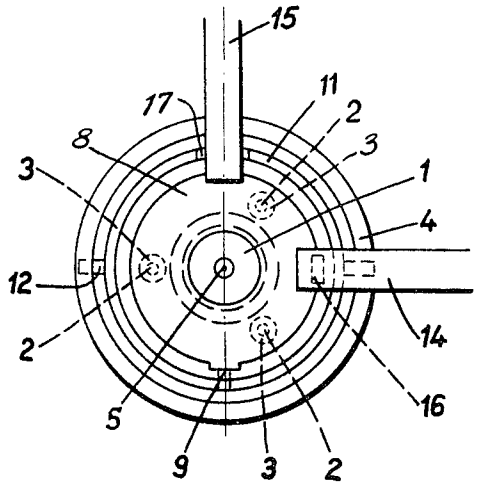


Fig. 2



SPECIMEN TILTING DEVICE FOR PARTICLE BEAM APPARATUS

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Fig. 3

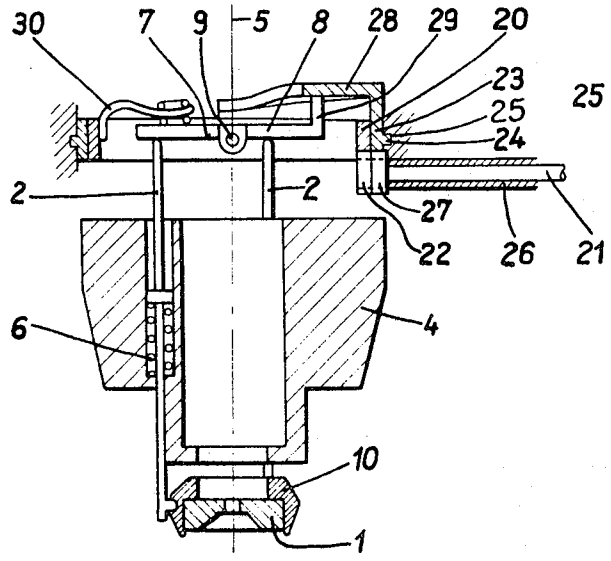


Fig. 4

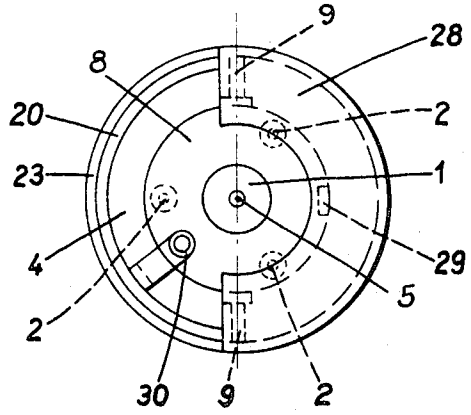
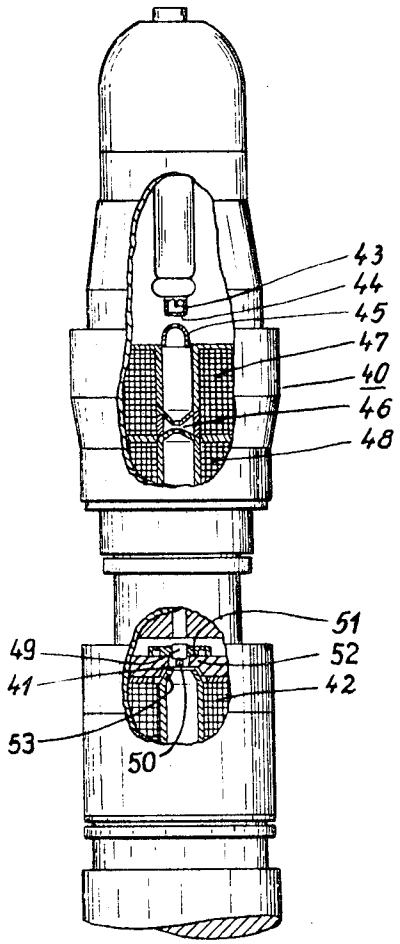


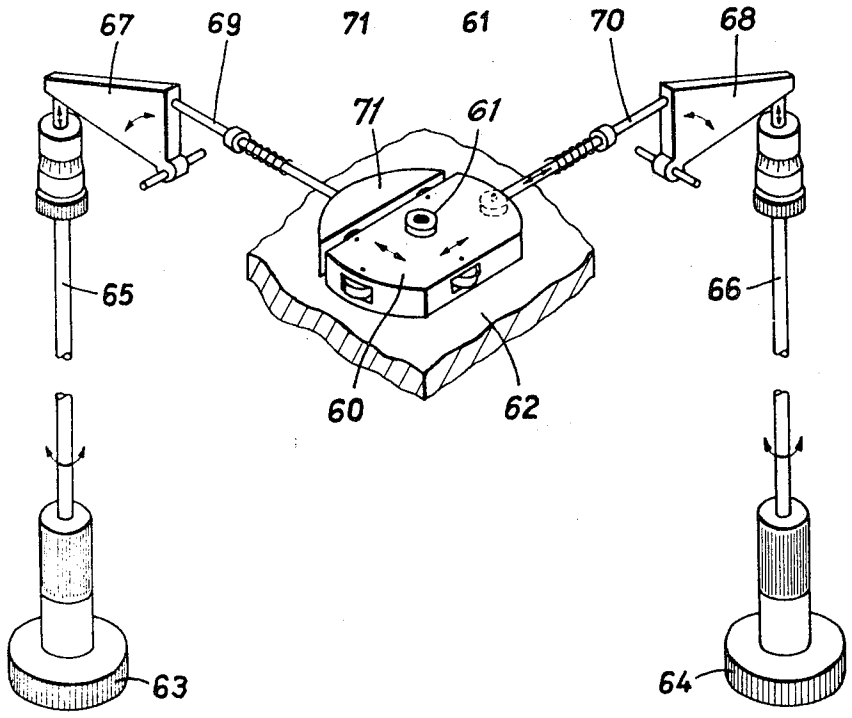
Fig. 5



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Fig. 6



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SPECIMEN TILTING DEVICE FOR PARTICLE BEAM APPARATUS

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Int. Cl. H01j 37/26
U.S. Cl. 250—49.5 20 Claims

ABSTRACT OF THE DISCLOSURE

A specimen tilting device for a corpuscular ray apparatus, such as an electron microscope. The device includes a tiltable specimen carrier and an adjusting plate which is spaced from this carrier. A support means supports the adjusting plate for tilting movement about a tilt axis which is adjacent to the adjusting plate and which extends perpendicularly with respect to the principal or ray axis of the device. A means is provided for tilting the adjusting plate about this tilt axis, and a transmission means which moves parallel to the principal axis extends between and is in mechanical engagement with the adjusting plate and the specimen carrier for transmitting tilting of the adjusting plate to the specimen carrier. Because this transmission means moves parallel to the principal axis, none of the components of the device are required to swing laterally about a tilt axis, so that only an exceedingly small space is required for the structure while at the same time making relatively large tilting of the specimen carrier possible.

My invention relates to a tiltable device for accommodating a specimen which is to be studied or processed in a particle beam or corpuscular ray apparatus, such as an electron microscope. As a rule, the specimen is supported on an apertured carrier, for example a diaphragm or a suitable mesh.

When using tilting devices of the above type, considerable difficulty has been encountered on account of the fact that the device is situated in an extremely restricted location where hardly any space is available laterally of the device to permit more than a very limited angular range of tilting movement for the specimen carrier. It is particularly difficult to extend the tilt-adjusting structure from the outside to the lateral side of the tilting device, since with the known tilting devices it is essential that the tilt control structure extend to the immediate vicinity of the specimen carrier, and this carrier, as a rule, is located in a particularly inaccessible part of the apparatus, namely within the objective lens aperture.

It is therefore a primary object of my invention to avoid or minimize the above-mentioned drawbacks by providing a structure capable of tilting the specimen carrier to any desired angle without any particular difficulty both with respect to operation of the device and accommodation of the latter in the particle beam apparatus.

In particular, it is an object of the invention to provide a specimen tilting device which is of a relatively simple design but adapted to the particular restrictions with respect to space usually encountered in particle beam apparatus, such as electron microscopes.

A further object of the invention is to provide a tilting assembly of the above type wherein it is possible to place the tilt-angle control structure at a location where the difficulties resulting from the structure surrounding the specimen carrier itself are not present.

Thus, it is an object of the present invention to provide a tilting device capable of determining the angular

position of the specimen carrier even if the latter, for example, is seated deep within the bore of a lens pole piece where no, or hardly any, space is available at the side of the carrier for accommodating such tilt control structure.

The objects of the invention further include devising a tilting device capable of providing a large range of angular movement for the specimen carrier without requiring a particularly large structure for producing this result.

Another object of the invention is the provision of a structure capable of adjusting the angle of tilt of the specimen carrier even though the carrier is introduced into the device along the principal axis of the particle beam.

It is also an object of the invention to provide a structure which is capable of tilting the specimen carrier not only about a single tilt axis normal to the principal beam axis but also to any other desired angular attitude.

It is furthermore an object of the invention to provide a structure which is capable of adjusting the angular attitude of the specimen carrier without creating any particular difficulties with respect to maintenance of an evacuated interior within the particle beam apparatus.

In particular, the objects of the present invention include the provision of a tilting structure which at least partly forms a unit with a cartridge which is removed from and replaced back into the ray apparatus in connection with changing the specimen so that, by making at least part of the tilting structure unitary with this cartridge and the specimen carrier, difficulties encountered with respect to maintenance of a suitable vacuum in the interior of the device can be avoided.

The objects of the present invention also include the provision of a structure capable of providing an apparent angular orientation of the specimen about the principal axis, which is to say an orientation in azimuth, without, however, actually turning the specimen itself.

Inasmuch as the specimen cartridge is conventionally mounted on a table capable of being shifted in a plane normal to the principal axis, the objects of the present invention also include the provision of a structure capable of maintaining the angular attitude of the specimen carrier even while the specimen stage is shifted in its plane which is normal to the principal axis.

The invention is illustrated by way of example in the accompanying drawings which form part of the application and in which:

FIG. 1 is a partly schematic sectional elevation of one embodiment of a structure according to the present invention;

FIG. 2 is a top plan view of the structure of FIG. 1;

FIG. 3 is a partly schematic sectional elevation of another embodiment of a structure according to the present invention;

FIG. 4 is a top plan view of the structure of FIG. 3;

FIG. 5 shows an electron microscope partly in section, so as to illustrate the environment for the structure of FIGS. 1–4; and

FIG. 6 illustrates the manner in which specimen table of the electron microscope can be adjusted in a plane normal to the principal axis.

While the embodiment shown in FIGS. 1 and 2 provides a solution where the adjusting plate, specimen carrier, transmission therebetween, and specimen cartridge all are assembled into a single unit, FIGS. 3 and 4 show an embodiment where the adjusting plate and its support means are situated beyond a unit which is formed in this case by the cartridge, specimen carrier, and transmission for transmitting movement of an adjusting plate to the carrier, as will be apparent from the description which follows.

Assuming that the specimen to be studied or processed is mounted on a diaphragm disc 1 (FIG. 1–4) which is formed with a suitable aperture through which the principal axis 5 extends, a transmission means which includes

elongated transmission members 2 is connected to, and cooperates with, the carrier 1 for moving parallel to the principal axis and tilting the carrier in response to tilting of an adjustable tilting plate 8. As is apparent from the plan views of FIGS. 2 and 4, there are in fact three elongated motion-transmitting members 2 in the form of rods spaced from each other 120° about the principal axis 5, this being the axis of the particle beam. The rods 2 are guided for movement by the cartridge 4 in a manner described below. The diaphragm 1, which forms the specimen carrier, is mounted in a ring 10. As is shown most clearly at the lower left portion of FIGS. 1 and 3, the ring 10 is formed at its exterior with recesses having substantially the configuration of a hemisphere, and these recesses respectively receive the convexly curved free ends of projections extending laterally from the rods 2, so that in this way a structure similar to a ball-and-socket joint is provided between the ring 10 of the carrier 1 and the longitudinally movable rods 2. Therefore, when these rods 2 alter their longitudinal positions relative to each other the ring 10 and the carrier 1 therewith will necessarily assume different angular attitudes.

In both of the embodiments disclosed in FIGS. 1–4 the rods 2 of the transmission means are guided for longitudinal movement in bores 3 formed in the cartridge 4 and extending therethrough in directions parallel to the principal axis 5. The rods 2 respectively pass through the bores 3 in the manner shown in FIGS. 1 and 3. As is apparent from FIGS. 1 and 3, the bottom ends of the bores 3 are of a smaller diameter than the remainder thereof so as to provide for a sliding engagement with the rods 2 at the place where they pass through the lowermost portions of the bores 3. Above these lowermost portions the bores 3 accommodate springs 6 which are coiled about the respective rods 2 and engage collars fixed to the rods 2 and slidable in the portions of the bores 3 which are of a larger diameter. In this way the rods 2 are not only guided for longitudinal movement but are also urged upwardly by the springs 6.

In FIGS. 1 and 3 there is illustrated the adjusting plate 8 which is formed with a central aperture through which the principal axis 5 extends. The plate 8 has a smooth undersurface 7 engaged by the convexly curved top ends of the rods 2. Inasmuch as these smoothly and convexly curved top ends of the rods 2 are maintained by the springs 6 in engagement with the surface 7, it is possible for the top ends of the rods 2 and the surface 7 to have an easy sliding movement relative to each other during tilting of the adjusting plate 8. This adjusting plate 8 is tiltable in both embodiments about a tilt axis 9 which is normal to the principal axis 5 and extends through the adjusting plate 8. It will be seen that through the rods 2 of the transmission means any angle to which the plate 8 is tilted about the tilt axis 9 will be transmitted to the specimen carrier 1 so as to place the latter automatically in the same angular attitude as the plate 8.

In the embodiment of FIGS. 1 and 2 the adjusting plate 8 is not directly mounted on the cartridge 4 for tilting movement about the tilt axis 9. IInstead a gimbal 11 is situated between the plate 8 and the cartridge 4. The gimbal 11 surrounds the plate 8 and is formed with opposed bearings through which the axis 9 extends. The bearings are engaged by respective pins projecting from the plate 8 so that in this way the plate 8 is supported for tilting movement about the tilting axis 9 on gimbal 11. The gimbal 11 itself has a pair of coaxial pins 12 and 13 extending along a second tilt axis which is normal to the tilt axis 9 as well as to the principal axis 5, and these pins 12 and 13 are received in suitable bearings formed by openings of the cartridge 4 itself, so that the gimbal 11 is tiltable about an axis perpendicular to the tilt axis 9. In this way a universal tilting movement of the plate 8 is possible, inasmuch as the plate 8 can tilt not only about the axis 9, but in addition the entire axis 9 together with the plate 8 can tilt about the common axis of the pins 12 and 13. In this way virtually any angular attitude of the plate 8, and thus of the specimen carrier 1, can be achieved.

An adjusting means is provided for adjusting the angular attitude of the adjusting plate 8, and this adjusting means includes a pair of elongated adjusting members 14 and 15 in the form of bars which have inner inclined wedge surfaces 14′ and 15′ in slidable engagement with respective projections 16 and 17 of plate 8 and gimbal 11. Therefore, longitudinal movement of the adjusting bar 14 will adjust the angle of the plate 8 about the tilt axis 9 while longitudinal movement of the adjusting bar 15 will adjust the angle of the gimbal 11 about the common axis of the pins 12 and 13. This universal support for the plate 8 affords setting the specimen at any desired angular attitude. The spring means 6, maintaining the upper ends of the rods 2 in engagement with the slide surface 7, not only provide proper transmission of the tilting movement from plate 8 to carrier 1, but also eliminate any play from the transmission.

It is apparent that since the gimbal 11 is carried directly by the cartridge 4, this cartridge together with the plate 8 and the supporting structure therefor, as well as the specimen carrier 1 and the means for transmitting movement of the plate to the carrier, form a single unitary assembly capable of being removed from, and introduced into, the microscope whenever the specimen is to be changed.

Referring now to FIGS. 3 and 4, it will be seen that the primary distinction from the embodiment of FIGS. 1 and 2, in addition to the location of the adjusting plate beyond the unit which includes the cartridge 4, resides in the different adjusting means for bringing about a change in angular attitude of plate 8 and carrier 1. In the embodiment of FIGS. 3 and 4 the adjusting plate 8, whose undersurface 7 is engaged by the upper ends of the rods 2 which are urged upwardly by the springs 6, is supported for tilting movement about a tilt axis 9 which is normal to the principal axis 5 and extends through the plate 8; but in this case the tilt axis 9 is formed by a pair of bearings receiving coaxial projections of the plate 8 situated in and carried by a gear ring 20. The adjusting means of this embodiment includes a rotary shaft 21 fixed to a pinion 22 which meshes with the gear ring 20 so that, in response to manual rotation of the shaft 21 by means of any suitable knob or the like fixed thereto, the gear ring 20 will turn about the principal axis which passes through the center of the ring 20, and thus the angular position of the axis 9 with respect to the principal axis can also be adjusted.

With this embodiment, therefore, the angular position of the adjusting plate 8 relative to the principal axis 5 can be adjusted. However, during this rotary movement of the plate 8 about the axis 5 the cartridge 4 and the motion transmitting rods 2 maintain their positions with respect to the principal axis 5. That is, the parts 2 and 4 do not turn about the principal axis 5 when the plate 8 turns about this axis, and of course at this time the surface 7 slides along the upper ends of the rods 2. In this way it is possible, without turning the specimen itself, to provide not only a desired angle of tilt for the specimen but also to provide an apparent rotation of the specimen in azimuth.

To adjust the tilt angle of plate 8 the adjusting means includes a second gear ring 23 coaxially surrounding the ring 20. The gear ring 23 is provided at its exterior surface with a plurality of projections 24 which are received in an annular groove 25 formed in any suitable part of the electron microscope such as the vacuum housing thereof. In this way the gear ring 23 is supported for free rotary movement about the principal axis 5. In the same way the inner gear ring 20 may be provided with unillustrated outer projections received in an annular groove formed in the inner surface of the gear ring 23 and situated at the same elevation as the groove 25, so that the gear ring 23 directly supports the gear ring 20 for rotary movement about the principal axis.

For turning the ring 23 the adjusting means includes a

second drive shaft **26** which is hollow and through which the inner drive shaft **21** coaxially extends. The tubular drive shaft **26** is coaxially fixed with a second pinion **27** through which the shaft **21** also extends, the pinion **27** being in the form of a ring which coaxially surrounds the shaft **21**. The pinion **27** meshes with the teeth at the underside of the gear ring **23** so that in response to rotary movement of the hollow drive shaft **26** the angular position of the gear ring **23** can be adjusted.

A cam means cooperates with the plate **8** and the ring **23** for adjusting the angular position of the plate **8** with respect to the tilt axis **9**. In the illustrated example this cam means includes a cam **28** extending along a circle about the principal axis **5** and having an undersurface extending approximately along a spiral whose axis coincides with the axis **5**. The undersurface of cam **28** is engaged by the upper end of a cam follower projection **29** fixed to, and projecting upwardly from, the plate **8** and situated along an axis perpendicular to the axis **9**. Hence, the change in elevation of the cam follower **29** resulting from rotation of the ring **23** will result in a change in the angle of plate **8** with respect to the tilt axis **9**, and the transmission means **2** will reproduce the same angle in the specimen carrier **1**.

A leaf spring **30** is fixed to the inner surface of the ring **20** and has a free end carrying a pressure-transmitting structure which engages the plate **8** at a part thereof diametrically opposed to the cam follower **29** so that with this structure the spring **30** serves to maintain the cam follower **29** in engagement with the lower camming surface of the cam **28**. Thus, the rotary movement of the cam **28** together with the ring **23** will result in movement of the plate **8** about the axis **9** more or less in opposition to the force of the spring **30**, so that a definite angle of tilt of the plate **8** will be achieved, and this angle will be transmitted to the specimen carrier **1**.

With this embodiment it is only required to rotate the gears **20** and **23** as a unit in order to turn the plate **8** about the axis **5** without changing the tilting angle of the plate **8** with respect to the tilt axis **9**. For this purpose an additional unillustrated releasable coupling can be provided for coupling the shafts **21** and **26** to each other for joint rotation.

The arrangement of the inner ring gear **20** directly within and surrounded by the outer gear **23**, and arrangement of the inner drive shaft **21** within the outer drive shaft **26**, result in an extremely compact assembly requiring the smallest possible amount of space, and therefore an extremely simple seal suffices for passage of the shafts **21** and **26** to the exterior of the vacuum housing of the particle beam apparatus.

The adjusting bars **14** and **15** of FIGS. 1 and 2, which are required only to move longitudinally, may also be guided through simple seals capable of maintaining the desired vacuum in the interior of the vacuum housing, although the outer ends of the adjusting bars **14** and **15** are accessible outside of the device.

The structure described above is capable of being used in an electron microscope, for example one of the type illustrated in FIG. 5. Referring to FIG. 5 there are illustrated proceeding from top to bottom in the direction of the electron beam principal axis, the following components of the electron microscope: the cathode **43**, the Wehnelt cylinder **44**, the anode **45**, the coil **47** of the upper condenser which has the lens gap **46**, the coil **48** of the second condenser, which is not illustrated in detail, and—in the region of the lower sectionally illustrated structure of FIG. 5—the coil **42** of the objective lens, which has the lens gap **41**. The objective assembly includes the upper objective pole piece **52** and the lower objective pole piece **53**. The tilting assembly **49** of the invention is shown at the lower sectional portion of FIG. 5 as a simple rectangle mounted on the specimen stage or table **51** constructed as shown in FIG. 6. For simplicity, the structures for adjusting the specimen stage and for actuating the tilting assembly **49** are not illustrated in FIG. 5. The specimen carrier **50** is indicated in FIG. 5 directly beneath the adjusting structure **49**, and these parts **49** and **50** may correspond to either the details of FIGS. 1 and 2 or to the details of FIGS. 3 and 4. As is apparent from FIG. 5, the specimen carrier **50** is situated at a location where at least the upper pole piece **52** of the objective lens surrounds the carrier, so that from FIG. 5 the difficulties encountered with respect to space restrictions in the immediate vicinity of the specimen carrier are clearly apparent.

In FIG. 6 the specimen stage **60**, which corresponds to the stage **51** of FIG. 5, carries the unit **61** which includes the specimen cartridge, the specimen carrier therebeneath, and at least the transmission means for transmitting the tilting movement of the plate **8** to the carrier. This specimen stage **60** is adjustable in a pair of mutually perpendicular directions, as indicated by the double-headed arrows of FIG. 6. For this purpose the stage **60** is supported for slidable movement on the upper surface of the upper objective pole piece formed by the horizontal plate **62**. A pair of rotary adjusting knobs **63** and **64** are accessible to the operator at the exterior of the device, and through suitable transmissions, which include the rotary shaft **65** and **66**, the rotation of the knobs **63** and **64** is transmitted to the turnable adjusting members **67** and **68** which act on the specimen stage **60** through rods **69** and **70** respectively. The stage **60** is provided at its periphery with rollers protruding beyond the periphery to engage suitable surfaces which guide the stage **60** for movement in the directions of the double headed arrows of FIG. 6. The guide rollers engage stationary guide surfaces of the microscope in the interior thereof, although the left guide rollers of FIG. 6 engage a guide surface of a shiftable member **71** directly acted upon by a push rod **69**. In this way frictional resistance to shifting of the stage **60** in its own plane normal to the principal axis is greatly reduced.

The invention is not limited to the particular details described above and shown in the drawings. Of course, the particular adjusting drives shown in FIGS. 3 and 4 may be used with the structure of FIGS. 1 and 2 so as to actuate an assembly where the adjusting plate itself forms a unit with the specimen cartridge. On the other hand, the gimbal mounting of FIGS. 1 and 2 need not form a unit with the cartridge but instead can be placed beyond this unit to provide a suitable adjustment of the specimen carrier.

Furthermore, it is possible to arrange the adjusting plate together with the adjusting structure therefor outside of the evacuated space, and to transmit the movement of the adjusting plate through suitable transmission members to the three transmission members **2**, independently of the shifting of the specimen stage as shown in FIG. 6.

Furthermore, the specimen carrier and the adjusting plate may be spaced from each other, not along the principal axis, but, for example, in a direction perpendicular to the principal axis. This is of advantage for some diffraction-type equipment. Moreover, several adjusting plates and transmissions similar to the rods **2** can be arranged in series one above the other so that the assembly in the region of the specimen carrier is quite narrow while at other regions, for providing sufficient interengagement between the elements, a broader spread of the driving structure can be provided without difficulty.

The invention affords the advantage of producing for a specimen in a particle beam apparatus practically any angular attitude, while at the same time the orientation of the specimen along the principal axis remains unchanged so that the sharpness of the image is not affected by changes in angular setting. It may be desirable to provide for the tilting structure a means for adjusting only once the elevation of the specimen carrier so that, when the position of the specimen carrier along the principal axis

is set to provide the sharpest possible image, a further adjustment will not be required.

I claim:

1. A specimen tilting device for electron microscopes and other particle beam apparatus, comprising a specimen carrier tiltable relative to the principal axis of the device, a control structure spaced from said carrier and tiltable about a tilt axis perpendicular to said principal axis and situated adjacent to said control structure, actuating means connected with said structure for changing its angular position relative to said principal axis, and guide means extending parallel to said principal axis and linking said structure to said carrier for transmitting the angular position of said structure to said specimen carrier while said guide means remains parallel to said principal axis.

2. A specimen tilting device for electron microscopes and other particle beam apparatus, comprising a specimen carrier tiltable relative to the beam axis of the device, a control plate spaced from said carrier in the direction of said beam axis and tiltable about an axis perpendicular to said beam axis and situated adjacent said control plate, actuating means connected with said control plate for changing its angular position relative to said beam axis, and guide means extending parallel to said beam axis and linking said plate to said carrier for transmitting the angular position of said plate to said specimen carrier while said guide means remains parallel to said beam axis.

3. In particle beam apparatus, such as an electron microscope, a tiltable specimen carrier, an adjusting plate spaced from said carrier, support means supporting said adjusting plate for tilting movement about a tilt axis adjacent said adjusting plate and perpendicular to the principal axis of the particle beam apparatus, means for tilting said adjusting plate about said tilt axis, and transmission means movable parallel to said principal axis and extending between and mechanically engaging said adjusting plate and specimen carrier for transmitting tilting of said adjusting plate to said specimen carrier.

4. In particle beam apparatus, such as an electron microscope, a tiltable specimen carrier through which the principal beam axis extends, an adjusting plate having a central opening through which said principal axis extends and situated along the latter axis at a location spaced from said carrier, support means supporting said plate for tilting movement about a tilt axis normal to said principal axis and situated adjacent said adjusting plate, means for tilting said adjusting plate about said tilt axis, and transmission means movable parallel to said beam axis and extending between and mechnically engaging said plate and carrier for transmitting tilting of said plate about said tilt axis to said carrier and for situating said carrier at an angular position corresponding to that of said plate with respect to said tilt axis.

5. In apparatus as recited in claim 4, said transmission means including a plurality of elongated transmission members distributed about and extending parallel to said principal axis, and means guiding said transmission members for longitudinal movement.

6. In particle beam apparatus, tiltable specimen carrier means adapted to be introduced into the apparatus at least in part by movement of said carrier means in a given direction along the principal axis of the particle beam, an adjusting plate situated along said principal axis behind said carrier means relative to said given direction, support means supporting said adjusting plate for tilting movement about a tilt axis normal to said principal axis and situated adjacent said adjusting plate, means for tilting said adjusting plate about said tilt axis, and transmission means moveable parallel to said principal axis and extending between and mechanically engaging said adjusting plate and specimen carrier for tilting the latter, in response to tilting of said adjusting plate, to angular attitudes corresponding to that of said adjusting plate.

7. In particle beam apparatus, such as an electron microscope, a tiltable specimen carrier, an adjusting plate, and a specimen cartridge situated between said plate and carrier, and adapted to be mounted in a specimen stage, said cartridge, carrier, and plate all being arranged along a principal axis along which the electron beam travels, support means supporting said adjusting plate for tilting movement about a tilt axis normal to said principal axis and situated adjacent said adjusting plate, means for tilting said adjusting plate about said tilt axis, and transmission means moveable parallel to said principal axis and mechanically engaging said adjusting plate and carrier for transmitting tilting of said plate to said carrier and for situating said carrier at an attitude corresponding to that of said plate, said cartridge being formed with openings through which said transmission means extends.

8. In apparatus as recited in claim 7, said transmission means including elongated transmission members extending parallel to and distributed about said principal axis, said cartridge being formed with said openings to accommodate said elongated transmission members which respectively extend through said openings of said cartridge, and said cartridge guiding, at said openings thereof, said elongated transmission members for longitudinal movement parallel to said principal axis.

9. In apparatus as recited in claim 8, spring means mechanically connected to said transmission members for urging the latter toward said adjusting plate, and said transmission members respectively having free ends slidably engaging a surface of said plate and maintained in engagement with said surface by said spring means.

10. In apparatus as recited in claim 7, said support means including a gimbal on which said plate is mounted for tilting movement about said tilt axis.

11. In apparatus as recited in claim 10, said cartridge supporting said gimbal for tilting movement about a second axis normal to said principal axis and perpendicular to said tilt axis.

12. In apparatus as recited in claim 11, said transmission means carrying said object carrier as well as transmitting thereto movement of said adjusting plate; and said cartridge, adjusting plate, object carrier, transmission means, and support means all forming a unitary assembly.

13. In apparatus as recited in claim 7, said transmission means carrying said object carrier and forming with the latter and said cartridge a single unitary assembly, said support means and plate being situated beyond said assembly.

14. In apparatus as recited in claim 7, a specimen stage carrying said cartridge, and adjusting means mechanically connected to said stage for shifting the latter in a plane normal to said principal axis, said means for tilting said plate about said tilt axis maintaining the adjustment of said plate during shifting of said stage.

15. In a particle beam apparatus, a tiltable specimen carrier, a specimen cartridge, and an adjusting plate all situated along the principal axis of the particle beam apparatus, said cartridge being located between said plate and said carrier, support means supporting said plate for tilting movement about a tilt axis normal to said principal axis and situated adjacent said plate, transmission means moveable parallel to said principal axis and supported by said cartridge and mechanically engaging said plate and carrier for tilting the latter in the same way that said plate is tilted, and adjusting means mechanically connected with said plate for adjusting the angular position thereof with respect to said tilt axis.

16. In apparatus as recited in claim 15, said support means including a gimbal surrounding said plate and supporting the latter for tilting movement about said tilt axis, and said gimbal itself being supported for tilting movement about a second axis normal to said tilt axis and principal axis, said plate having a projection situated along said second axis and said gimbal having a projection situated along said tilt axis, and said adjusting means including a pair of elongated adjusting members respec-

tively parallel to said tilt and second axes and movable in the directions in which said tilt and second axes extend, said adjusting members respectively having inclined wedge surfaces engaging said projections so that the longitudinal positions of said adjusting members will determine the angular positions of said plate and gimbal respectively, to determine the angular attitude of said plate which through said transmission means determines the angular attitude of said specimen carrier.

17. In apparatus as recited in claim **15**, said support means including a rotary gear ring surrounding and turnable about said principal axis and having its center situated in said principal axis, said gear ring surrounding and carrying said plate while supporting the latter for tilting movement about said tilt axis, and said adjusting means including a drive mechanically connected to said gear ring for determining the angular position thereof with respect to said principal axis so as to determine the angular position of said tilt axis with respect to said principal axis.

18. In apparatus as recited in claim **17**, a second gear ring coaxial with said first-mentioned gear ring, said adjusting means including a second drive mechanically connected to said second gear ring for determining the angular position of the latter with respect to said principal axis, and cam means mechanically connected to said plate and second gear ring for tilting said plate about said tilt axis in response to movement of one of said gear rings about said principal axis with respect to the other of said gear rings.

19. In apparatus as recited in claim **18**, said cam means including a cam carried by said second ring and a cam follower carrier by said plate and engaging said cam.

20. In apparatus as recited in claim **18**, said drives for said pair of gear rings respectively including a pair of pinions having a common axis and meshing respectively with said gear rings, said drives including, in addition to said pinions, an inner rotary shaft coaxially fixed to one of said pinions and extending through the other of said pinions, and an outer hollow tubular drive shaft through which said inner shaft extends, said hollow drive shaft being coaxially fixed to the other of said pinions.

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WILLIAM F. LINDQUIST, *Primary Examiner.*

U.S. Cl. X.R.

307—237, 299, 304; 317—235