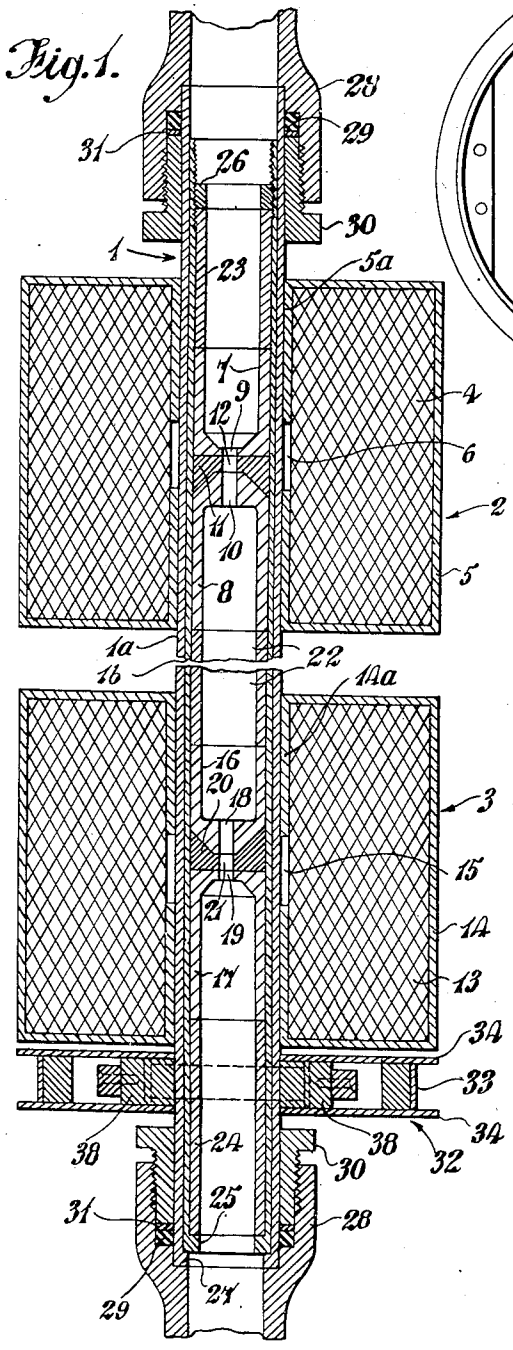
April 26, 1949. G. LIEBMANN 2,468,403

ELECTRON MICROSCOPE AND OTHER ELECTRONIC APPARATUS EMPLOYING ELECTRON LENSES

Filed Feb. 10, 1948

Fig. 1.



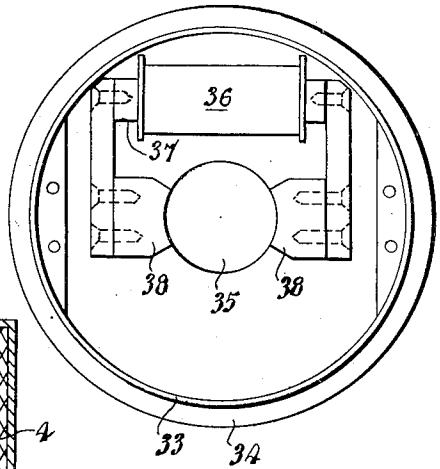


Fig. 2.

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ELECTRON MICROSCOPE AND OTHER ELECTRONIC APPARATUS EMPLOYING ELECTRON LENSES

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20 Claims. (Cl. 250—49.5)

1

The invention relates to electron microscopes and other electronic apparatus in which two or more electron lenses are arranged on an axis in axially spaced relationship, and more particularly to apparatus in which as magnetic electron lenses there are employed solenoids or iron-shrouded solenoids provided with pole-piece inserts.

An object of the invention is to provide a new and improved principle of construction of electronic apparatus of the above noted character, which simplifies the assembly of the various electron-optical components of magnetic electron lenses and the assembly of the lenses with other parts of the apparatus. Another object is to provide a construction of such electronic apparatus having a magnetic lens structure of the character indicated associated with a vacuum-tight envelope which is structurally independent of the lens structure. A further object is to construct an electron lens or lens system as a mechanical unit for ready fitment to and removal from the associated vacuum-tight envelope. Other objects are to eliminate adjustable vacuum-tight connections between the electron lens sections and other sections of such electronic apparatus, hitherto needed for lens adjustment, and to provide simpler and less costly connections. Further objects are to provide an improved method and form of assembly which ensures in a simple and practical fashion the correct setting and alignment of the various electron-optical elements in apparatus of the class above indicated, as well as the maintenance thereof during the use of the apparatus. Another object is to provide a construction having the various parts of an electron-optical system mechanically pre-set in their designed relative positional relationships, with provision for adjustments to be carried out electrically without disturbing the mechanical pre-settings. Other objects will be apparent as the disclosure herein proceeds.

The invention accordingly consists in the features of construction, combinations of elements, and relation of parts, all as herein illustratively described, and the scope of the applications of which will be indicated in the appended claims.

In the accompanying drawing which illustrates one of various possible embodiments of the invention,

Fig. 1 is a diagrammatic sectional view in elevation, depicting one form of an electron lens section according to the invention for an electron microscope, certain elements which form no part of the present invention having been omitted, and

Fig. 2 is a diagrammatic plan view of the magnetic beam-centering device shown in the structure of Fig. 1, with an end cover disc of the device removed.

2

Although for the purpose of more fully explaining the nature of certain features of the invention, an embodiment of the invention is here shown and will be described with especial reference to electron microscopes, the invention is not limited exclusively to its application to such instruments, since the principles and features of the invention are equally applicable to other electronic apparatus employing magnetic electron lenses, such as electron diffraction cameras, fine focus X-ray tubes and certain types of cathode ray tubes. Accordingly, it is to be understood that the disclosure herein is both given and intended to be interpreted illustratively and that other types of electronic apparatus (besides electron microscopes) of the general nature hereinabove indicated are embraced within the scope of application of this invention.

Conducive to a clearer understanding of certain features of this invention, it may be noted that in an electron microscope, a specimen is "illuminated" by a stream of electrons originating at a thermionic cathode and accelerated by an accelerating voltage, say of 30 to 60 kv. Commonly, the intensity of this electron stream impinging on the specimen is adjusted by means of a "condenser" electron lens placed between the thermionic cathode and the specimen. A greatly enlarged electronic image of the specimen is projected by an "objective" electron lens, or by an "objective" lens and one or more "projector" electron lenses, onto a screen which converts the electronic image into a light image by means of a fluorescent screen, or into a photographic image by means of a photographic plate.

Hitherto, in electron microscopes employing solenoids as magnetic electron lenses, it has been customary to enclose the solenoid in an iron shroud having a tubular inner wall which forms part of the vacuum-tight envelope of the evacuated chamber of the instrument, containing the electron beam. This inner wall of the shroud is usually interrupted by an annular gap to form a gap in the iron circuit, and this gap is mechanically closed in order to complete the vacuum-tight envelope by means of a tubular insert made from a non-magnetic material, e. g., brass, this gap being bridged magnetically within the evacuated chamber by a set of suitably shaped pole-pieces inserted into the part of the vacuum-tight envelope formed by the said inner wall of the iron shroud. With this type of construction, the

electron lens sections of the evacuated envelope of the instrument are usually joined to the other sections of the envelope by means of flexible metal bellows (known as Sylphon bellows) which permit the required adjustment of the electron lenses with respect to each other.

In accordance with the present invention, in an electron microscope or other electronic apparatus employing magnetic electron lenses, a different principle of construction is provided, as will now be explained in fuller detail illustratively by reference to the embodiment shown in the drawing.

Referring now to Fig. 1 of the drawing, in an electronic apparatus such as an electron microscope employing a magnetic electron lens system, the lens system is associated with a straight relatively thin-walled vacuum-tight tubular envelope 1 of the evacuated chamber containing the electron beam. The envelope 1 consists of non-magnetic material, e. g. brass, or nickel-copper alloy, and is utilised for aligning the various components of the electron lens system. In the embodiment, the electron lens system shown comprises two magnetic lenses denoted generally by reference numerals 2 and 3 respectively. The lens 2 comprises an iron-shrouded solenoid 4 embracing the envelope 1 so that the inner tubular wall 5*a* of its iron shroud 5 forms a sliding fit over the envelope 1. This inner wall 5*a* of the shroud has an aperture 6 therein extending around the wall to form an air gap in the magnetic circuit, which is bridged within the envelope 1 by a set of suitably shaped upper and lower iron pole-pieces 7 and 8 inserted into the envelope 1. The magnetic flux is transferred from the iron shroud 5 to the pole-piece inserts 7 and 8 through the non-magnetic wall of the envelope 1, the reluctance of this "air gap" constituted by the intervening non-magnetic wall being small compared with the reluctance of the "air gap" between the pole-piece inserts 7 and 8 which constitute the electron lens proper. As shown, each of the pole-piece inserts 7 and 8 has the form of a tube or cylinder which is closed at one end to form the pole-piece face and is a sliding fit within the tubular envelope 1. The lower, closed, end of the upper pole-piece 7 has a cylindrical axial hole 9 therein, and likewise the upper, closed, end of the lower pole-piece 8 has a cylindrical axial hole 10 therein, to allow the electron beam to pass through. The closed ends of the pole-pieces may also be provided with pumping holes (not shown). The correct distance between the pole-pieces 7 and 8, defining the "air gap" between them, is maintained by a suitable form of spacer 11 of non-magnetic material, e. g., brass, which is located between and with its ends abutting against the opposed end faces of the pole-pieces, this spacer being made hollow (e. g., tubular) or with an aperture to allow the electron beam to pass through. In the form shown, the spacer 11 is a short cylinder or disc which is a sliding fit within the tubular envelope 1 and has its end faces shaped to fit in abutting relation against the opposed end faces of the pole-pieces, the spacer having a cylindrical axial hole 12 therein aligned with the holes 9 and 10 in the pole-pieces for allowing passage of the electron beam.

The construction of the other electron lens 3 is analogous to that of the lens 2 and accordingly need not be described in further detail beyond indicating its corresponding components, viz., solenoid 13 and iron shroud 14 having a gap 15 in its inner wall 14*a*, a set of pole-piece inserts 16 and 17 within the envelope 1 and bridging the gap 15 in the iron circuit of the shroud 14, the inserts 16 and 17 having holes 18 and 19 for passage of the electron beam and being spaced by a spacer 20 having a hole 21 for the beam.

The correct distance between the sets of pole-pieces 7, 8 and 16, 17 belonging to the respective lenses 2 and 3 is maintained by a spacer 22 of non-magnetic material, e. g., brass, interposed between the pole-pieces 8 and 16. The spacer is of suitable form, e. g., tubular as shown, having a sliding fit within the tubular envelope 1 and having a passage for the electron beam. Likewise, additional spacers such as 23 and 24 may be provided at each end of the assembled sets of pole-pieces and intervening spacers 11, 20 and 22, for maintaining the assembly in the correct axial position in the envelope 1.

If desired, there may also be included in the assembly of the various pole-piece inserts and spacers, various other elements (not shown) forming components of the electron lens system, such as beam stops or the like for limiting the angle of the electron beam proceeding through the lens system so as to reduce spherical aberrations.

The tubular envelope 1, broadly speaking, fulfils two functions at the same time; it constitutes a vacuum-tight envelope and also serves for the correct axial alignment of the inserted pole-pieces and spacers. The envelope 1 may consist of a single tube which performs both these functions, but in a preferred construction, as shown, the envelope 1 comprises two straight relatively thin-walled tubes 1*a* and 1*b* of non-magnetic material, which fit telescopically one within the other, the outer tube 1*a* constituting the vacuum-tight envelope proper, upon which the iron-shrouded solenoids 4 and 13 are slidingly fitted, and the inner tube 1*b* receiving the various pole-piece inserts and spacers and constituting an alignment tube for their correct axial alignment. This double-tube construction of the envelope allows of the various pole-pieces, spacers and any other elements which are to be inserted into the envelope, being assembled in the alignment tube 1*b* to form an independent structural unit for insertion into the vacuum-tight envelope tube 1*a*. This construction permits easy withdrawal of the alignment tube and unit, e. g. for cleaning or adjusting the pole-piece inserts or other elements (such as beam stops or the like) in the unit, without interfering with the vacuum-tight junctions of the envelope tube 1*a*.

The alignment tube 1*b* is shown as having an inwardly directed flange 25 forming a stop at its lower end, against which the lower end spacer 24 abuts. The various pole-pieces, spacers and any other desired inserts are assembled in abutting end to end relation in the tube 1*b* by inserting them in proper sequence into the upper, open, end of the tube. A ring 26 screwed into the threaded upper end of the tube 1*b* so as to abut against the upper end spacer 23 forms a secondary stop to retain the inserted assembly in correct position in the tube. The alignment tube 1*b* supporting the various inserts assembled therein is supported in the envelope tube 1*a*, by the lower end of the tube 1*b* resting upon an inwardly directed flange 27 at the lower end of the envelope tube.

If the pole-pieces of the lenses are machined with great accuracy, and the iron used for them is of good homogeneity, and extraneous disturbing magnetic fields are excluded by suitable magnetic shielding means (not shown), the invention

permits of assembling the various electron lenses in correct optical alignment without any adjustable connecting members such as Sylphon bellows or the like, and permits of maintaining the lenses in their correct alignment during subsequent operation of the instrument.

The described electron lens section of the instrument is vacuum-tightly joined to the other evacuated sections of the instrument, such as the cathode space, or specimen chamber, or photographic camera attachment, by means of connectors embodying rubber or rubber-like gasket seals. In Fig. 1, two such connectors are depicted, one at each end of the envelope 1. Each connector comprises a tubular socket body 28 which receives an end of the envelope tube 1*a* and is adapted to be joined to the adjacent section of the instrument. An annular rubber or rubber-like gasket 29 seated in the socket is arranged between the exterior of the envelope tube 1*a* and the surrounding wall of the socket, and a gland ring 30 is screwed into the socket and compresses the gasket 29 through an intervening metal washer 31, so as to make a vacuum-tight sealing joint between the envelope tube 1*a* and the socket 28.

Sometimes it may be necessary or desirable to provide for a limited amount of external adjustment of the position of the electron beam for centering purposes and this is effected according to a feature of the invention, by applying a weak transverse magnetic field to an appropriate portion of the envelope 1. This field may be produced by means of either a permanent magnet or a D. C. energised coil or coils mounted on the envelope. By way of example, there is shown in the drawing one such magnetic centering device mounted on the envelope for centering the beam before it passes through the electron lens system. The centering device shown comprises a frame or housing 32 of non-magnetic material, e. g., brass, constituted of a short tube or cylinder 33 with end closure discs 34 each having a central aperture 35 of diameter to fit the envelope tube 1*a*. Within the housing 32 is mounted an electromagnet structure, seen more clearly in Fig. 2, which comprises a coil 36 mounted on a core 37 fitted with soft iron pole-pieces 38 which have their faces shaped to fit closely to and follow the curvature of the wall of the envelope tube 1*a*. If desired, soft iron inserts (not shown) may be provided within the envelope 1 to concentrate and parallelize the transverse magnetic field formed between the pole-pieces 38, by producing a high ratio of length of strictly homogeneous field to length of fringing magnetic field, which can be readily achieved owing to the small cross-section of the electron beam. It will also be appreciated that, if so desired, a magnetic beam-centering device, such as that described, may be provided between the solenoids of successive electron lenses.

I claim:

1. In electronic apparatus of the class described, in combination, a vacuum-tight tubular envelope of non-magnetic material, and a magnetic electron lens comprising a solenoid and a shroud of magnetic material housing said solenoid and mounted coaxially on said envelope, said shroud including an inner tubular wall forming a sliding fit on said envelope and having an annular aperture in said wall to form an air gap in the magnetic circuit of said shroud, an assembly of inserts assembled within said envelope in end to end abutting relation axially of said envelope and including a pair of axially

spaced pole-pieces of magnetic material and spacing means of non-magnetic material between and abutting against said pole-pieces for maintaining a predetermined axial spacing therebetween, and means for locating and retaining said assembly in a predetermined axial position in said envelope with said pole-pieces opposite said aperture to magnetically bridge said air gap, said inserts having engagement with the wall of said envelope so as to be axially aligned thereby, and said inserts having axially aligned apertures for passage of an electron beam through said assembly.

2. The combination defined in claim 1, wherein said inserts each slidably engage the wall of said envelope.

3. The combination defined in claim 2, wherein said inserts are each of cylindrical form having a sliding fit in said envelope.

4. The combination defined in claim 1, wherein said means for locating and retaining said assembly include means on said envelope forming a stop at one end of said assembly and means detachably and adjustably secured to said envelope forming an adjustable and removable stop for the other end of said assembly.

5. In electronic apparatus of the class described, the combination defined in claim 1 and further comprising a connector having a socket coaxially receiving an end of said envelope, a sealing gasket within said socket and surrounding said envelope, and a gland for compressing said gasket to form a vacuum-tight seal between said envelope and said socket.

6. In electronic apparatus of the class described, the combination defined in claim 1 and further comprising means embracing a portion of said envelope for applying a transverse magnetic field thereto.

7. In electronic apparatus of the class described, in combination, a vacuum-tight tubular envelope of non-magnetic material, and a plurality of magnetic electron lenses disposed in axially spaced and aligned relation along said envelope, said lenses comprising a plurality of solenoids, one for each lens, and a plurality of shrouds of magnetic material housing said solenoids respectively and mounted coaxially on said envelope, each shroud including an inner tubular wall forming a sliding fit on said envelope and having an annular aperture in said wall to form an air gap in the magnetic circuit of said shroud, an assembly of inserts assembled within said envelope in end to end abutting relation axially of said envelope and including a plurality of pairs of axially spaced pole-pieces of magnetic material, one pair for each lens, spacing means of non-magnetic material between and abutting against the pole-pieces of each pair of pole-pieces for maintaining a predetermined axial spacing between the pole-pieces of each pair, and spacing means between successive pairs of pole-pieces for maintaining a predetermined axial spacing between the successive pairs of pole-pieces and means for locating and retaining said assembly in a predetermined axial position in said envelope so that said pairs of pole-pieces lie respectively opposite said apertures to magnetically bridge said air gaps respectively, said inserts having engagement with the wall of said envelope so as to be axially aligned thereby, and said inserts having axially aligned apertures for passage of an electron beam through said assembly.

8. The combination defined in claim 7, where-

in said inserts each slidably engage the wall of said envelope.

9. The combination defined in claim 8, wherein said inserts are each of cylindrical form having a sliding fit in said envelope.

10. The combination defined in claim 7, wherein said means for locating and retaining said assembly include means on said envelope forming a stop at one end of said assembly and means detachably and adjustably secured to said envelope forming an adjustable and removable stop for the other end of said assembly.

11. In electronic apparatus of the class described, the combination defined in claim 7 and further comprising a connector having a socket coaxially receiving an end of said envelope, a sealing gasket within said socket and surrounding said envelope, and a gland for compressing said gasket to form a vacuum-tight seal between said envelope and said socket.

12. In electric apparatus of the class described, the combination defined in claim 7 and further comprising means embracing a portion of said envelope for applying a transverse magnetic field thereto.

13. In electronic apparatus of the class described, in combination, means including a tube of non-magnetic material forming a vacuum-tight envelope of the apparatus, a lens alignment tube of non-magnetic material telescopically fitted within said first-mentioned envelope tube and a magnetic electron lens comprising a solenoid and a shroud of magnetic material housing said solenoid and mounted coaxially on said envelope tube, said shroud including an inner tubular wall forming a sliding fit on said envelope tube and having an annular aperture in said wall to form an air gap in the magnetic circuit of said shroud, an assembly of inserts assembled in end to end abutting relation within and axially of said alignment tube and including a pair of axially spaced pole-pieces of magnetic material and spacing means of non-magnetic material between and abutting against said pole-pieces for maintaining a predetermined axial spacing therebetween, means for supporting said assembly in a predetermined axial position in said alignment tube, and means for supporting said alignment tube in a predetermined axial position in said envelope tube, whereby to locate said pole-pieces opposite said aperture to magnetically bridge said air gap, said inserts having engagement with the wall of said alignment tube so as to be axially aligned thereby, and said inserts having axially aligned apertures for passage of an electron beam through said assembly.

14. In electronic apparatus of the class described, the combination claimed in claim 13 and further comprising a connector having a socket coaxially receiving an end of said envelope tube, a sealing gasket within said socket and embracing said envelope tube, and a gland for compressing said gasket to form a vacuum-tight seal between said envelope tube and said socket.

15. In electronic apparatus of the class described, the combination defined in claim 13 and further comprising means embracing a portion of said envelope tube for applying a transverse magnetic field thereto.

16. The combination defined in claim 13, said inserts each slidingly engaging the wall of said alignment tube, said envelope tube including abutment means forming a stop at one end thereof for supporting said alignment tube thereon, said alignment tube including abutment means forming an axial stop at one end of said assembly of inserts, and means detachably and adjustably secured to said alignment tube forming an adjustable and removable secondary axial stop at the other end of said assembly.

17. In electronic apparatus of the class described, in combination, means including an envelope tube of nonmagnetic material forming a vacuum-tight envelope of said apparatus, a lens alignment tube of non-magnetic material telescopically fitted within said envelope tube, and a plurality of magnetic electron lenses disposed in axially spaced and aligned relation along said tubes, said lenses comprising a plurality of solenoids, one for each lens, and a plurality of shrouds of magnetic material housing said solenoids respectively and mounted coaxially on said envelope tube, each shroud including an inner tubular wall forming a sliding fit on said envelope tube and having an annular aperture in said wall to form an air gap in the magnetic circuit of said shroud, an assembly of inserts assembled in end to end abutting relation within and axially of said alignment tube and including a plurality of pairs of axially spaced pole-pieces of magnetic material, one pair for each lens, spacing means between and abutting against the pole-pieces of each pair of pole-pieces for maintaining a predetermined axial spacing between the pole-pieces of each pair, and spacing means between successive pairs of pole-pieces for maintaining a predetermined axial spacing between the successive pairs of pole-pieces, means for supporting said assembly in a predetermined axial position in said alignment tube, and means for supporting said alignment tube in a predetermined axial position in said envelope tube, whereby to locate said pairs of pole-pieces respectively opposite said apertures to magnetically bridge said air gaps respectively, said inserts having engagement with the wall of said alignment tube so as to be axially aligned thereby, and said inserts having axially aligned apertures for passage of an electron beam through said assembly.

18. In electronic apparatus of the class described, the combination claimed in claim 17 and further comprising a connector having a socket coaxially receiving an end of said envelope tube, a sealing gasket within said socket and embracing said envelope tube, and a gland for compressing said gasket to form a vacuum-tight seal between said envelope tube and said socket.

19. In electronic apparatus of the class described, the combination defined in claim 17 and further comprising means embracing a portion of said envelope tube for applying a transverse magnetic field thereto.

20. The combination defined in claim 17, said inserts each slidingly engaging the wall of said alignment tube, said envelope tube including abutment means forming a stop at one end thereof for supporting said alignment tube thereon, said alignment tube including abutment means forming an axial stop at one end of said assembly of inserts, and means detachably and adjustably secured to said alignment tube forming an adjustable and removable secondary axial stop at the other end of said assembly.

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No references cited.