Nov. 25, 1952 J. W. COLTMAN ET AL 2,619,598

ELECTRON DIFFRACTION DETECTING SYSTEM

Filed June 29, 1949

Fig.1.

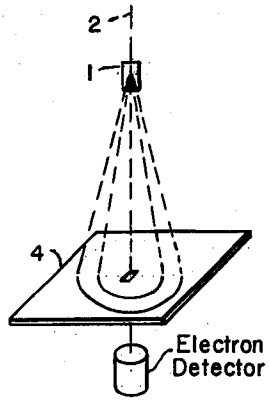


Fig.2.

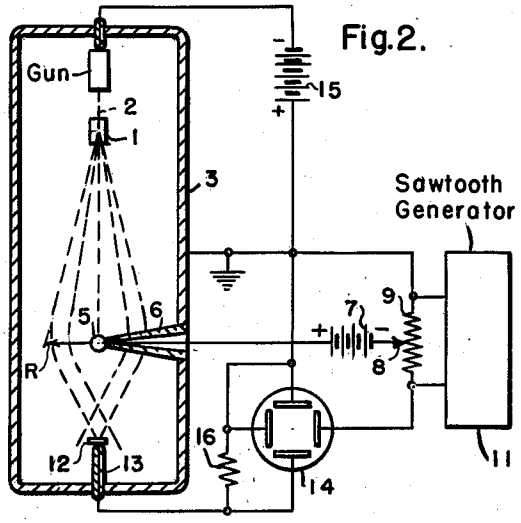


Fig.3.

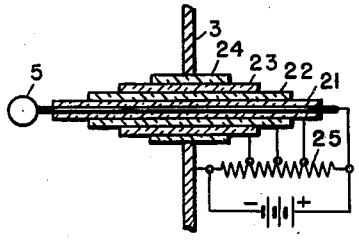


Fig.4.

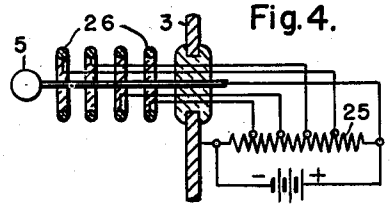


Fig.6.

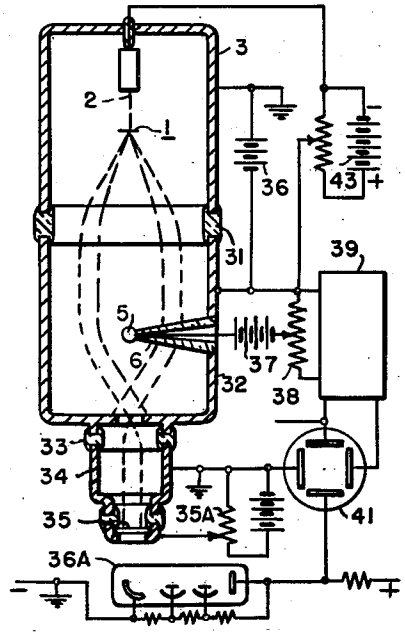


Fig.7.

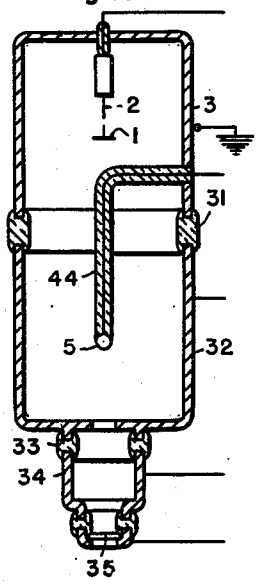
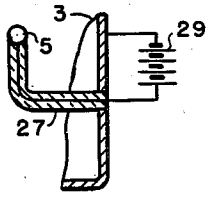


Fig.5.



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ELECTRON DIFFRACTION DETECTING SYSTEM

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Application June 29, 1949, Serial No. 102,122

19 Claims. (Cl. 250—49.5)

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Our invention relates to electron diffraction cameras, and in particular relates to arrangements by which the variation of intensity of the diffraction pattern with angle of diffraction may be registered graphically and measured.

In electron diffraction cameras a fine beam of constant voltage electrons is projected onto a specimen of a substance for which it is desired to obtain a pattern. It is found that electrons are diffracted in such an arrangement at various angles from the axis of the impinging beam in such a way as to produce conical streams of electrons diverging at various angles to the axis of the impinging stream. The intensity distribution of the diffracted electrons at various angles relative to the axis of the cones is found to be a characteristic of the material undergoing study and may be referred to as the electron diffraction pattern of that material.

In accordance with the prior art, such diffraction patterns have been recorded by positioning photographic films or plates to be intersected by the electron cones. However, this procedure is unsatisfactory in that it gives only rough measurements of intensity variation, and is somewhat time-consuming because it is necessary to develop the photographs before the desired information as to the diffraction pattern is obtained. The procedure becomes especially unsatisfactory if, as is sometimes the case, the physical characteristics of the sample being studied are changing with time. It is obvious that in any case where the changes are rapid it becomes practically impossible to record the diffraction patterns accurately.

In application Serial No. 102,123 filed substantially contemporaneously with this one and assigned to the same assignee and entitled "Electron Diffraction Camera," John W. Coltman discloses an arrangement in which the system of conical electron beams forming such a diffraction pattern impinges upon a plate electrode having a small aperture through which a small section of the beam is allowed to pass to impinge upon a collector electrode connected to a measuring oscilloscope. By magnetically deflecting the electron beam, this plate aperture is in effect displaced along a radius of the electron beam system, and variations in the intensity of the latter are recorded on an oscilloscope. The present application describes an alternative arrangement in which magnetic deflection of the beam system is avoided by employing what may be considered to be an electron-optical system in which the focal length is varied to make possible a recording of the current distribution in the diffracted beam.

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One feature of our invention is the provision of an arrangement whereby an oscilloscope records a graph relating the diffraction angle with the total number of electrons diffracted through the angle.

One object of our invention is, accordingly, to provide a novel apparatus for recording, in an electron diffraction apparatus, the relation between diffraction angle and total number of electrons diffracted through that angle.

Another object of our invention is to provide a novel form of electron diffraction camera which directly registers the relationship between diffraction angle and the total number of electrons deflected through such an angle.

Still another object of our invention is to provide a novel electron diffraction camera which records on the screen of an oscilloscope a curve truly representing the diffraction angle as abscissa and as ordinate the total number of electrons diffracted through at the angle.

Still another object of our invention is to provide a graphical electron diffraction pattern registering device which records diffraction angle as abscissa against total electron current as ordinate, and in which the sensitivity for the ordinate scale remains the same throughout the abscissa range.

Other objects of our invention will become apparent upon reading the following description taken in connection with the drawings, in which:

Figure 1 is a diagram useful in explaining the principles of our invention;

Fig. 2 is a schematic showing of an elementary form of device embodying the principles of our invention;

Figs. 3, 4 and 5 are schematic representations of alternative forms of one portion of the device shown in Fig. 2;

Fig. 6 is a schematic illustration of an alternative form of the embodiment shown in Fig. 2; and

Fig. 7 is an illustration of a modified form of a portion of the embodiment shown in Fig. 6.

Referring in detail to Figure 1, a sample 1 of material which it is desired to obtain an electron diffraction pattern is supported by any suitable means (not shown) in the path of an extremely fine electron beam 2. So-called electron guns and other arrangements for producing such fine streams of electrons are well known in the electronics art today and are believed to require no separate description.

After impinging at a glancing angle on the

sample 1, it will be found that the electrons are diffracted in such a way as to produce, in effect, a number of half-cones having various apex angles, coaxial to the axis of the original electron beam 2. If a fluorescent plate 4 were supported in the path of the conical beams, it would be intersected by the conical beams and would be found to show successive semicircles representing the traces of these cones at the plate 4. Such arrangements as I have so far described are found in certain diffraction cameras of the prior art on which my arrangement is an improvement.

The above-mentioned sample and electron beam may be enclosed within a suitable container which may be vacuum-tight if desired and which is believed to require no detailed description since such arrangements are well known in the electronics art today. A publication entitled "RCA Electron Diffraction Unit" published by Radio Corporation of America, Rockefeller Center, New York city, describes an apparatus employing such an electron beam.

Our present invention employs the general arrangement as illustrated in Fig. 2 in which an electrical field is impressed by what we may term a focusing electrode 5 on the paths of the electrons in the above-mentioned conical beam and acts, in effect, as an electron lens which by imparting curved paths to these electrons brings all the electrons in a cone of a given aperture angle to a focus, as indicated by the dotted lines in Fig. 2. The conical beams nearer the central axis are brought to a focus at points just below the focusing electrode 5 while the foci of conical beams of larger aperture angle are positioned at greater and greater distances from electrode 5. The actual distance f from the focusing electrode to the focus at which electrons constituting a cone of any given aperture angle converge is dependent upon the magnitude of the voltage impressed on the electrode 5. Thus mathematical analysis shows that the distance f above-mentioned in cm. is given approximately by the formula

$$f=\frac{R^2\overline{V}}{AB}$$

where A is the radius in cm. of the electrode 5, B its potential in volts relative to container 3, $\overline{V}$ the energy in electron-volts of an electron when it emerges from the sample and R is the perpendicular distance in cm. from the center of electrode 5 to the path the electron would have followed had focusing electrode 5 not been used.

While we have described a simple electron lens system, it will be evident to those skilled in the art that other electron lenses may be used provided they are axially symmetric and have a marked dependence of focal distance on the distance R; i. e. have high spherical aberration.

It will be evident from these considerations that by locating a catcher-electrode 12 on the central axis of the conical beam system, the electrons in some one cone will be caused to focus upon it; and that by varying the potential of the focusing electrode 5 (e. g. by a periodic voltage generator 11), one of the conical beams after another may be focused on the catcher-electrode 12. By causing current collected by the catcher-electrode 12 to deflect the luminous spot on the screen of an oscilloscope 14 in one coordinate, and by deflecting the luminous spot along another coordinate by means of the periodic voltage derived from source 11, a graph representing the variation of electron current in the cone with aperture angle thereof may be traced on the screen of the oscilloscope 14.

In conformance with the foregoing, a focusing electrode 5, which may be of extremely small diameter, is supported by an insulator 6 at a point on the extension of the path of the electron beam 2, and is maintained at a suitable positive potential relative to the container 3, by a source of direct-current voltage 7, in series with the movable tap 8 on a potential divider 9. The potential divider 9 is supplied with voltage from a saw-tooth generator 11 of a type too well known in the art to require separate description. It will be evident that the combined effect of the voltage drop across the potential divider 9 and the voltage source 7 is to impress a periodically varying (i. e., a saw-tooth) wave voltage on the electrode 5, relative to the container 3. Some distance from the extension of the electron beam 2 is positioned the catcher-electrode 12 which is supported by an insulating bushing 13 from the wall of the container 3. The electrode 12 is connected to impress on one of the deflecting plates of the oscilloscope 14 a voltage which is proportional to a number of electrons brought to a focus on electrode 12 at any instant by the focusing electrode 5. The electrode 12 should preferably be of relatively small surface area. The opposite deflecting plate to that just referred to in oscilloscope 14 is connected to the envelope 3. The other set of deflecting plates in oscilloscope 14 is impressed with a saw-tooth voltage derived from the saw-tooth generator 11.

The cathode of the electron gun from which the electron beam is derived is connected through a direct-current voltage source 15 sufficient to accelerate the electrons in the beam 2 to the desired velocity for bombarding the sample 1. The envelope 3 is preferably grounded.

With the arrangement above described, a moment's consideration will show that at any instant the electrons in some particular one of the conical beams will impinge on the catcher-electrode 12, the electrons in the other conical beams passing the electrode 5 to strike the walls of the container 3 and be returned to the electron gun through the voltage source 15. However, the electrons of the particular conical beam incident upon the catcher-electrode 12 will flow back to the electron gun through a resistor 16 and will thereby deflect the luminous spot on the oscilloscope 14 to a distance proportional to the current flow focured on catcher-electrode 12 at that instant.

Correspondingly, the position of the luminous spot on the screen of oscilloscope 14 will also be determined by the instantaneous value, at the moment, at the voltage impressed on the horizontal deflection plates of the oscilloscope 14.

As the voltage of saw-tooth generator 11 changes, the conical beams having wider and wider apertures will be focused on the catcher-electrode 12, while at the same time, the luminous spot on screen 14 is deflected further and further along the axis of abscissas. The luminous spot will, accordingly, trace on the screen of oscilloscope 14 a graph representing the variation during the periodic cycle of saw-tooth generator 11, of the current flow in conical beams of different aperture angle.

One of the practical problems in connection with the arrangement thus described, is to impart the desired potential to the electrode 5

without distorting the electric gradient of the electrical field which focuses the electron beams. One way of doing this is to make the supporting member 6 for the electrode 5 of some high resistance material (e. g., carbon), which will permit current flow therein to produce a potential gradient in the region it occupies which is a replica of the potential gradient which would exist there were the support 6 and the lead wire which it encloses absent from the system. The wall thickness of the member 6 may be tapered in such a way as to produce the desired variation of potential gradient from point to point.

In Fig. 3, we show an alternative expedient for avoiding the distortion of the electric field in the neighborhood of the lead which supplied voltages to the electrode 5. This arrangement is somewhat similar in appearance to the "condenser bushings" now known in the electrical art and comprises an insulating tube 21 closely surrounding the in-lead to the electrode 5 and provided with a conductive coating on its exterior; a second insulating tube 22 of somewhat shorter length surrounds the first insulating tube 21 and is likewise provided with a conductive coating on its exterior; a third insulating tube 23 likewise provided with a conductive coating and shorter than the tube 22 surrounds the latter, and a fourth insulating tube 24 provided with a conductive coating connected to the container wall 3 surrounds the tube 23. The various conducting coatings above-mentioned are respectively connected to suitable tap points on a potential divider 25 which is connected between the container 3 and the external terminus of the in-lead to electrode 5. By varying the position of these tap points, the potential gradient in the neighborhood of the insulating tubes inside the container 3 may be varied at will to approximate the value it would have were the in-lead to electrode 5 absent.

Fig. 4 shows still another arrangement for controlling the potential gradient between the electrode 5 and the wall of container 3. It comprises a plurality of conducting rings 26 which may be insulatingly supported on the in-lead to electrode 5 and which are connected by conductors passing through the centers of the rings 26 to variable taps on a potential divider similar to that already described in Fig. 3. By varying the position of these taps, the potential gradient in the space surrounding the rings 26 may be made to approximate that which would exist were the in-lead to the electrode 5 absent from the system.

Fig. 5 shows stil another arrangement for imparting the desired potential to the electrode 5 and comprises a support for the latter positioned along the extension of the electrode beam 2 in the direction away from the sample 1. At a point some distance from the electrode 5, this support is turned at right angles and passes through the wall of container 3 to the terminal of the voltage source 29 which imparts to the electrode 5 its desired potential. The in-lead to the electrode 5 is provided with a coating or sheath 27 of insulating material.

In Fig. 6, we show a modified form of the arrangement in Fig. 3 which is designed to make it possible to employ a smaller voltage to energize the electrode 5. In the Fig. 6 modification, the wall of the container is interrupted at a point somewhat below the sample 1 by an insulating wall portion 31 and the container wall below

the insulator 31 comprises a conductive wall portion 32 through which the in-lead and support for the electrode 5 are brought in in the same manner as in Fig. 1.

An annular plate provided with a central aperture closes the lower end of the wall portion 32. Insulatingly supported by a member 33 on this annular plate is a wall portion 34 which insulatingly supports at its lower end a fluorescent screen 35 which is given a positive potential relative to wall portion 34 by a voltage source 35A. The wall portion 34 is preferably grounded. The wall portion 3 is likewise grounded, while the wall portion 32 is kept at a negative potential relative to the wall portion 3 by a voltage source 36. The electron gun producing the electron stream 2 is provided with a voltage somewhat more negative than that of wall portion 32 by means of the adjustable voltage source 43.

As a result of this arrangement, it will be seen that the electrons in the stream 2 are first accelerated to the voltage corresponding to that of the sources 36 and 43 in series, and thereupon impinge upon the sample 1. Passing through the latter, they produce a system of conical electron beams representing the diffraction pattern of the substance 1 and then after passing by the insulator 31, enter the field within the container 32 and are largely deprived of their kinetic energy by virtue of the negative potential on container 32. They, therefore, approach the electron lens constituted by the electrode 5 with a comparatively low velocity corresponding to the voltage of source 43 and as a result, the potential to which electrode 5 must be elevated in order to readily focus the electrons on the aperture in the annular plate above-mentioned, is reduced to a readily usable value. To give an example, the voltage source 36 may be of 45 kilovolts and the potential of the electrode 5 may be of 5 kilovolts. The above-mentioned potential is impressed on the electrode 5 by the voltage source 37 in series with the potential divider 38 which is supplied with saw-tooth waves by a saw-tooth generator 39.

The saw-tooth generator 39 supplies the horizontal deflection plates of the oscilloscope 41, while the vertical plates of that oscilloscope are respectively connected to ground and to be energized in correspondence with the current reaching the catcher-electrode 35.

Those electrons which are not focused on the aperture in the annular plate above-mentioned, pass to the cathode of the source of electron beams 2, while those electrons which are focused on said aperture strike catcher-electrodes 35 and pass through source 35A to energize the vertical deflection plates of the oscilloscope 41.

For the sake of simplicity, the vertical plates of the oscillscope 14 in Fig. 2 have been shown as driven from a voltage derived directly from the electron current impinging on collector 13 in Fig. 2. In practice, there is seldom enough current to accomplish this, and it may be necessary to insert amplifiers in this circuit such as are well known in the art. Alternatively, it may be desirable to use a detector of the fluorescent screen-photomultiplier type such as is described in the application to be filed contemporaneously with this one, entitled "Electron Diffraction Camera" John W. Coltman, Serial No. 102,123 filed June 29, 1949. Fig. 6 has been arranged to show such a type of detection. In using such a detector, it is advantageous if the electrons being detected have a high energy, and therefore

in Fig. 6 means have been shown by which the original kinetic energy of the electrons may be restored after the selection process is completed. This means comprises the use of wall portion **34**, insulatedly supported from wall portion **32** by means of insulator **33**, and held at ground potential, and this may be assisted by a positive potential impressed on screen **35** by voltage source **35A**. Electrons leaving enclosure **32** are accelerated on entering the region of strong electric field between wall enclosure **34**, which is at ground potential and enclosure **32** which is at high negative potential supplied by source **36**. The high speed electrons then may enter the enclosure containing screen **35** for detection by that fluorescent screen and photomultiplier **36A**. Such a photomultiplier and energizing circuits therefor are too well known to require detailed description, but reference may be made to F. H. B. Marshall and J. W. Coltman Patent 2,512,355, X-ray Thickness Gauge, which issued June 20, 1950. Suitable configuration of the aperture in the base of enclosure **32** and of the chamber **34**, together with potential fixing devices typified by adjustable voltage source **35A**, may be chosen in accordance with well known principles of electron optics to shape the electron beam in a manner convenient for detection.

Fig. 7 shows still another way of supporting the electrode **5** in the container of the type shown in Fig. 6 and comprises an in-lead wire which passes from the voltage source **37** through an insulated bushing in the wall of the container **3** and then passes along the extension of the electron beam **2** downward to support the electrode **5**. The in-lead thus supporting electrode **5** is cased in insulating sleeve **44**. Otherwise, the connections of Fig. 7 are similar to those of Fig. 6.

It will be recognized that the electrode **5** in Fig. 2 may likewise be supported in position by an arrangement similar to that just described in connection with Fig. 7, and that the electrode **5** in Fig. 6 may be supported by the expedients shown in Figs. 3, 4 and 5. While the diameter of the sphere constituting electrode **5** may be given various values, it will, in many cases, be found sufficient if it is no larger than the diameter of the in-lead to it, and this electrode may consist of simply an exposed portion of such an in-lead.

Since numerous changes may be made in the above-described construction, and different embodiments of the invention may be made without departing from the spirit and scope thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

We claim as our invention:

1. An electron diffraction recording device comprising means for bombarding a sample material with a concentrated electron beam to produce a conical electron beam system, and an electron lens system having a high spherical aberration for converging the electrons in each of the various cones simultaneously to a different point on the extended axis of said conical beam system.

2. An electron diffraction recording device comprising means for bombarding a sample material with a concentrated electron beam to produce a conical electron beam system, an electron lens system for focusing the electrons in various cones at different points on the extended axis of said conical beams, and a catcher-electrode of restricted size positioned at a point on said axis.

3. An electron diffraction recording device comprising means for bombarding a sample material with a concentrated electron beam to produce a conical electron beam system, an electron lens system for focusing the electrons in various cones at different points on the extended axis of said conical beam system, a catcher-electrode of restricted size positioned at a point on said axis, and means for varying the focal length of said electron lens.

4. An electron diffraction recording device comprising means for bombarding a sample material with a concentrated electron beam to produce a conical electron beam system, an electron lens system for focusing the electrons in various cones at different points on the extended axis of said conical beam system, a catcher-electrode of restricted size positioned at a point on said axis, and means for periodically varying the focal length of said electron lens system.

5. An electron diffraction recording device comprising means for bombarding a sample material with a concentrated electron beam to produce a conical electron beam system, an electron lens system for focusing the electrons in various cones at different points on the extended axis of said conical beam system, a catcher-electrode of restricted size positioned at a point on said axis, means for periodically varying the focal length of said electron lens system, and means for plotting the current flowing from said catcher-electrode against said variations in focal length of the electron lens system.

6. In combination with means for producing a conical electron beam system constituting the diffraction pattern of a sample material, an electrode positioned on the axis of said conical beam system, means for impressing a periodically varying voltage on said electrode relative to said sample, a catcher-electrode positioned on said axis more remote from said sample than said electrode, and current-responsive means energized by the output of said catcher-electrode.

7. In combination with means for producing a conical electron beam system constituting the diffraction pattern of a sample material, an electrode positioned on the axis of said conical beam system, means for impressing a periodically varying voltage on said electrode relative to said sample, a catcher-electrode positioned on said axis more remote from said sample than said electrode, current-responsive means energized by the output of said catcher-electrode, said current-responsive means recording one coordinate of a graph, and the other coordinate of said graph being responsive to said periodic voltage.

8. In combination with means for producing a conical electron beam system constituting the diffraction pattern of a sample material, an electrode positioned on the axis of said conical beam system, means for impressing a periodically varying voltage on said electrode relative to said sample, a catcher-electrode positioned on said axis more remote from said sample than said electrode, current-responsive means energized by the output of said catcher-electrode, said current-responsive means comprising one pair of deflecting plates of an oscilloscope, the other pair of deflecting plates of said oscilloscope being energized by said periodic voltage.

9. The arrangement described in claim 6, in which said periodic voltage has a saw-tooth wave form.

10. The arrangement described in claim 7 in

which said periodic voltage has a saw-tooth wave form.

11. The arrangement described in claim 8 in which said periodic voltage has a saw-tooth wave form.

12. In an apparatus for recording electron diffraction patterns of sample materials, means for bombarding said material with a concentrated electron beam to produce a conical electron diffraction pattern, said means being positioned in one portion of a container having a first conducting wall portion, said container also having a second conducting wall portion insulated from said first conducting wall portion and surrounding the axis of said conical beam system, means for supporting a focusing electrode within said second conducting wall portion and for imparting to it a predetermined potential relative thereto, an aperture in said second conducting wall portion positioned on the axis of said conical beam system, a third conducting wall portion surrounding the extension of said axis through said aperture, and a catcher-electrode positioned on said axis beyond said third conducting wall portion.

13. The arrangement set forth in claim 12 in which means are provided for impressing a saw-tooth voltage upon said focusing electrode, relative to said second conducting wall section.

14. The arrangement set forth in claim 12 in which means are provided for maintaining said second wall section at a potential close to that of the cathode from which said electron beam originates, while said first and third conducting wall

sections are maintained at a substantial positive potential, relative to said cathode.

15. The arrangement described in claim 12 in which said focusing electrode is supported from said second wall portion by means for regulating the potential gradient.

16. The arrangement described in claim 14 in which said catcher-electrode comprises a screen emitting light in response to electron impact.

17. The arrangement according to claim 16 in which a photomultiplier irradiated by said screen energizes an indicating device.

18. The arrangement according to claim 17 in which the indicating device is a graph recorder having its amplitude-coordinate energized by the output of said photomultiplier, and its time-coordinate energized by a periodic-voltage source which also impresses voltage on said focusing electrode.

19. The arrangement according to claim 18 in which the indicating device is an oscilloscope.

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