May 27, 1947. R. T. BAYNE 2,421,182

STROBOSCOPE

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Fig. 1.

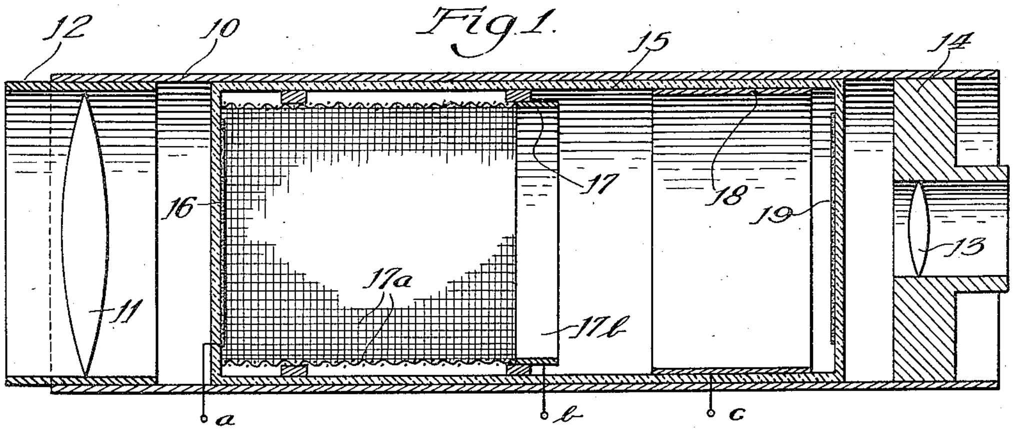
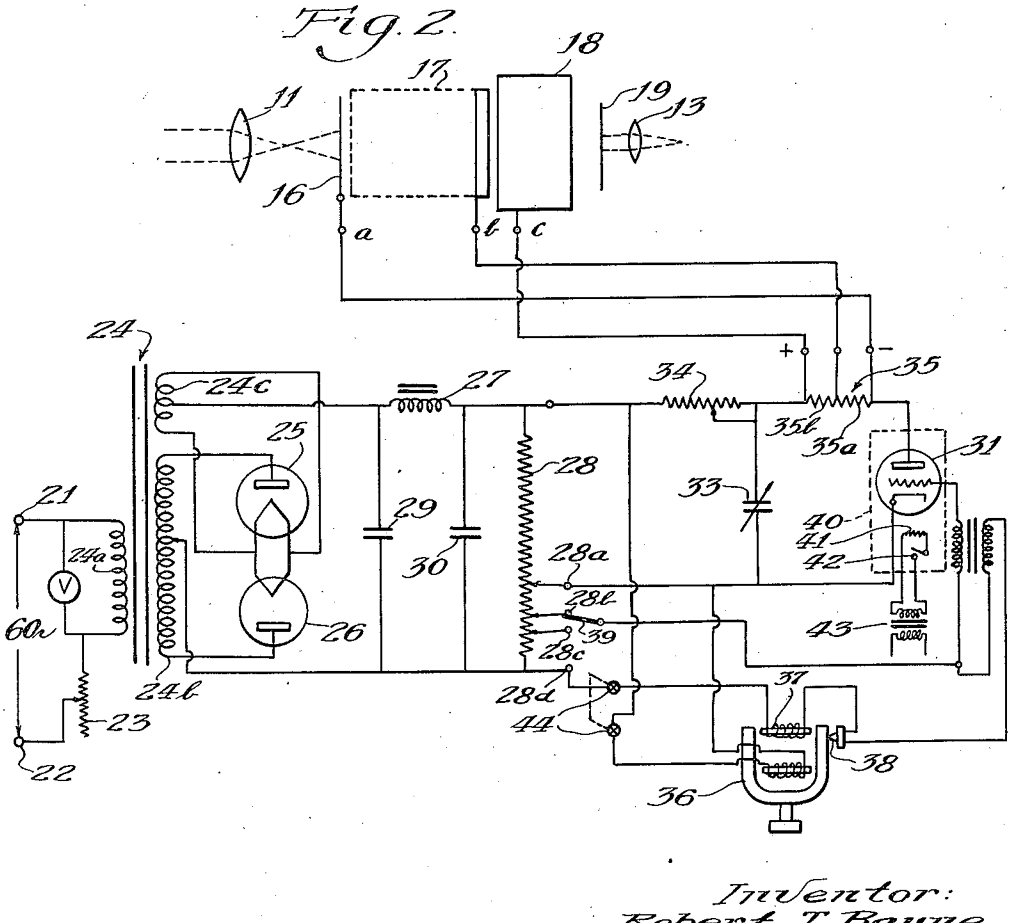


Fig. 2.



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STROBOSCOPE

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Application October 29, 1943, Serial No. 508,257

15 Claims. (Cl. 250—41.5)

1

This invention relates to a stroboscope, and more particularly to a stroboscope operating electronically rather than by flashes of light.

One feature of this invention is that it provides an improved stroboscope apparatus; another feature of this invention is that stroboscopic inspection of a device may be made with a device normally illuminated, either indoors or outdoors, and without the use of interrupted light; still another feature of this invention is that electrons are freed in a pattern instantaneously corresponding to an instantaneous view of the object or device being studied, and movement of these electrons is controlled to provide the desired intermittent view, the electrons being adapted to affect electron-sensitive means, as a fluorescent screen; and yet another feature of this invention is that the apparatus may be controlled to provide any desired effective period of view. Other features and advantages of this invention will be apparent from the following specification and the drawings, in which:

Figure 1 is a longitudinal sectional view of one embodiment of a portion of my invention; and Figure 2 is a diagram of the circuit associated with a portion of the embodiment shown in Figure 1.

One difficulty with stroboscopes operating on the flashing light principle, of course, is that they are not satisfactory for use under normal conditions where the object or device to be studied is quite well illuminated. For example, a device operating outdoors, in sunlight, or even indoors under general illumination, as in a factory, cannot be well studied by the use of such stroboscopes.

I have devised and am here disclosing and claiming an entirely new type of stroboscope, wherein an optical image of the device being studied, an image which can be derived by lenses under conventional general illumination, is used to free electrons in a pattern instantaneously corresponding to an instantaneous view of the object; and movement of these electrons through an electron lens system to a fluorescent screen is controlled in such a way that, without affecting their pattern, they may be caused to affect the screen only briefly at desired periods.

Referring now more particularly to the specific embodiment of my invention illustrated in Figures 1 and 2, and it being understood that this embodiment, and particularly the portion thereof shown in Figure 1, is a simplified although operative arrangement, it will be seen that a cylinder or tube 10 of any appropriate insulating material

2

is adapted to contain the three principal parts of this portion of my invention. These parts comprise the objective lens arrangement, here shown as a simple lens 11 mounted in a tube section 12 slidable in the tube 10 for focusing; an eye piece arrangement comprising the lens 13 in the mounting piece 14, also slidable in the tube 10 for proper focusing; and a cylindrical glass envelope or tube 15. This tube contains a photo-sensitive cathode 16 in the form of a disc of substantial area; an electron lens or image converter system comprising the electrodes 17 and 18; and an electron-sensitive arrangement for rendering the pattern of the electrons visible, as a fluorescent screen 19 on the other end of the tube. The glass tube is here shown as a right cylinder with flat ends, with the cathode and screen extending over most but not quite all of the area of the ends, and co-axial, so that the cathode and screen are transverse to and concentric with the axis of the cylindrical tube 15.

Light derived from the moving object being studied, usually a rotating object, is passed through the objective lens 11 and throws an image on the translucent or semi-transparent cathode 16 which, under proper conditions of voltage, frees electrons in a pattern corresponding to this optical image. The electrons are then caused to move toward the other end of the tube by voltage applied to the electron lens system, this movement being effected without changing the patterns of the electrons, although the size of the pattern may be either reduced or enlarged by the electron lens system, the embodiment shown contemplating a reduction in size to about one-half. This reduced size but unchanged pattern of electrons strikes the fluorescent screen 19 and causes it to glow in a similar pattern which is visible through the eye piece 13. By energizing the electrodes very briefly, but in a regular period, the image or pattern of the fluorescent screen will correspond to a given instantaneous position of the object being studied, in accordance with conventional stroboscope practice.

The cathode can be prepared by placing a small sheet of silver within a helix of tungsten wire in the evacuated glass container near the left end (speaking with respect to Figure 1), and electrically heating the tungsten to about 1,000° C. to evaporate the silver and cause it to coat the surface of the glass, a shield preventing the silver from coating other portions of the container. The evaporation of the silver should be discontinued when the glass becomes brown and before it turns to deep blue, so that the cathode will be sufficiently transparent. After the silver deposit has been made, the tube is baked for an hour at 400° C. to de-gas it and then the silvered surface is oxidized by passing an electrical discharge through oxygen in the tube at a very low pressure, as for example at 1/10 to 1/1,000 millimeter of mercury, using the silver as the cathode of the discharge, with a voltage drop of about 400 volts and a current density of not over one milliampere per square centimeter of the cathode. When the oxidation is complete, caesium in the form of a salt, as caesium chloride or caesium dichromate mixed intimately with powdered calcium is fired from a "getter" capsule inside the tube to activate the cathode. This process is completely described in a book entitled "Electron Optics" by Meyers, published by D. van Nostrand & Co.

The fluorescent screen may be of any conventional material of the kind used for fluorescent screens in Braun tubes, preferably with a high persistence time, since this will reduce flicker of the image when working at low frequency of operation of the device. A fluorescent material providing satisfactory persistence characteristics is zinc sulphide, which retains 25% of the brightness of the initial image 2/10 of a second after the actuating electrons have ceased striking it.

While the image converter or electron lens system shown here is a desirable arrangement for this device, it will be understood that other forms of electron lens systems may be used. It is of primary importance, however, that the system be of a type giving an axially symmetric electrostatic field. The trajectory of an electron in an axially symmetric electrostatic field is given by the following equation:

$$\frac{d^2r}{dz^2}+\frac{\left(1+\left(\frac{dr}{dz}\right)^2\right)}{2V}\frac{dv}{dz}\frac{dr}{dz}-\frac{\left(1+\left(\frac{dr}{dz}\right)^2\right)}{2V}\frac{dv}{dr}=0$$

In the above equation, r is the radial distance from the axis in centimeters; z is the axial distance from the cathode, in centimeters; and v is the voltage on the lens system. Since this equation is homogeneous with respect to v, the lens system voltage, the voltage or voltages on the electrodes creating the lens system can be increased or decreased by a constant factor without altering the trajectory of the electron. That is, decreasing or eliminating the voltage on the electrodes of the electron lens system varies only the velocity of movement of the group or pattern of electrons toward the screen, and not the trajectory of any individual electrons, so that the pattern is not affected.

Advantage is taken of this feature to achieve the desired movement of the electrons periodically, the electrodes of the lens system being only very briefly energized periodically to cause a movement of electrons in a pattern corresponding to the optical image on the cathode; and this movement is brief enough (as for example less than 1/1,000 of a second of energization 60 times per second) that the images created on the fluorescent screen correspond to only a desired instantaneous view of the object, as at the same point in each revolution. By keeping the ratio of voltages on the two electrodes constant and unchanged, the actual voltage can be raised from zero to an effective operating voltage, as 700 or 800 volts, and then dropped back to zero without effecting any defocusing action, so that there is no distortion of the image on the fluorescent screen.

Electron lens system calculations are complex and will not be gone into detail here. It is to be noted that the existence of the lens system is a function of the existence of the second derivative of the axial potential, in terms of differential equations, and that it is not necessarily coincident with the physical boundaries of the electrodes used to create the electrostatic field. In the particular embodiment of the invention illustrated here, one operative embodiment, the lens element **17** comprises the copper wire screen **17a** having an internal diameter of 5 centimeters and a length of 6 centimeters; this screen being welded or otherwise mechanically and electrically connected to the thin cylindrical sheet metal portion **17b**, which would also have an internal diameter of 5 centimeters and a width of .9 centimeters. The other electrode **18** is preferably somewhat larger, as with an internal diameter of 6 centimeters, and it has a length of 3 centimeters and a space 2 centimeters from the nearest edge of the other electrode **17**. This particular electrode system should have the electrode **18** energized with a voltage double that impressed on the electrode **17**, both being positive with respect to the cathode, of course, held at an effective zero potential. The energizing system which will be hereinafter described is designed to deliver a potential of plus 350 volts to the electrode **17**, and of plus 700 volts to the electrode **18** at the peak voltage. It will be understood, however, that this is variable and may be run higher, or may be lesser depending upon the tube design. This electrode system provides an axially symmetric electrostatic field of such character that, if the appropriate differential equations are solved, it will be found that the electrode lens system (the second derivative of the axial voltage) extends from 4 centimeters to about 13 centimeters.

Referring now more particularly to Figure 2, an operative arrangement for regularly periodically energizing the electron lens electrodes is shown. The upper part of Figure 2 comprises a diagrammatic representation of the tube shown in more detail in Figure 1; the left-hand portion illustrates a power pack of conventional design; and the right-hand portion shows an appropriate relaxation oscillator and associated frequency stabilizing means.

Referring first to the power pack, the terminals **21** and **22** are adapted to be connected to a conventional power source, as a commercial 110 volt, 60 cycle power line, this voltage being delivered through a manually variable rheostat **23**, which may be of 300 ohms maximum value, to the primary **24a** of a transformer **24**, the primary being shunted by a voltmeter. The rheostat is used to adjust the input voltage to a predetermined value to improve the frequency stability of the relaxation oscillator. The high voltage secondary **24b** of this transformer has its opposite ends connected to the anodes of a full wave rectifying arrangement, here shown as two type '81 tubes **25** and **26**. The cathodes of these tubes are energized by a low voltage secondary **24c** of the transformer, the center tap of this secondary being connected to a filter arrangement here shown as a choke **27**, which may be of 30 henries. The other side of the choke is connected to the upper end of the bleeder or voltage divider resistor **28**, which may be of 13,500 ohms value and capable of easily handling the 60 milliampere current supply. The center tap of the high voltage secondary **24b** is connected to the lower end of the resistor **28**, and condensers **29** and **30** complete the filter, 5 microfarad and 10 microfarad being appropriate values for these condensers. The particular arrangement shown employs a tap or contact 28a as the zero potential point connected to the cathode of the thyratron tube 31, the upper end of the resistor 28 being 800 volts positive with respect to this point. The connections 28b, 28c and 28d provide various negative grid biases, as will hereafter be more fully explained, these being intended to provide negative voltages of 4.75, 5.75 and 7.75 volts, respectively, where the system is designed for a thyratron tube of the FG-17 type.

A condenser 33 is adapted to provide storage for a quantity of energy used for periodically rendering the electron lens system operative. The condenser is charged from the power pack through the variable resistor 34, then periodically discharged through the resistor 35 and tube 31. The resistor is divided into two equal portions 35a and 35b, so that any voltage existing across it is equally divided and the potential applied to the terminal c of the stroboscope tube is always twice that applied to the terminal b, speaking with respect to the terminal a or cathode potential. In accordance with known relaxation oscillator arrangements, the condenser 33 is relatively slowly charged through the resistor 34 until the grid and plate potentials of the plate 31 bear such a relation to each other that the tube breaks down and discharges, the discharge being effected in an interval which is relatively quite brief as compared with the charging interval.

While the condenser, resistor and tube could be used alone to give a brief discharge periodically, the periods or intervals between discharges would not have the absolute precision of recurrence which is desirable for stroboscope work. Accordingly, I provide means for stabilizing the period or recurrent energization of the electron lens system. One portion of this stabilizing means comprises a tuning fork 36 adapted to be kept in vibration by an actuating coil 37, and to develop a current in accordance with its vibration in the microphone 38. This synchronizing wave, controlled by the tuning fork, is developed through a grid transformer on the grid of the tube 31. By throwing the movable arm of the switch 39 to the contact 28c, the normal or steady bias on the grid of the tube 31 is dropped below the cut-off point for the maximum plate voltage developed by charging of the condenser 33, so that the tube can discharge only when its grid has been swung more positive by the synchronizing wave derived from the tuning fork. For example, when the grid has a negative bias of 4.75 volts (by use of the tap 28b), the FG-17 tube will discharge when the plate is 750 volts positive, so that the tube will discharge automatically when the condenser voltage has reached this level. On the other hand, when the tap 28c is used and the grid is biased to 5.75 volts negative, it requires substantially in excess of 800 volts for the tube to break down. Accordingly, under the synchronizing conditions the discharge of the tube is not governed by the time when the condenser has reached full charge, but by the time when the alternating voltage employed on the grid has caused it to swing to the neighborhood of 4.75 volts negative.

The stabilization of the discharge period is further improved by temperature control means associated with the tube 31, since tubes of this type have different characteristics at different temperatures. The tube is surrounded by an oven 40, an insulated box or housing of any appropriate type, and this is provided with a heater

element 41 and a thermostat 42, power for the heater being derived from any conventional current supply through the transformer 43. The thermostat is set to operate at some temperature higher than would ever be reached under normal operating conditions, and it is intermittently opened and closed to keep the oven and thus the tube within a fraction of a degree of a desired temperature. The tube characteristics can be determined for a desired stabilized temperature and, in conjunction with the tuning fork, exceedingly accurate stroboscope operation obtained.

While the resistor 34 and condenser 33 are preferably variable, as illustrated, in order to enable adjustment of the period of operation of the stroboscope, representative values will be given for one chosen assumed set of facts merely as illustrative of one operating condition of this device. It may be assumed that it is desired to make stroboscopic observation of a rotating object with a speed of rotation of 3600 R. P. M., with sufficiently brief periods of operation of the electron lens system that the image on the fluorescent screen is sharp and clear. If the object to be studied has a radius of 4 feet, the velocity of the fastest moving point is 25.12 feet per second. If the period of operation of the electron lens system (and thus movement of the electrons to the fluorescent screen) is .001 second, it will be seen that the point on the object has moved .3 inch. Since the ultimate image of the object on the fluorescent screen will have a radius of only about one inch, it will be seen that the movement reproduced on the screen will be less than .01 inch, considered satisfactory definition for most purposes. Since the object is rotating 3600 R. P. M. (60 revolutions per second) and it is desired to provide an image once each revolution, the time of charge of the condenser must be less than $^1/_{60}$ of a second, less than .01665 second. Accordingly, the value of resistor and condenser chosen must be such that the resistor is small enough to keep the time constant of the combination at less than .01665 second, but large enough not to permit enough current to flow through it to maintain discharge of the thyratron once such discharge has been initiated. With the particular type of tube used, use of about 100,000 ohms in the resistor 34 would make the maximum flow through it about 8 milliamperes, insufficient to maintain the discharge, so that this is a satisfactory value. By use of the known formulae for calculating the charging time of a condenser through a resistance of given value, it will be found that the condenser would have a value of .0594 microfarad to charge through a 100,000 ohm resistor in $^1/_{60}$ of a second. If the extinction voltage of the tube is 20 volts, use of a value of 5000 ohms for the resistor 35 will give a discharge time of .00104 second. Accordingly, for the particular set of facts assumed, the condenser would be set at .0594 microfarad, the resistor 34 at 100,000 ohms or just slightly less, and the resistor 35 would have a value of 5,000 ohms.

In order to synchronize the tube operation with the tuning fork period, the ganged switches 44 would be closed and a tuning fork with a 60 cycle per second period used, the switch arm 39 being moved to the contact 28c. Under these conditions it is desirable to reduce the value of the condenser or resistance 34, or both, slightly; so that the material period of the oscillator will be slightly less than that desired, and the period of operation will thus be more definitely under the control of the tuning fork.

While I have shown and described certain embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as disclosed in the appended claims.

I claim:

1. Stroboscopic apparatus including: means for developing a stream of electrons in a pattern of considerable area instantaneously corresponding to an instantaneous view of an object being studied; means adapted to be affected by the stream of electrons to render said pattern visible; and means for periodically simultaneously interrupting the entire stream of said electrons without affecting the pattern thereof.

2. Stroboscopic apparatus including: a photosensitive cathode of considerable area; means for affecting said cathode by light derived from a view of an object being studied, to develop a stream of electrons in a pattern instantaneously corresponding to an instantaneous view of said object; a fluorescent screen adapted to be affected by the stream of electrons to render said pattern visible; and means for periodically simultaneously interrupting the entire stream of said electrons without affecting the pattern thereof.

3. Stroboscopic apparatus including: a tube; a photo-sensitive cathode of considerable area in said tube; optical means associated with said tube for throwing on said cathode a light image derived from a view of an object being studied, to develop a stream of electrons in a pattern instantaneously corresponding to an instantaneous view of said object; a fluorescent screen in another portion of said tube adapted to be affected by the stream of electrons to render said pattern visible; and means having at least a portion adjacent the path of movement of the stream of electrons for periodically simultaneously interrupting the entire stream of said electrons without affecting the pattern thereof.

4. Apparatus of the character claimed in claim 3, wherein the cathode and screen are within an evacuated envelope having at least the portions thereof adjacent the cathode and screen transparent.

5. Stroboscopic apparatus including: a tube; means for freeing electrons in said tube in a pattern of considerable area instantaneously corresponding to an instantaneous view of an object being studied; electron-sensitive means in another portion of said tube adapted to be affected by the electrons to render said pattern visible; means having at least a portion adjacent the path of said electrons, for causing simultaneous movement of all of the electrons toward the electron-sensitive means without affecting the pattern thereof; and means for rendering the movement causing means cyclically and periodically operative and inoperative.

6. Apparatus of the character claimed in claim 5, wherein the movement causing means is operative for only a brief portion of each cycle period.

7. Stroboscopic apparatus including: a tube; a photo-sensitive cathode of considerable area in said tube; means associated with said tube for affecting said cathode by light derived from a view of an object being studied, to free electrons in a pattern instantaneously corresponding to an instantaneous view of an object being studied; a fluorescent screen in another portion of said tube adapted to be affected by the electrons to render said pattern visible; an electron lens system associated with said tube for causing simultaneous movement of all of the electrons toward the screen and focusing them thereon without affecting the pattern thereof; and means for cyclically and periodically briefly electrically energizing said lens system to periodically effect said movement of all of said electrons, the movement being interrupted between such periods of brief energization.

8. Apparatus of the character claimed in claim 7, wherein the electron lens system comprises a pair of electrodes adapted to provide an electrical field symmetrical about an axis passing through the centers of the cathode and the screen.

9. Stroboscopic apparatus including: a tube; a photo-sensitive cathode of considerable area in said tube; means associated with said tube for affecting said cathode by light derived from a view of an object being studied, to free electrons in a pattern instantaneously corresponding to an instantaneous view of an object being studied; a fluorescent screen in another portion of said tube adapted to be affected by the electrons to render said pattern visible; an electron lens system associated with said tube for causing simultaneous movement of all of the electrons toward the screen and focusing them thereon without affecting the pattern thereof, comprising a pair of cylindrical electrodes adapted to provide an electrical field symmetrical about an axis passing through the centers of the cathode and the screen; and means for cyclically and periodically briefly electrically energizing said electrodes to periodically effect said movement of all of said electrons, the movement being interrupted between such periods of brief energization.

10. Apparatus of the character claimed in claim 9, wherein the electrodes are energized for only a very small fraction of each period.

11. Apparatus of the character claimed in claim 9, wherein the last mentioned means energizes the electrodes with voltages bearing a predetermined ratio, and wherein this means maintains said ratio unvarying despite variation in the absolute value of such voltages, this means comprising a source of periodically varying voltage and voltage dividing means connected to said source.

12. Apparatus of the character claimed in claim 5, wherein the last mentioned means comprises a relaxation oscillator.

13. Apparatus of the character claimed in claim 9, wherein the last mentioned means comprises a relaxation oscillator.

14. Stroboscopic apparatus including: a tube; a photo-sensitive cathode of considerable area in said tube; means associated with said tube for affecting said cathode by light derived from a view of an object being studied, to free electrons in a pattern instantaneously corresponding to an instantaneous view of an object being studied; a fluorescent screen in another portion of said tube adapted to be affected by the electrons to render said pattern visible; an electron lens system associated with said tube for causing simultaneous movement of all of the electrons toward the screen and focusing them thereon without affecting the pattern thereof, comprising a pair of cylindrical electrodes adapted to provide an electrical field symmetrical about an axis passing through the centers of the cathode and the screen; a relaxation oscillator for cyclically and periodically briefly energizing said electrodes to periodically effect said movement of all of said

electrons, the movement being interrupted between such periods of brief energization; and means for stabilizing the frequency of said oscillator.

15. Stroboscopic apparatus including: a tube; means for freeing electrons in said tube in a pattern instantaneously corresponding to an instantaneous view of an object being studied; electron-sensitive means in another portion of said tube adapted to be affected by the electrons to render said pattern visible; means having at least a portion adjacent the path of said electrons for causing simultaneous movement of all of the electrons toward the electron-sensitive means without affecting the pattern thereof; a relaxation oscillator for cyclically and periodically briefly rendering the movement causing means operative; and means for stabilizing the frequency of said oscillator.

ROBERT T. BAYNE.

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Certificate of Correction

May 27, 1947.

Patent No. 2,421,182.

ROBERT T. BAYNE

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Column 3, line 42, for "æ is the" read θ *is the*; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 22nd day of July, A. D. 1947.

[SEAL]

LESLIE FRAZER,
First Assistant Commissioner of Patents.

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