

[54] **X-RAY DIAGNOSTIC APPARATUS**
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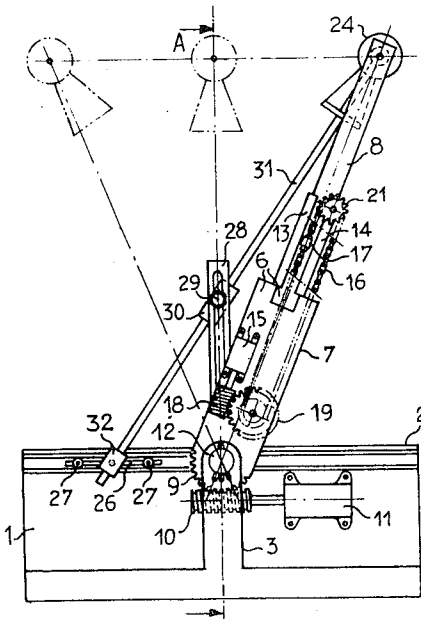
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[57] **ABSTRACT**
X-ray diagnostic apparatus, particularly adapted for rectilinear tomography, comprising a column carrying the X-ray source pivoting about a horizontal axis, said column being composed of a lower and an upper parts, the latter one longitudinally displaceable relatively the former one by means of an electric motor controlled by a signal, which is a function of the angle of inclination of the column.

4 Claims, 4 Drawing Figures



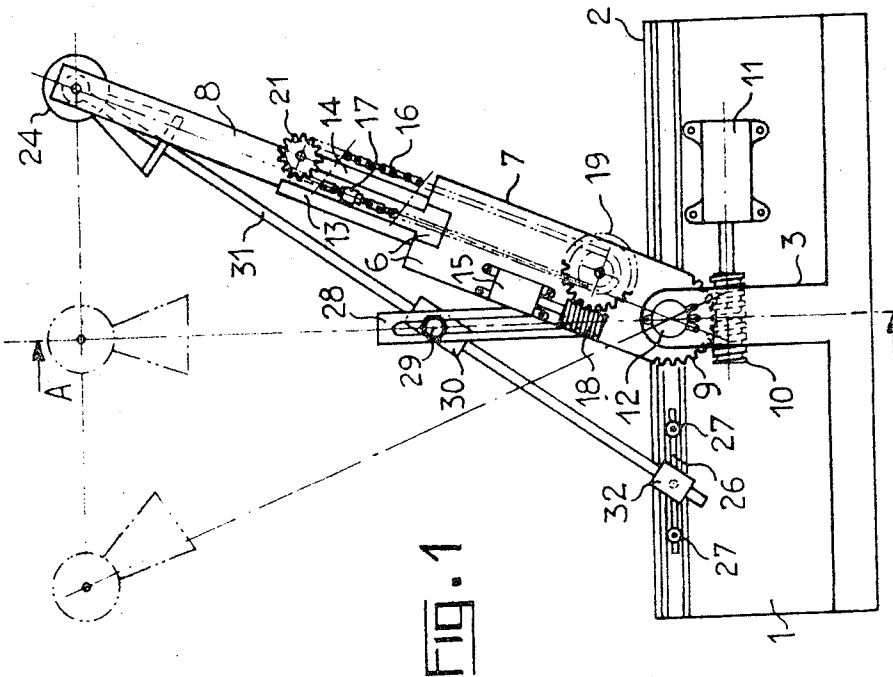
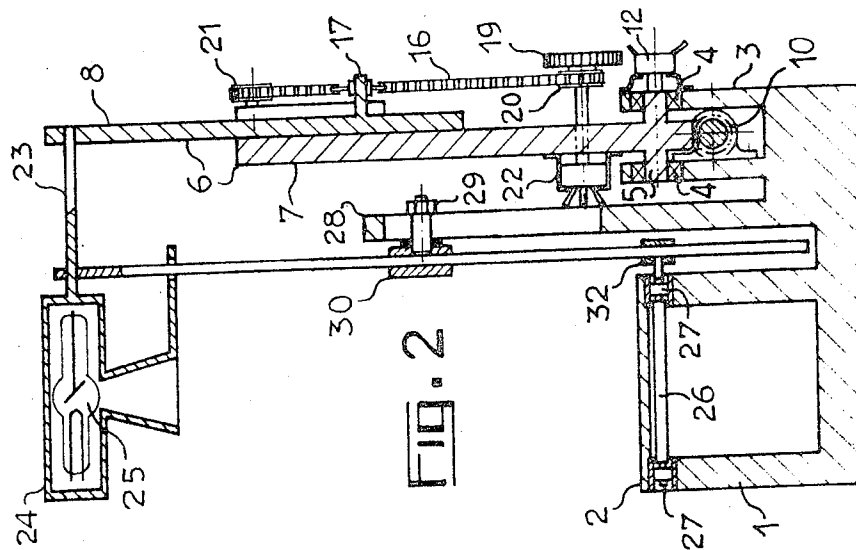


FIG. 3

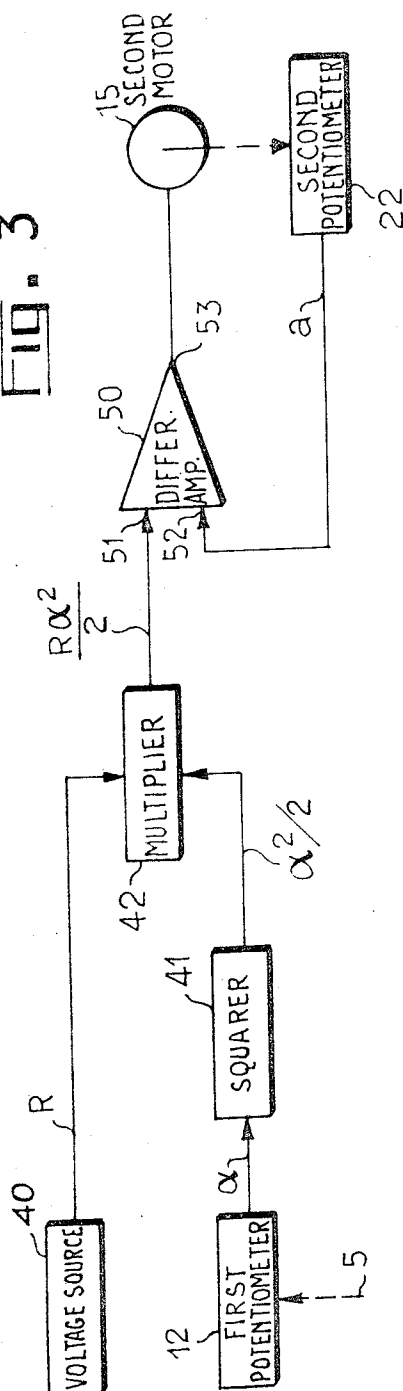
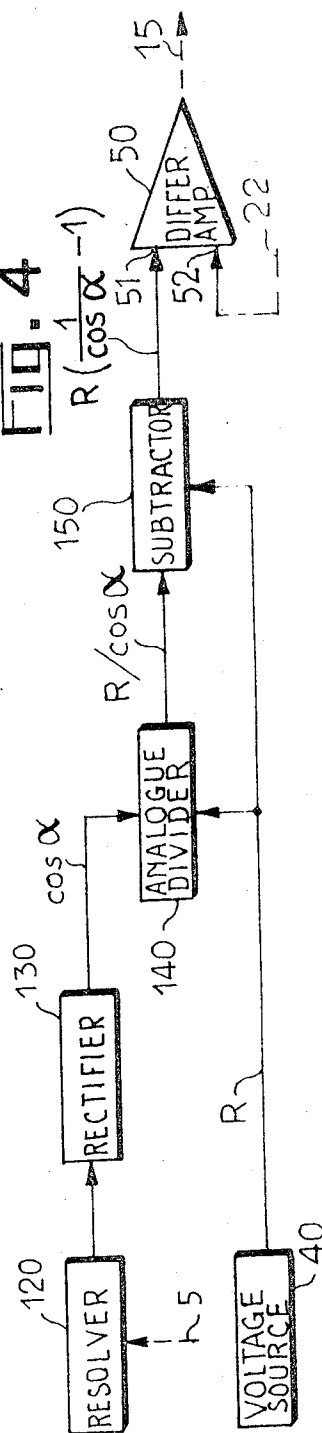


FIG. 4



X-RAY DIAGNOSTIC APPARATUS

The present invention relates to improvements in X-ray diagnostic apparatus and, more particularly, to apparatus of this kind which can take oblique-incident X-ray photographs and also be used for tomography.

The tomography technique is employed to eliminate the opacity created by organs or elements which are located in front of or behind of the part of the body being examined, considered in relation to the X-ray source. In order to produce an X-ray photograph by tomography, the X-ray tube and the film are given homothetic relative displacements, in opposite directions, about a homothetic center or axis located in the plane where part of the body to be examined is located.

Tomography apparatus of this kind, in which the focus of the tube, and the film, carry out rectilinear displacements, are well known and have been described for example in French Pat. No. 800,445. In apparatus of this kind, the focus of the X-ray tube, and the film, describe truly homothetic relative trajectories in relation to the plane of section defined by the homothetic axis. In this case, the tube is located in a casing carried by a carriage which can move along guide rails parallel to the plane of the table. The presence of these rails means that an assembly of this kind is a bulky one and does not lend itself to the taking of X-ray photographs of varying focal distance.

In order to overcome this drawback, it is known to locate the X-ray tube at the end of an arm and to pivot the latter so as to make the tube focus describe a circular arc.

In French Pat. No. 1,495,520 there is proposed an improved tomography apparatus of this kind. In this apparatus, the X-ray tube is carried by one of the ends of a supporting arm fixed at its other end to a horizontal axis preferably located in the plane of the film. The tomography axis defining the plane of section is materialized by a vertically displaceable pivot located on a bar linking the X-ray tube casing to the film cassette frame. However, in an apparatus of this kind, there is not a strictly homothetic relationship between the respective trajectories of tube and film and this means that there is a loss in the sharpness of the X-ray photographs produced with this kind of tomography.

In order to overcome this drawback, it has been proposed, for example in French Pat. No. 1,569,601, that a radiographic apparatus be used which is capable of carrying out rectilinear tomography where the movement of the tube focus and the film are strictly homothetic. In an apparatus of this kind, the column carrying the tubes is made up of two parts. The first part of the column is fixed to the shaft that is coupled to the drive motor for pivoting it, and the second part, carrying the X-ray tube at its top end, is located in the first part in such a fashion as to be longitudinally displaceable in relation thereto. This apparatus likewise comprises a correcting cam with an aperture in which there engages a horizontal rod fixed to the second part of the column. Said cam, at the time of a tomography operation, is fixed in relation to the table and said curvilinear opening guides the rod fixed to the second part of the column, in order to modify the column length. The aperture is profiled in order to give the tube focus a rectilinear trajectory during the pivoting of the arm. An apparatus of this kind can only be used for one nominal focal length and if it is desired to change the focal

length in a tomography operation, then a special correcting cam has to be provided for each focal length it is desired to use.

The apparatus forming the subject of the present invention allows to overcome these drawbacks. In other words, it can, in particular, both execute tomography operations and take oblique incidence X-ray photographs at varying focal lengths in a continuous manner and without any mechanical intervention, whilst causing the tube focus to describe quasirectilinear trajectories.

According to the invention, there is provided an X-ray diagnostic apparatus, particularly adapted for tomography with variable focal distances, including : an X-ray source ; a housing ; a column for carrying said X-ray source comprising : a lower portion mounted on said housing for pivoting about a horizontal axis and an upper portion carrying said X-ray source at its upper end, said upper portion being assembled with lower one for longitudinal displacements in relation thereto, both said portions having parallel longitudinal axes perpendicular to said horizontal one ; a first electric motor having a stator fixed to said housing and a rotor mechanically coupled to said lower portion for controlling said pivoting thereof about said horizontal axis ; a second electric motor having a stator fixed to said lower portion and a rotor mechanically coupled to said upper portion for controlling said longitudinal displacements ; means for delivering an electrical signal which is a function of the angle of inclination γ of said column ; electronic analogue circuit means fed by said signal for controlling said second motor in dependence of said angle γ , whereby the motion of said X-ray source during the pivoting of said column is made to be substantially rectilinear.

The invention will hereinafter be further described with reference to the accompanying drawings, given only by way of example, wherein :

FIG. 1 schematically illustrates part of an embodiment of the apparatus in accordance with the invention ;

FIG. 2 illustrates the apparatus of FIG. 1 in section along line A—A when the column carrying the X-ray tube is in a vertical position, that is to say perpendicular to the plane of the film ;

FIG. 3 illustrates a block diagram of an embodiment of the electronic circuit utilized in the apparatus in accordance with the invention ;

FIG. 4 illustrates a block diagram of another embodiment of the electronic circuit in accordance with the invention.

In FIGS. 1 and 2, the reference 1 represents the frame carrying the X-ray apparatus, in particular a horizontal table 2. The table 2 normally carries a bed-rest for the patient (not shown in FIG. 1), this generally being movable in a plane parallel to the film plane.

The frame 1 first of all comprises a component 3 of forked form, whose both branches comprise . . . a bearing 4. Assembled in these bearings 4 there is a horizontal shaft 5 fixed to a column 6 which carries the X-ray tube. The column 6 is made up of two parts, 7 and 8, the longitudinal axes of which are parallel to one another. The first or lower part 7 is fixed to the shaft 5 and is provided at its bottom end with a gear (toothed ring) 9 engaging with an endless screw (wormgear) 10 fixed to the shaft of a first electric motor 11 whose stator is fixed to the frame 1. The electric motor 11 drives

the column 6 in order to pivot it around the shaft 5. This shaft likewise drives the slider of a first potentiometer 12.

The second or upper part 8 of the column 6 is mounted in slides 13 and 14 fixed to the first part 7, in order to render it movable longitudinally in relation to the latter (in parallel to its longitudinal axis). These longitudinal displacements are produced by a second electric motor 15, mounted on the first part 7 and driving a chain 16 attached to a finger 17 integral with the second part 8. The chain 16 is driven by the motor 15 through a reduction gear comprising an endless screw 18 and a first gear 19, the chain being taken around two pinions 20 and 21 the first 20 of which is fixed to the shaft of the first gear 19 and the second 21 of which rotates idly in a bearing located near the top end of the first piece 7 and integral therewith. The shaft of the first gear 19 also drives the slider of a second potentiometer 22. The second part 8 carries at its top end a shaft 23 which in turn carries a casing 24 surrounding an X-ray tube 25.

Beneath the table 2 a film cassette carriage 26 is located, with rollers 27 allowing its displacement in parallel to the longitudinal axis of the table 2.

The frame 1 is furthermore equipped with a vertical rod 28 along which a horizontal pivot 29 carrying a slide 30 in which there engages a rod 31 known as a tomography rod, can be fixed. The rod 31 is likewise engaged in another slide 32 which can pivot about a horizontal spindle fixed to the film cassette carriage 26. The top end of the rod is coupled to a shaft 23 carrying the casing 24 so as to pivot about said shaft 23. The connection between the focus of the X-ray tube 25 and the film cassette carriage 26, which is established by means of this rod 31, causes these elements to carry out homothetic displacements about a homothetic center determined by the pivot 29, said center being adjustable by displacing the pivot 29 along the rod 28. The plane of section whose X-ray photograph is produced by the tomography process, is that plane parallel to the plane of the film which intersects with the axis of the pivot 29.

It will be noted here that it is likewise possible to drive the second part 8 by means of a screwed rod whose axis is parallel to that of the column and which is coupled to the shaft of the second motor 15, and of a nut fixed to the second part 8 and engaging said screwed rod. The rotation of the rod displaces the nut and consequently the second part 8 with it.

When the second motor 15 is disconnected, the first motor 11 drives the arm so that the focus of the X-ray tube describes a circular arc whose radius R is equal to the distance between the focus and the shaft 5; this is a case described in the above mentioned French Pat. No. 1,495,520.

If it is desired to give the focus a rectilinear trajectory, then the distance between the focus and the shaft 5 must be modified during the pivoting of the column 6, as a function of the angle γ of inclination of the column with respect to the vertical.

This distance must correspond to

$$L = a + R = R \cdot \sqrt{1 + \tan^2 \gamma} = R / \cos \gamma,$$

where R is the distance between focus and spindle when the column 6 is perpendicular to the film plane ($\gamma = 0$), and a is the extension of the column 6 which will enable a rectilinear displacement of the focus of

the X-ray tube 25 to be produced. From this, then, we obtain $a = R (1/\cos \gamma - 1)$ and, since

$$\cos \gamma = 1 - (\gamma^2/2!) + (\gamma^4/4!) - (\gamma^6/6!) + \dots$$

we can state with reasonable accuracy that $a = R\gamma^2/2$.

This approximation does not give rise to any substantial error for angles (absolute value) of less than or equal to 25° .

FIG. 3 schematically illustrates an electronic circuit enabling the longitudinal movement of the second part 8 of the column 6 to be controlled as a function of the angle γ .

This circuit comprises a source 40 producing an analogue voltage which is proportional to the selected focal length R . The first potentiometer 12, whose slider is driven by the shaft 5 of the column 6, supplies an analogue voltage corresponding to the angle γ . This voltage is applied to a circuit 41 producing a signal proportional to the square of the input signal. This kind of circuit may for example be made up by means of a first multiplier circuit of arbitrary design, whose two inputs are fed in parallel with the same signal. This circuit then produces a signal proportional to $\gamma^2/2$.

This signal as well as the voltage proportional to R are applied respectively to two inputs of a second multiplier circuit 42, preferably in the form of a four-quadrant multiplier as described for example in the work by Samuel Seely entitled "Electronic Circuits" published by Holt, Reinhart and Winston, Inc. in 1968, in pages 264 to 266 and 269, thereof.

This circuit produces at its output an analogue voltage which is proportional to $R \gamma^2/2$.

It is possible to replace this multiplier 42 by an operational amplifier whose variable gain is proportional to R , and this can likewise produce a voltage corresponding to $R \gamma^2/2$.

This voltage in turn is applied to a first input 51 of a differential amplifier 50 whose second input 52 receives from the second potentiometer 22 a voltage proportional to the real elongation of the arm, the slider of said second potentiometer 22 being mechanically coupled to, the shaft of the second electric motor 15 which drives the second part 8 of the column 6.

The differential amplifier 50 produces at its output 53 a signal proportional to the difference between $R\gamma^2/2$ and the real variation in the length of the column 6, which signal is fed to the control windings of the second motor 15. Thus, in order to control the length of the column 6 as a function of the angle γ of its inclination in relation to the vertical, the second motor 15 is servo-controlled to the setpoint value $R \gamma^2/2$.

It will be noted here that the first and second multiplier circuits 41 and 42 are advantageously designed as two identical integrated circuits, of known type, namely "four-quadrant multipliers."

It would be equally feasible to effect the extension of the arm in accordance with the formula $a = R/\cos \gamma - R$, as illustrated by the circuit in FIG. 4.

In this case, the first potentiometer 12 indicating the angle γ , will be replaced by a sine-cosine potentiometer producing $\cos \gamma$ or by a resolver device 120. A resolver would be constituted for example by a transformer with a primary winding located in the stator and two secondary windings located in the rotor of a rotary electrical machine, said two secondary windings being at 90° to one another. If the primary winding is supplied with a constant amplitude alternating voltage, the two second-

ary windings will produce voltages whose amplitude are respectively proportional to $\cos \phi$ and $\sin \phi$, where ϕ is the angle between the primary winding and the secondary winding which furnishes the cosine of ϕ .

By coupling the rotor of the resolver to the horizontal shaft 5, there is obtained at the terminals of one of the windings an alternating voltage which has an amplitude proportional to $\cos \gamma$. This voltage, after rectification (in a rectifier 130), produces an analogue voltage proportional to $\cos \gamma$. If this voltage is applied to one of the inputs of an electronic divider circuit 140 and the voltage proportional to the focal length R , to the other, then there is obtained at the output of this divider 140 a voltage corresponding to $R/\cos \gamma$. This voltage is subsequently applied to a first input of a subtracting circuit 150 whose other input receives the voltage corresponding to R . The subtracting circuit produce an output voltage corresponding to $R/\cos \gamma - R = R ((1/\cos \gamma) - 1)$ which can be applied to the first input of the differential amplifier 50.

In a similar but more complex manner, it is possible to effect the mathematical operation $R \sqrt{1 + \tan^2 \gamma} - R$, and in order to obtain $\tan \gamma$, it is merely necessary to apply the output voltages from the resolver to the respective inputs of a divider.

The analogue circuits which carry out the requisite operations, have been described in chapter 5 of the aforesaid work by Seely or in chapter 8 of the work entitled "Electron Tube Circuits" by the same author, the second edition of which was published in 1958 by McGraw-Hill.

It will also be noted that adjustments of the focal length R , that is to say the distance between the focus and the film plane, the column being perpendicular to the latter, will preferentially be effected by means of electronic controls which are an integral part of the control panel (not shown in the figure).

Where operating with discrete values of total length R , the control panel will be provided with control buttons for each of these focal lengths. These control buttons likewise enable the analogue voltage sources 40 corresponding to this value R , to be connected to one of the inputs of the second multiplier circuit 42.

However, where the apparatus in accordance with the invention can be operated with a continuously variable focal length, a control in the variation thereof must also control the displacement of the slider of a third potentiometer (not shown), for example with the help of a third motor (not shown), in order to supply at this slider a voltage corresponding to the selected focal length.

The apparatus in accordance with the invention can be used for diagnostic radiography and is particularly well suited to the execution of variable focal length tomography operations, the production of X-ray photographs and even the carrying out of X-ray fluoroscopy, at oblique incidences, if equipped with an image intensifier.

Of course, the invention is not limited to the embodiments described and shown which were given solely by way of example.

What we claim is :

1. X-ray diagnostic apparatus, particularly adapted for tomography with variable focal distances, including : an X-ray source ; a housing ; a column for carrying said X-ray source comprising : a lower portion mounted on said housing for pivoting about a horizon-

tal axis and an upper portion carrying said X-ray source at its upper end, said upper portion being assembled with said lower one for longitudinal displacements in relation thereto, both said portions having parallel longitudinal axes perpendicular to said horizontal one ; a first electric motor having a stator fixed to said housing and a rotor mechanically coupled to said lower portion for controlling said pivoting thereof about said horizontal axis, a second electric motor having a stator fixed to said lower portion and a rotor mechanically coupled to said upper portion for controlling said longitudinal displacements ; means for delivering an electrical signal which is a function of the angle of inclination γ of said column ; electronic analogue circuit means fed by said signal for controlling said second motor in dependence of said angle γ , whereby the motion of said X-ray source during the pivoting of said column is made to be substantially rectilinear.

2. Apparatus as claimed in claim 1, further comprising : a second potentiometer having a slider mechanically coupled to said rotor of said second motor for delivering a second voltage proportional to the position of said upper portion in relation to said lower one ; and a variable direct voltage source for delivering a third voltage proportional to the selected focal distance R ; and wherein said electrical signal delivering means comprises a first potentiometer having a slider mechanically coupled to the rotor of said first motor for delivering a first voltage proportional to said angle γ ; and wherein said electronic circuit means comprises : a squaring circuit for delivering a signal proportional to the half of the square of said first voltage applied to its input ; a multiplier circuit for delivering a signal proportional to the product of said third voltage with said half-square of said first voltage i.e. proportional to $R \gamma^2/2$; and a differential amplifier for delivering an error signal proportional to the difference between said product signal and said second voltage whereby controlling said second motor.

3. Apparatus as claimed in claim 1, further comprising : a second potentiometer having a slider mechanically coupled to said rotor of said second motor for delivering a second voltage proportional to the position of said upper portion in relation to said lower one ; and a variable direct voltage source for delivering a third voltage proportional to the selected focal distance R ; and wherein said electrical signal delivering means comprises : a resolver fed by a constant amplitude alternating current, having a rotor mechanically coupled to said rotor of said first motor for delivering an alternating voltage with an amplitude proportional to the cosine of said angle γ ; and amplitude detector means for rectifying said alternating voltage and for delivering a fourth direct voltage whose level is proportional to cosine γ ; and wherein said electronic circuit means comprises : an electronic analogue divider circuit for delivering a fifth voltage proportional to the ratio of said third to said fourth voltages i.e. proportional to $R/\cos \gamma$; an electronic subtracting circuit for delivering a sixth voltage proportional to the difference between said ratio voltage and said third voltage i.e. proportional to $R/\cos \gamma - R$; and a differential amplifier for delivering an error signal proportional to the difference between said sixth and said second voltages whereby controlling said second motor.

4. Apparatus as claimed in claim 1, further comprising : a second potentiometer having a slider mechani-

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cally coupled to said rotor of said second motor for delivering a second voltage proportional to the position of said upper portion in relation to said lower one ; and a variable direct voltage source for delivering a third voltage proportional to the selected focal distance R ; and wherein said electrical signal delivering means comprises : a potentiometer of the sine-cosine type having a slider coupled to said rotor of said first motor for delivering a fourth voltage whose level is proportional to the cosine of said angle γ ; and wherein said electronic circuit means comprises : an electronic ana-

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logue divider circuit for delivering a fifth voltage proportional to the ratio of said third to said fourth voltages i.e. proportional to $R/\cos \gamma$; an electronic subtracting circuit for delivering a sixth voltage proportional to the difference between said ratio voltage and said third voltage i.e. proportional to $R/\cos \gamma - R$; and a differential amplifier for delivering an error signal proportional to the difference between said sixth and said second voltages whereby controlling said second motor.

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