

Feb. 28, 1967

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3,307,180

ANTI-AIRCRAFT SIGHTING DEVICE

Filed May 26, 1965

2 Sheets-Sheet 1

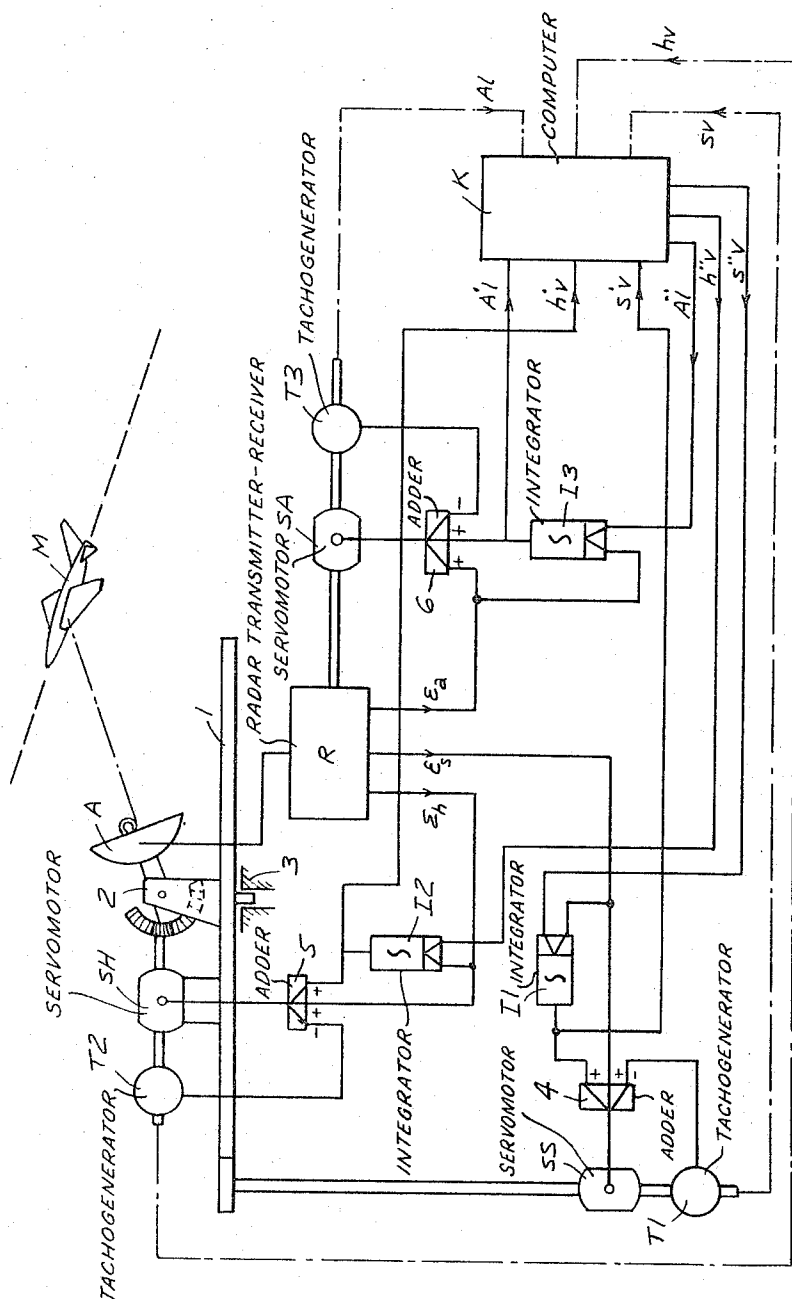


FIG. 1

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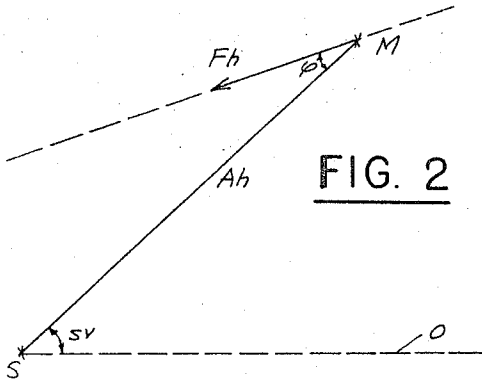


FIG. 2

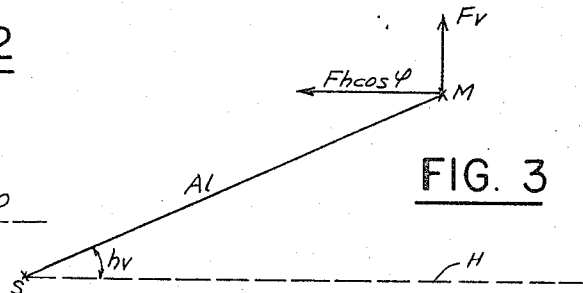


FIG. 3

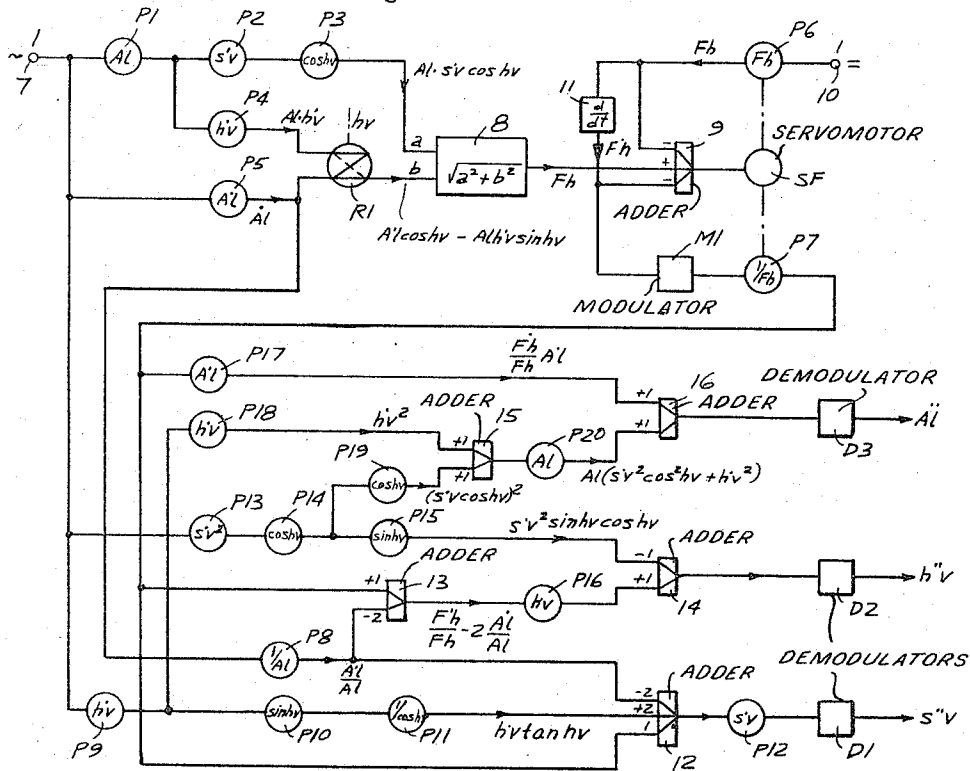
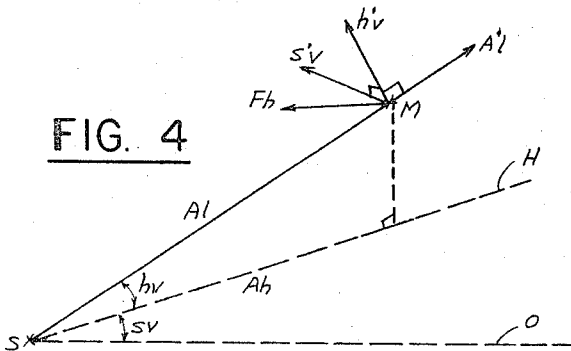


FIG. 5

FIG. 4



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ANTI-AIRCRAFT SIGHTING DEVICE

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Filed May 26, 1965, Ser. No. 458,922

Claims priority, application Sweden, June 3, 1964,

6,767/64

7 Claims. (Cl. 343—7.4)

The present invention is related to an anti-aircraft sighting device, in particular a radar sighting device, of the type provided with an equipment for automatic target tracking, which comprises in conventional manner servomotors for laying the sight proper, that is the radar antenna in a radar sighting device, in azimuth and elevation respectively and for setting a range measuring unit, which servomotors are supplied with control signals from the sighting device representing the azimuth angular deviation and the elevation angular deviation respectively between the actual direction of the sight and the true direction to the target and the difference between the range presently set in the range measuring unit and the true range to the target, so that the servomotors will endeavor continuously when the target is moving to keep the sight directed upon the target and the range measuring unit set upon the true range to the target. For the large velocities of modern air targets a very large amplification and a fast response should be required in the abovementioned servocircuits in order to obtain a sufficiently accurate target tracking. The control signals supplied from the sighting device to the servomotors, which are representing the errors in the direction of the sight and in the setting of the range measuring unit, comprise, however, and this is in particular true for radar sighting devices such disturbances that the servo-circuits, in which these control signals are used, cannot be given a large amplification and a rapid response. In order to solve this problem, at least partially, the sighting device can be provided with a special computer arranged to compute on the basis of the target data determined by the sighting device and a certain assumption regarding the movement of the target some suitable regenerative control signal for the servo-motors so that these will automatically, without any assistance of the error signals from the sighting device, keep the sight directed upon the target and the range measuring unit set upon the range to the target, so long as the target is moving in the manner assumed. Then the error signals from the sight have only to provide a correction of the direction of the sight and the setting of the range measuring unit, if the target is deviating from the assumed manner of movement, wherefore the servo-circuits for these error signals do not have to be provided with a large amplification factor and a rapid response. Hitherto one has generally arranged the computer to calculate the azimuth angular velocity and the elevation angular velocity of the target about the azimuth axis and the elevation axis of the sight as regenerative control signals for the assumption that the target is moving in a straight course with a constant velocity, and these regenerative control signals have been supplied to the servomotors laying the sight in azimuth and in elevation respectively. With the very large velocities of modern air targets, however, the targets display considerable azimuth angular accelerations and elevation angular accelerations and also significant radial accelerations relative to the sighting device, in particular when the targets are passing close to the sighting device. If the regenerative control signals are representing the calculated values for the azimuth angular velocity and the elevation angular velocity of the target, no consideration will be paid to the abovementioned accelerations of the target. Further-

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more, the assumption that the target is moving in a straight course with a constant velocity is not realistic under all circumstances as modern air-targets have in many cases, for instance during dive attacks, a considerable acceleration in the direction of the course flight. It has, therefore, turned out to be impossible to achieve a sufficiently accurate target tracking in direction and in range by the aid of regenerative control signals representing the elevation angular velocity and the azimuth angular velocity of the target and calculated with the assumption that the target is moving in a straight course with a constant velocity.

The object of the present invention is therefore to provide an anti-aircraft sighting device of the type mentioned in the introduction and in particular a radar sighting device of this type, which provides an improved automatic target tracking, particularly for targets passing close to the sighting device and having an accelerated motion. Characteristic for the sighting device according to the invention is that it comprises an electric computer, preferably an analogue computer, which is supplied with data determined by the sight regarding the azimuth angle, the elevation angle and the range to the target and also the azimuth angular velocity, the elevation angular velocity and the radial or range velocity of the target with respect to the site of the sighting device and which is arranged to compute on the basis of said data and the assumption that the target is moving in a straight course with a variable velocity the azimuth angular acceleration of the target about the azimuth axis of the sight and the elevation angular acceleration of the target about the elevation axis of the sight and to produce signals proportional to the calculated azimuth angular acceleration and the calculated elevation angular acceleration respectively, which signals are applied as regenerative control signals to the servomotor laying the sight in azimuth and to the servomotor laying the sight in elevation respectively.

When considered necessary, the computer can be arranged to compute on the basis of the above mentioned assumption regarding the movement of the target also the radial or range acceleration of the target with respect to the site of the sighting device and to produce a signal proportional to said calculated range acceleration, to be applied as a regenerative control signal to the servomotor setting the range measuring unit. Under most circumstances, however, the range acceleration of the target is considerably smaller than the elevation angular acceleration and the azimuth angular acceleration of the target and a certain error in the target tracking in range is also generally less serious than an error in the target tracking in azimuth and in elevation, wherefore in many cases it can be sufficient to calculate the azimuth angular acceleration and the elevation angular acceleration of the target and to produce signals proportional thereto to be used as regenerative control signals for the servomotors laying the sight in azimuth and elevation.

The invention gives an accurate target tracking without any assistance from the error signals from the sighting device, even if the target displays very large azimuth angular acceleration, elevation angular acceleration and range acceleration with respect to the sight and has an accelerated movement, provided that it is moving in a straight course and consequently its acceleration is in the direction of flight. The assumption that the aircraft is moving in a straight course and that its acceleration vector is lying in the direction of this course is certainly not correct under all circumstances, but will in the practice not cause any serious errors, as one is interested in an accurate target tracking above all immediately before and during the firing at the target and the target is in most

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cases fired at, at least when it comes to light anti-aircraft artillery, when the target itself is attacking and consequently generally flying in a straight course.

It turns out that the expressions for the azimuth angular acceleration, the elevation angular acceleration and the range acceleration of the target with respect to the sight are comparatively simple also with the assumption that the target is moving with a variable velocity in a straight course, wherefore the sighting device according to the invention becomes comparatively simple, compact and cheap. According to the invention the computer is consequently arranged to calculate the value of the expression

$$\left(\frac{\dot{F}l}{F\dot{l}} - 2\frac{\dot{A}l}{A\dot{l}} + 2\dot{h}v \tan hv\right)\dot{s}v$$

as a measure for the azimuth angular acceleration of the target about the azimuth axis of the sight, to calculate the value of the expression

$$\left(\frac{\dot{F}l}{F\dot{l}} - 2\frac{\dot{A}l}{A\dot{l}}\right)\dot{h}v - (\dot{s}v)^2 \sin hv \cos hv$$

as a measure for the elevation angular acceleration of the target about the elevation axis of the sight and possibly also to calculate the value of the expression

$$\frac{\dot{F}l}{F\dot{l}}\dot{A}l + A\dot{l}[(\dot{s}v \cos hv)^2 + \dot{h}v^2]$$

as a measure for the range acceleration of the target with respect to the site of the sight. In these expressions $F\dot{l}$ is the total velocity of the target or the component of its velocity in a predetermined direction, $\dot{F}l$ the total acceleration of the target or the component of its acceleration in said predetermined direction, $A\dot{l}$ the range from the sight to the target as determined by the sight, $\dot{A}l$ the range or radial velocity of the target as determined by the sight, $h\dot{v}$ the elevation angle to the target as determined by the sight with respect to the plane in which the sight is laid in azimuth, $\dot{h}v$ the elevation angular velocity of the target as determined by the sight about the elevation axis of the sight and $\dot{s}v$ the azimuth angular velocity of the target as determined by the sight about the azimuth axis of the sight.

For the quantity $\dot{F}l/F\dot{l}$ the computer is preferably arranged to determine the ratio between the acceleration component of the target which is parallel with the azimuth laying plane of the sight and the velocity component of the target in the same direction.

In order to obtain an accurate control of the servomotors by the regenerative control signals representing the calculated accelerations of the target in the different coordinate directions, the servomotors must be provided with feedback. Preferably each regenerative control signal is supplied to the associated servomotor through an integrator and a signal generator is coupled to the servomotor for producing a signal proportional to the speed of the servomotor and this signal is fed back negatively or in opposition to the servomotor. As an alternative the regenerative control signal can be applied directly to the associated servomotor, in which case a signal generator is coupled to the servomotor for producing a signal proportional to the acceleration of the servomotor and this acceleration signal is fed back negatively to the servomotor.

In the following the invention will be further described with reference to the enclosed drawing, in which

FIG. 1 shows schematically by way of example an anti-aircraft radar sighting device according to the invention;

FIG. 2 is a projection of the movement of the target and the relationship between the target and the sight in the plane, in which the sight is laid in azimuth, that is in a plane perpendicular to the azimuth axis of the sight. In the following it will be assumed for the sake of sim-

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plicity that the azimuth axis of the sight is vertical and that consequently the sight is laid in azimuth in the horizontal plane;

FIG. 3 is a corresponding projection of the movement of the target and the relationship between the target and the sight in a plane containing the direction from the sight to the target and the azimuth axis of the sight; that is a vertical plane containing the direction to the sight, if the azimuth axis of the sight is vertical as assumed above;

FIG. 4 shows in perspective the relationship between the sight and the target and the directions of the different coordinate velocities of the target, and

FIG. 5 shows more in detail the electric analogue computer in the sighting device shown in FIG. 1.

The anti-aircraft sighting device shown in FIG. 1 comprises in conventional manner a radar antenna A, which is pivoted in a stand 2 on a platform 1, as schematically shown in the drawing. The platform 1 is journaled in a support structure 3 so that it can be rotated together with the antenna. For the sake of simplicity it is assumed that the platform 1 can be rotated about a vertical axis. The antenna A is mounted in the stand 2 so that it can be pivoted about an axis perpendicular to the axis of rotation of the platform 1, that is about a horizontal axis in the assumed case. The antenna A can consequently be layed in azimuth as well as in elevation in a conventional manner. The antenna is laid in elevation by means of a servomotor SH and in azimuth by means of a servomotor SS rotating the platform 1. The antenna A is in a conventional manner connected to a transmitter-receiver equipment R for radar signals. The transmitter-receiver equipment R comprises a range measuring unit, which can be operated or set by means of a servomotor SA. The radar sight is in any conventional manner designed for automatic target tracking, that is the transmitter-receiver equipment R comprises means for producing a first error signal e_s representing the azimuth angular deviation between the actual direction of the antenna A and the true direction to the target M, a second error signal e_h representing in the same way the elevation angular deviation between the actual direction of the antenna and the true direction to the target and a third error signal e_a representing the difference between the range set in the range measuring unit and the true range to the target. The error signal e_s is connected through an adder circuit 4 to the servomotor SS as a control signal therefor and the servomotor SS will consequently endeavor to rotate the platform 1 and thereby lay the antenna A in azimuth so that the error signal e_s is maintained zero, that is so that the antenna is kept directed upon the target M in azimuth. In a corresponding way the error signal e_h is connected through an adder circuit 5 to the servomotor SH laying the antenna A in elevation so that this servomotor will endeavor to keep the antenna directed upon the target in elevation. The error signal e_a is connected through a corresponding adder circuit 6 as a control signal to the servomotor SA, which will consequently endeavor to keep the range measuring unit set on the true range to the target. Tachogenerators T1, T2 and T3 are coupled to the servomotors SS, SH and SA and generate consequently signals representing the rates of rotation of the servomotors, that is the elevation angular velocity and the azimuth angular velocity of the antenna and the rate of change of the setting of the range measuring unit respectively. These signals are connected through the adder circuits 4, 5, 6 to the associated servomotors SS, SH and SA as negative feedback signals. As previously mentioned, the error signals e_s , e_h and e_a contain such disturbances that the servo-circuits, in which these control signals are used, cannot be given a sufficient amplification and a sufficiently rapid response so that the antenna and the range measuring unit under the influence of these control signals are brought to

track a target accurately, which is passing close to the sight with large velocity.

In order to remedy this disadvantage, the sighting device according to the invention is provided with a computer K, preferably an electric analog computer, which is supplied from the sight with the target data determined by the sight, viz. the azimuth angle α , the elevation angle β and the range R to the target and the azimuth angular velocity $\dot{\alpha}$, the elevation angular velocity $\dot{\beta}$ and the range velocity $\dot{R}$ of the target. As the computer K is an electromechanical analog computer, the values for the azimuth angle α , the elevation angle β and the range R respectively, are conveyed from the sight to the computer by means of mechanical connections from the shafts of the servomotors SS, SH and SA to those electromechanical computer elements in the computer, as for instance potentiometers and resolvers, which are to be adjusted in relation to these values. In FIG. 1 these mechanical connections are indicated by dash-and-dot lines. Electrical signals representing the azimuth angular velocity $\dot{\alpha}$, the elevational angular velocity $\dot{\beta}$ and the range velocity $\dot{R}$ of the target are derived from the servo-circuits for the servomotors SS, SH and SA in a manner to be described in detail in the following and are in the computer K connected as control signals to servomotors, which operate those electromechanical computer components, potentiometers and similar, in the computer, which are to be set in agreement with the azimuth angular velocity, the elevation angular velocity and the range velocity respectively.

According to the invention the computer is arranged to calculate on the basis of the target data supplied from the sight the azimuth angular acceleration $\ddot{\alpha}$ of the target about the azimuth axis of the sight, the elevation angular acceleration $\ddot{\beta}$ of the target about the elevation axis of the sight and the range acceleration $\ddot{R}$ of the target with respect to the site of the sight for the assumption that the target is moving in a straight course with variable velocity, and to produce signals proportional to said quantities. These signals are used as regenerative control signals for the servomotors SS, SH and SA and are connected to the associated servomotor through an integrator I1, I2 and I3 respectively and the corresponding adder circuit 4, 5 and 6 respectively. Each integrator is additionally supplied with the corresponding error signal e_s , e_h and e_a respectively from the target tracking equipment of the radar station R. Assuming that the error signals e_s , e_h and e_a respectively from the target tracking equipment in unit R are zero, that is that the antenna is directed accurately towards the target and the range measuring unit is set accurately on the range to the target, the integral from anyone of the integrators I1, I2, I3 of the corresponding regenerative control signals proportional to the calculated acceleration of the target in the corresponding coordinate direction will obviously control the associated servomotor SS, SH and SA respectively together with the feed back signal from the corresponding tachogenerator T1, T2 and T3 respectively, and the servomotors will consequently keep the antenna directed towards the target and the range measuring unit set on the range to the target with large accuracy, so long as the target is moving in the manner assumed, that is in a straight course. The error signals e_s , e_h and e_a from the target tracking equipment of the radar station need consequently to be used only for the correction of errors in the regenerative control of the servomotors, which arise when the target is not moving in the assumed manner or are caused by inaccuracies in the regenerative control of the servomotors, which arise when the target is not moving in the assumed manner or are caused by inaccuracies in the regenerative control. It can be shown that the output signals from the integrators I1, I2 and I3 are with good accuracy representing

the azimuth angular velocity and the elevation angular velocity of the antenna and the rate of change of the setting of the range measuring unit respectively, that is these signals represent the azimuth angular velocity, the elevation angular velocity and the range velocity respectively of the target, wherefore these signals are supplied to the computer K as measures for these target data. The shown design of the servo-circuits gives also a good filtering of the radar noise, which should in other cases appear in these signals supplied to the computer K.

In the embodiment of the invention shown in FIG. 1 the azimuth angular velocity and the elevation angular velocity of the antenna A and thus of the target are determined by means of direct voltage tachogenerators T1 and T2 coupled to the servomotors SS and SH. This is advantageous, as direct voltage tachogenerators can be given a high accuracy. The servo-circuits in FIG. 1 are consequently direct voltage servo-circuits. It is understood, however, that the feedback signals produced by the tachogenerators T1 and T2 should also be achieved by means of angular velocity sensitive gyros mounted on the platform 1 and the elevating mass of the antenna A respectively. Furthermore it is obvious that each feedback signal can be composed of several signals derived from different signal generators, which signals together represent the azimuth angular velocity or the elevation angular velocity respectively of the antenna with respect to the ground, if the antenna platform 1 is mounted on a movable support. It is also obvious that the regenerative control signals can be connected directly to the associated servomotors, if these are provided with signal generators producing signals proportional to the azimuth angular acceleration and the elevation angular acceleration respectively of the antenna. It is, however, difficult to obtain accelerometers with the same high accuracy as tachogenerators.

As already mentioned it is not always necessary that the servomotor SA for the range measuring unit is supplied with a regenerative control signal from the computer K, as in most cases the range acceleration of the target is considerably smaller than its azimuth angular acceleration and elevation angular acceleration and as the demand for accuracy is normally less in the target tracking in range than in the target tracking in direction.

The expression to be computed by the computer K for the azimuth angular acceleration of the target about the azimuth axis of the sight can be deduced from FIG. 2, which is a projection in the horizontal plane, assumed to be perpendicular to the azimuth axis of the sight, of the movement of the target and the relationship between the target and the site of the sight. In FIG. 2, S designates the site of the sight and M the target. The azimuth angle in the horizontal plane between the direction to the target and a fixed reference direction O is designated with α . The horizontal range between the sight and the target is designated with R and the horizontal velocity component of the target with $\dot{R}$.

FIG. 2 gives directly

$$\dot{\alpha} = \frac{\dot{R}}{R} \quad (1)$$

and

$$\ddot{\alpha} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} \quad (2)$$

where $\dot{R}$ and $\ddot{R}$ are functions of the time. Derivation of the expression (2) gives

$$\ddot{\alpha} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} \quad (3)$$

FIG. 2 gives also

$$\dot{R} = -R \dot{\alpha} \quad (4)$$

and if this relation is inserted in the expression (3) one obtains

$$\ddot{\alpha} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} = \frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} \quad (5)$$

If the relations (1) and (2) are inserted in the above expressions (5), one obtains

$$\dot{s}v = \left(\frac{\dot{F}h}{Fh} - 2\frac{\dot{A}h}{Ah} \right) \dot{s}v \quad (6)$$

Furthermore one has that

$$Ah = Al \cos hv \quad (7)$$

where hv is the elevation angle between the direction to the target and the horizontal plane. Derivation of the expression (7) gives

$$\dot{A}h = \dot{A}l \cos hv - Al \dot{h}v \sin hv \quad (8)$$

By dividing the expression (8) with Ah and using the relation (7), one obtains

$$\frac{\dot{A}h}{Ah} = \frac{\dot{A}l}{Al} - \dot{h}v \tan hv \quad (9)$$

If the relation (9) is inserted in the expression (6), one obtains

$$\dot{s}v = \left(\frac{\dot{F}h}{Fh} - 2\frac{\dot{A}l}{Al} + \dot{h}v \tan hv \right) \dot{s}v \quad (10)$$

which is consequently the expression to be calculated by the computer K for the azimuth angular acceleration $\dot{s}v$ of the target about the azimuth axis of the sight.

The expression to be calculated by the computer K for the elevation angular acceleration of the target about the elevation axis of the sight can be deduced from FIG. 3, which shows the projection of the movement of the target and the relation between the site of the sight and the target in a vertical plane containing the direction to the target. Same reference characters are used in FIG. 3 as in FIG. 2 and furthermore H designates the horizontal plane, hv the elevation angle for the direction to the target relative to the horizontal plane, Al the slanting range from the site of the sight to the target, and Fv the vertical velocity component of the target.

FIG. 3 gives directly

$$\dot{h}v = \frac{Fh \cos \varphi \sin hv}{Al} + \frac{Fv \cos hv}{Al} \quad (11)$$

where Fh , Fv , φ , hv and Al are functions of the time.

FIG. 3 also gives

$$\dot{A}l = -Fh \cos \varphi \cos hv + Fv \sin hv \quad (12)$$

Derivation of the expression (11) gives

$$\begin{aligned} \dot{h}v = & \frac{\dot{F}h \cos \varphi \sin hv}{Al} + \frac{\dot{F}v \cos hv}{Al} - \frac{Fh \sin \varphi \sin hv \dot{\varphi}}{Al} + \\ & \frac{Fh \cos \varphi \cos hv \dot{h}v}{Al} - \frac{Fv \sin hv \dot{h}v}{Al} - \\ & \frac{Fh \cos \varphi \sin hv \dot{A}l}{Al^2} - \frac{Fv \cos hv \dot{A}l}{Al^2} \end{aligned} \quad (13)$$

As it is assumed that the target is moving in a straight course, the total velocity and the total acceleration of the target has the same direction and the following relation is consequently true.

$$\frac{\dot{F}v}{Fv} = \frac{\dot{F}h}{Fh} = \frac{\dot{F}}{F} \quad (14)$$

where F is the total velocity of the target and $\dot{F}$ the total acceleration of the target. It is also obvious that the same ratio is achieved between any acceleration component of the target and the velocity component of the target in the same direction as the acceleration component. Insertion of the relation (14) in the expression (13) gives

$$\begin{aligned} \dot{h}v = & \frac{\dot{F}h}{Fh} \left(\frac{Fh \cos \varphi \sin hv}{Al} + \frac{Fv \cos hv}{Al} \right) - \\ & \frac{Fh \dot{\varphi} \sin \varphi \sin hv}{Al} + (Fh \cos \varphi \cos hv - Fv \sin hv) \frac{\dot{h}v}{Al} - \\ & \frac{\dot{A}l}{Al} \left(\frac{Fh \cos \varphi \sin hv}{Al} + \frac{Fv \cos hv}{Al} \right) \end{aligned} \quad (15)$$

By using the relations (1), (2), (7), (11) and (12) in this expression, one obtains

$$\dot{h}v = \left(\frac{\dot{F}h}{Fh} - 2\frac{\dot{A}l}{Al} \right) \dot{h}v - (\dot{s}v)^2 \sin hv \cos hv \quad (16)$$

which is consequently the expression to be calculated by the computer K for the elevation angular acceleration $\dot{h}v$ of the target about the elevation axis of the sight.

The expression possibly to be calculated by the computer K for the range acceleration of the target with respect to the site of the sight can be obtained by derivation of the expression (12), which gives

$$\begin{aligned} \dot{A}l = & -\dot{F}h \cos \varphi \cos hv + \dot{F}v \sin hv + Fh \dot{\varphi} \sin \varphi \\ & \cos hv + Fh \dot{h}v \cos \varphi \sin hv + Fv \dot{h}v \cos hv \end{aligned} \quad (17)$$

By inserting the relations (1), (2), (7), (11), (12) and (14) in this expression, one obtains

$$\dot{A}l = \frac{\dot{F}h}{Fh} \dot{A}l + Al [(\dot{s}v \cos hv)^2 + \dot{h}v^2] \quad (18)$$

which is consequently the expression for the range acceleration $\dot{A}l$ of the target, which is to be calculated by the computer K, if a regenerative control signal is required also for the servomotor operating the range measuring unit.

As understood from the above relation (14) and what has been said in connection with this relation, the quantity $\dot{F}h/Fh$ in the above expression (10), (16) and (18) for the azimuth angular acceleration, the elevation angular acceleration and the range acceleration respectively of the target can in principle be replaced by the ratio $\dot{F}v/Fv$ between the vertical acceleration of the target and the vertical velocity of the target or by the ratio $\dot{F}/F$, between the total acceleration of the target and the total velocity of the target or by the ratio between any other acceleration component of the target and the velocity component in the same direction as the acceleration component. It is, however, important that the acceleration component and the velocity component are chosen in such a direction that the ratio between them does not become indefinite for a certain type of movement of the target. For this reason the ratio $\dot{F}v/Fv$ is inexpedient, as this ratio will obviously become indefinite, as soon as the target course is horizontal. From this point of view it should be most advantageous to use the ratio $\dot{F}/F$ between the total acceleration of the target and the total velocity of the target, as this ratio is never indefinite. To evaluate the total velocity of the target requires however more extensive arithmetic operations than to evaluate its horizontal velocity, wherefore it is preferable to use the ratio $\dot{F}h/Fh$ between the horizontal acceleration and the horizontal velocity of the target. This is possible, as this ratio will be indefinite only if the target has a vertical or substantially vertical course, which is a very unlikely type of movement for the target.

Regarding the various quantities contained in the above deduced expressions (10), (16) and (18) for the azimuth angular acceleration $\dot{s}v$, the elevation angular acceleration $\dot{h}v$ and the range acceleration $\dot{A}l$ of the target following quantities are directly determined by the sight and supplied to the computer K, viz. the range Al to the target, the range velocity $\dot{A}l$ of the target, the elevation angle hv to the target, the elevation angular velocity $\dot{h}v$ of the target and the azimuth angular velocity $\dot{s}v$ of the target. Regarding the value for the horizontal velocity Fh of the target this must however be calculated by the computer. The expression for the horizontal velocity Fh of the target can be deduced from FIG. 4, which shows in perspective the relationship between the target M and the site S of the sight and the different coordinate velocities of the target determined by the sight, viz. the azimuth angular velocity $\dot{s}v$, the elevation angular velocity $\dot{h}v$ and the range of velocity $\dot{A}l$.

From FIG. 4 it can be seen that the target has a horizontal velocity component in the direction perpendicular to the projection Ah of the direction to the target and that this velocity component has the value

$$Ah \dot{s}v = A\dot{l} \dot{s}v \cos hv \quad (19)$$

In addition thereto the target has a horizontal velocity component, which is parallel to the horizontal projection of the direction to the target and has the value

$$-A\dot{l} \cos hv + A\dot{l} \dot{h}v \sin hv \quad (20)$$

Vectorial addition of these two mutually perpendicular velocity components will give the total horizontal velocity Fh of the target, having consequently the expression

$$Fh = \sqrt{(A\dot{l}\dot{s}v \cos hv)^2 + (-A\dot{l} \cos hv - A\dot{l}\dot{h}v \sin hv)^2} \quad (21)$$

It requires consequently only one vector addition for calculating the horizontal velocity of the target. In order to calculate the total velocity of the target, however, it should be necessary to make two vector additions, wherefore this is a more complicated arithmetic operation.

FIG. 5 shows a block diagram of the computer K for calculating the above deduced expressions for the azimuth angular acceleration, the elevation angular acceleration and the range acceleration of the target and for producing signal voltages proportional to said expressions to be applied to the servomotors SS, SH and SA as regenerative control signals. The computer is an electric analogue computer comprising as computer components essentially potentiometers, which are so designed and so operated in dependence of the input data supplied to the computer that they have voltage divisions proportional to the quantities indicated within each potentiometer symbol in FIG. 5. As already mentioned, those potentiometers which are to be set in dependence of the azimuth angle sv , the elevation angle hv and the range Al to the target are mechanically coupled to the servomotors SS, SH and SA respectively, whereas those potentiometers which are to be set in dependence of the azimuth angular velocity $\dot{s}v$, the elevation angular velocity $\dot{h}v$ and the range velocity $\dot{Al}$ of the target as determined by the sight are coupled to servomotors within the computer but not shown in the drawing, which are controlled by the signals supplied to the computer from the sight and are representing the azimuth angular velocity, the elevation angular velocity and the range velocity of the target respectively.

At terminal 7 the computer is supplied with a reference alternating voltage assumed for the sake of simplicity to have the amplitude value 1. This reference voltage is connected to a first potentiometer P1 having a voltage division proportional to the range Al to the target. The voltage from the potentiometer P1 is connected to two series-connected potentiometers P2 and P3 having a voltage division proportional to the azimuth angular velocity $\dot{s}v$ and to $\cos hv$ respectively. The voltage from the potentiometer P3 is consequently proportional to $Al \dot{s}v \cos hv$. The voltage from the potentiometer P1 is also connected to a potentiometer P4 having a voltage division proportional to the elevation angular velocity $\dot{h}v$. The voltage from the potentiometer P4 is consequently proportional to $Al \dot{h}v$. The reference voltage on terminal 7 is also applied to a potentiometer P5 having a voltage division proportional to the range velocity $\dot{Al}$. The voltages from the potentiometers P4 and P5 are connected to each one of the input windings of an electric resolver R1, the rotor of which is rotated relative to the stator of the resolver in agreement with the elevation angle hv to the target. The output voltage from the one output winding of the resolver R1 is consequently proportional to $\dot{Al} \cos hv - A\dot{l} \dot{h}v \sin hv$. This voltage and the voltage

from the potentiometer P3 are connected to each one of the input terminals of a unit 8 of the type producing an output signal proportional to the square root of the sum of the squares of the two input quantities. The unit 8 can for instance be of the type described in any of the U.S. patent specifications 2,600,264, 2,781,169 and 2,997,236, but can of course also consist of some other conventional device giving an output signal proportional to the square root of the sum of the squares of two input signals. The output voltage from unit 8 is consequently, according to the expression (21) above, proportional to the horizontal velocity Fh of the target. This output voltage is a direct voltage and is connected through an adder circuit 9 as a control voltage to a servomotor SF. A potentiometer P6 supplied from the terminal 10 with a reference direct voltage of the magnitude 1 is coupled to the shaft of the servomotor SF. The voltage from the potentiometer P6 is consequently proportional to the horizontal velocity Fh of the target and this voltage is fed back in opposition to the servomotor SF through the adder circuit 9 and is also connected to a differentiating circuit 11 producing consequently an output voltage proportional to the horizontal acceleration component $\dot{F}h$ of the target. This voltage is also fed back in opposition to the servomotor SF through the adder circuit 9, whereby an accurate speed control of the servomotor is achieved. The voltage from the differentiating circuit 11, obviously being a direct voltage, is connected to a modulator M1, the output alternating voltage of which is connected to a potentiometer P7, which is coupled to the shaft of the servomotor SF and has a voltage division proportional to $1/Fh$. The alternating voltage from the potentiometer P7 is consequently proportional to $\dot{F}h/Fh$. For the calculation of the azimuth angular acceleration $\dot{s}v$ of the target the computer comprises a potentiometer P8 having the voltage division $1/Al$ and being supplied with the voltage proportional to $\dot{Al}$ from the potentiometer P5. The voltage from the potentiometer P8 is consequently proportional to $\dot{Al}/Al$. Furthermore the computer comprises for the calculation of $\dot{s}v$ a potentiometer P9 having the voltage division $\dot{h}v$ and being fed with the reference voltage from terminal 7. The output voltage from the potentiometer P9 is connected to two series-connected potentiometers P10 and P11 having the voltage division $\sin hv$ and $1/\cos hv$ respectively. The voltage from the potentiometer P11 is consequently proportional to $\dot{h}v \tan hv$. This voltage and the voltage from the potentiometer P8 are connected to an adder circuit 12. The voltage proportional to $\dot{F}h/Fh$ from the potentiometer P7 is also connected to this adder circuit. The adder circuit 12 is designed to add the supplied input voltages with the mutual proportions and polarities indicated at the input terminals of the adder circuit. The output voltage from the adder circuit 12 is connected to a potentiometer P12 having the voltage division $\dot{s}v$. The alternating voltage from the potentiometer P12 is consequently, according to the above expression (10), proportional to the calculated azimuth angular acceleration $\dot{s}v$ of the target. As the voltage from the potentiometer P12 is an alternating voltage, whereas the regenerative control signal for the azimuth laying servo of the antenna must be a direct voltage signal, the voltage from the potentiometer P12 is connected to a demodulator D1, which gives consequently a direct voltage proportional to the computed azimuth angular acceleration $\dot{s}v$ of the target. For the calculation of the elevation angular acceleration $\dot{h}v$ of the target the computer comprises a potentiometer P13 having the voltage division $(\dot{s}v)^2$, which is supplied from the reference alternating voltage on terminal 7. The output voltage of this potentiometer is applied to a potentiometer P14 having the voltage division $\cos hv$. The voltage from the potentiometer P14 is connected to an additional potentiometer P15 having the voltage

division $\sin hv$. The output voltage from this potentiometer is consequently proportional to $(\dot{s}v)^2 \sin hv \cos hv$. Furthermore, the computer comprises an adder circuit 13 having as input voltages the voltage proportional to $\dot{A}l/\dot{A}l$ from the potentiometer P8 and the voltage proportional to Fh/Fh from the potentiometer P7. The adder circuit 13 is designed to add the two input voltages with the mutual proportions and polarities, indicated at the input terminals of the adder circuit, wherefore the output voltage from the adder circuit 13 is proportional to $Fh/Fh - 2\dot{A}l/\dot{A}l$. This voltage is connected to a potentiometer P16 having the voltage division $\dot{l}v$. The output voltage of this potentiometer is connected to an additional adder circuit 14 together with the voltage from the potentiometer P15. The adder circuit 14 is designed to add the two input voltages with the mutual proportions and polarities indicated at the input terminals of the adder circuit, wherefore the output voltage from the adder circuit 14 will, according to the above expression (16), be proportional to the calculated elevation angular acceleration $\dot{l}v$ of the target. The output alternating voltage from the adder circuit 14 is connected to a demodulator D2, which gives consequently an output direct voltage proportional to the computed elevational angular acceleration $\dot{l}v$ of the target.

For the calculation of the range acceleration $\dot{A}l$ of the target with respect to the site of the sight the computer comprises a potentiometer P17 having the voltage division Al and being fed with the voltage proportional to Fh/Fh from the potentiometer P7. The output voltage from this potentiometer is consequently proportional to $\dot{A}l \dot{F}h/Fh$. Furthermore, the computer comprises a potentiometer P18 having the voltage division $\dot{l}v$ and being fed with the voltage proportional to hv from the potentiometer P9. The voltage from the potentiometer P18 is consequently proportional to $(\dot{l}v)^2$. An additional potentiometer P19 having the voltage division $\cos hv$ is fed with the voltage from the potentiometer P14, wherefore the output voltage from the potentiometer P19 is proportional to $(\dot{s}v \cos hv)^2$. This voltage is together with the voltage from the potentiometer P18 connected to an adder circuit 15, which is adding the two voltages with the mutual proportions and polarities indicated at the input terminals of the adder circuit. The output voltage from the adder circuit 15 is connected to a potentiometer P20 with the voltage division Al . The output voltage from the potentiometer P20 is consequently proportional to $Al[(\dot{s}v \cos hv)^2 + \dot{l}v^2]$. This voltage is together with the voltage from the potentiometer P17 connected to an adder circuit 16, which is adding the two voltages with the mutual proportions and polarities indicated at the input terminals of the adder circuit, wherefore the output voltage from the adder circuit 16 will, according to the above expression (18), be proportional to the computed range acceleration $\dot{A}l$ of the target. The alternating voltage from the adder circuit 16 is connected to a demodulator D3, which produces consequently an output direct voltage proportional to the computed range acceleration $\dot{A}l$, which direct voltage can be connected as regenerative control signal to the servomotor SA.

It should be noticed that the electric analog computer for the calculation of the azimuth angular acceleration, the elevation angular acceleration and the range acceleration of the target, which is schematically shown in FIG. 5 and described above, is only an example of a computer suitable for this purpose. The same arithmetic operations can of course be made also by a computer of a different type or design.

I claim:

1. An anti-aircraft sighting device comprising, in combination: a sight layable in azimuth and elevation for

determining the direction to a target, an automatic target tracking equipment for measuring the range to the target and for generating error signals representing the azimuth angular deviation and the elevation angular deviation between the direction of the sight and the direction of the target and the deviation between the range presently set in said tracking equipment and the range to the target, servomotors controlled by said error signals for laying said sight in azimuth and elevation and for setting the range in said tracking equipment, means associated with the sight and the tracking equipment for producing target data signals representing the azimuth angle, the elevation angle, and the range to the target and the azimuth angular velocity, the elevation angular velocity and the range velocity of the target in relation to the site of the sight, an electric computer supplied with said target data and arranged to compute on the basis of said data and the assumption that the target is moving in a straight course with a variable velocity, the azimuth angular acceleration and the elevation angular acceleration of said target and to produce signals proportional to said computed azimuth angular acceleration and said computed elevation angular acceleration respectively, said signals being connected to the servomotor laying said sight in azimuth and the servomotor laying said sight in elevation respectively as regenerative control signals for said servomotors.

2. An anti-aircraft sighting device as claimed in claim 1, wherein said computer is arranged to compute on the basis of said target data and of an assumption that the target is moving in a straight course with variable velocity, also the range acceleration of said target and to produce a signal proportional to said computed range acceleration, said signal being applied as a regenerative control signal to the servomotor for setting said range measuring unit.

3. An anti-aircraft sighting device as claimed in claim 1, and comprising an integrator, each one of said regenerative control signals computed and produced by said computer being connected to the associated servomotor through said integrator, and wherein means are provided for generating signals proportional to the rate of change in the azimuth angle and the elevation angle respectively of said sight effected by the operation of said servomotors, said signals being fed back to the corresponding servomotors in opposition.

4. An anti-aircraft sighting device as claimed in claim 1, wherein said computer is arranged to calculate a first expression

$$\left(\frac{\dot{F}l}{Fl} - 2 \frac{\dot{A}l}{Al} + 2\dot{h}v \tan hv \right) \dot{s}v$$

and a second expression

$$\left(\frac{\dot{F}l}{Fl} - 2 \frac{\dot{A}l}{Al} \right) \dot{h}v - (\dot{s}v)^2 \sin hv \cos hv$$

wherein $\dot{F}l$ is the acceleration of the target in a predetermined direction, Fl is the velocity of the target in said predetermined direction, Al is the range to the target

as determined by said sight, $\dot{A}l$ is the range velocity as determined by the sight, hv is the elevation angle to the target as determined by the sight with respect to the plane in which the sight is laid in azimuth, $\dot{h}v$ is the elevation angular velocity of the target as determined by said sight about the elevation axis of the sight and $\dot{s}v$ is the azimuth angular velocity of the target as determined by said sight about the azimuth axis of the sight, and wherein a computer is arranged to produce first and second signals proportional to said first and second expression respectively, said first signal being applied as a regenerative control signal to the servomotor laying said sight in azimuth and said second signal being applied as a regenerative control signal to the servomotor laying said sight in elevation.

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5. An anti-aircraft sighting device as claimed in claim 4, wherein said computer is arranged to calculate also a third expression

$$\frac{\dot{F}l}{F}Al + Al[(\dot{s}v \cos hv)^2 + \dot{h}v^2]$$

and to produce a third signal proportional to said third expression, said third signal being applied as a regenerative control signal to the servomotor operating said range measuring unit.

6. An anti-aircraft sighting device as claimed in claim 4, wherein said computer is arranged to calculate the quantity $\dot{F}h/Fh$, where Fh is the velocity component of the target parallel to the azimuth plane of said sight and $\dot{F}h$ is the acceleration component of the target in the same direction as said velocity component, and to use said quantity as the quantity $\dot{F}l/F$ when calculating said first and second expressions.

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7. An anti-aircraft sighting device as claimed in claim 6, wherein said computer is arranged to calculate the expression

$$\sqrt{(Al \dot{s}v \cos hv)^2 + (\dot{A}l \cos hv - Al \dot{h}v \sin hv)^2}$$

and to produce a signal proportional thereto, and wherein the computer includes a servomotor controlled by said signal and signal generators coupled to said servomotor for generating a signal proportional to the ratio between the rate of rotation of the servomotor and the angle of rotation of the servomotor, said signal being used in the computer as a measure for the quantity $\dot{F}h/Fh$.

No references cited.

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