Dec. 1, 1953 R. C. GOERTZ ET AL 2,660,794

COMPUTING GUN SIGHT

Filed Sept. 12, 1942 3 Sheets-Sheet 1

FIG. 1

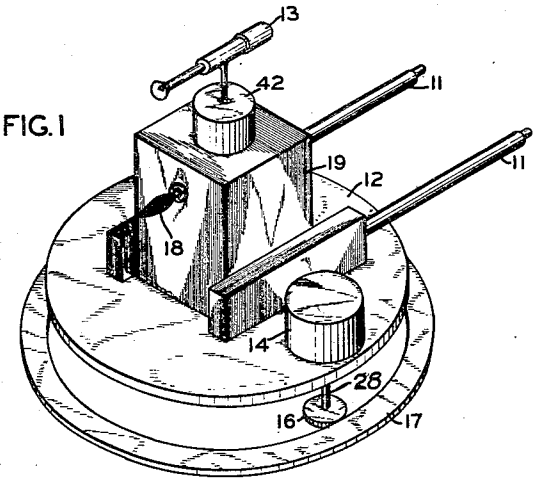


FIG. 2

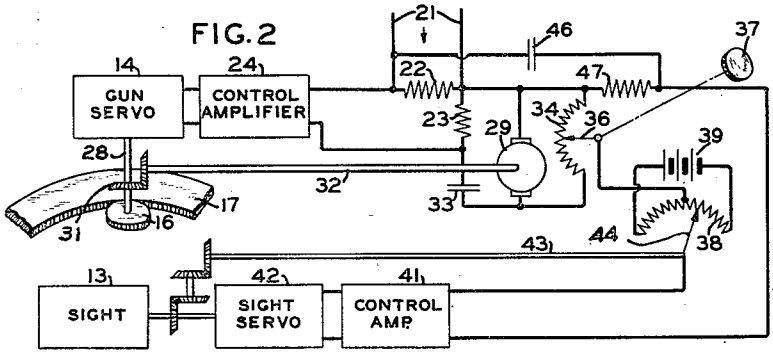
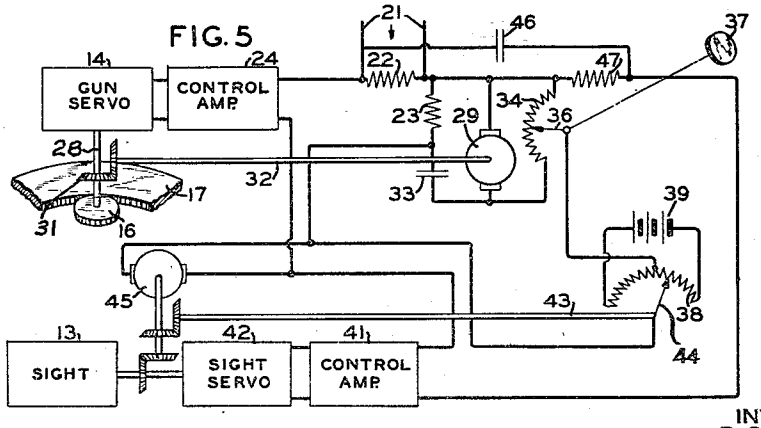


FIG. 5



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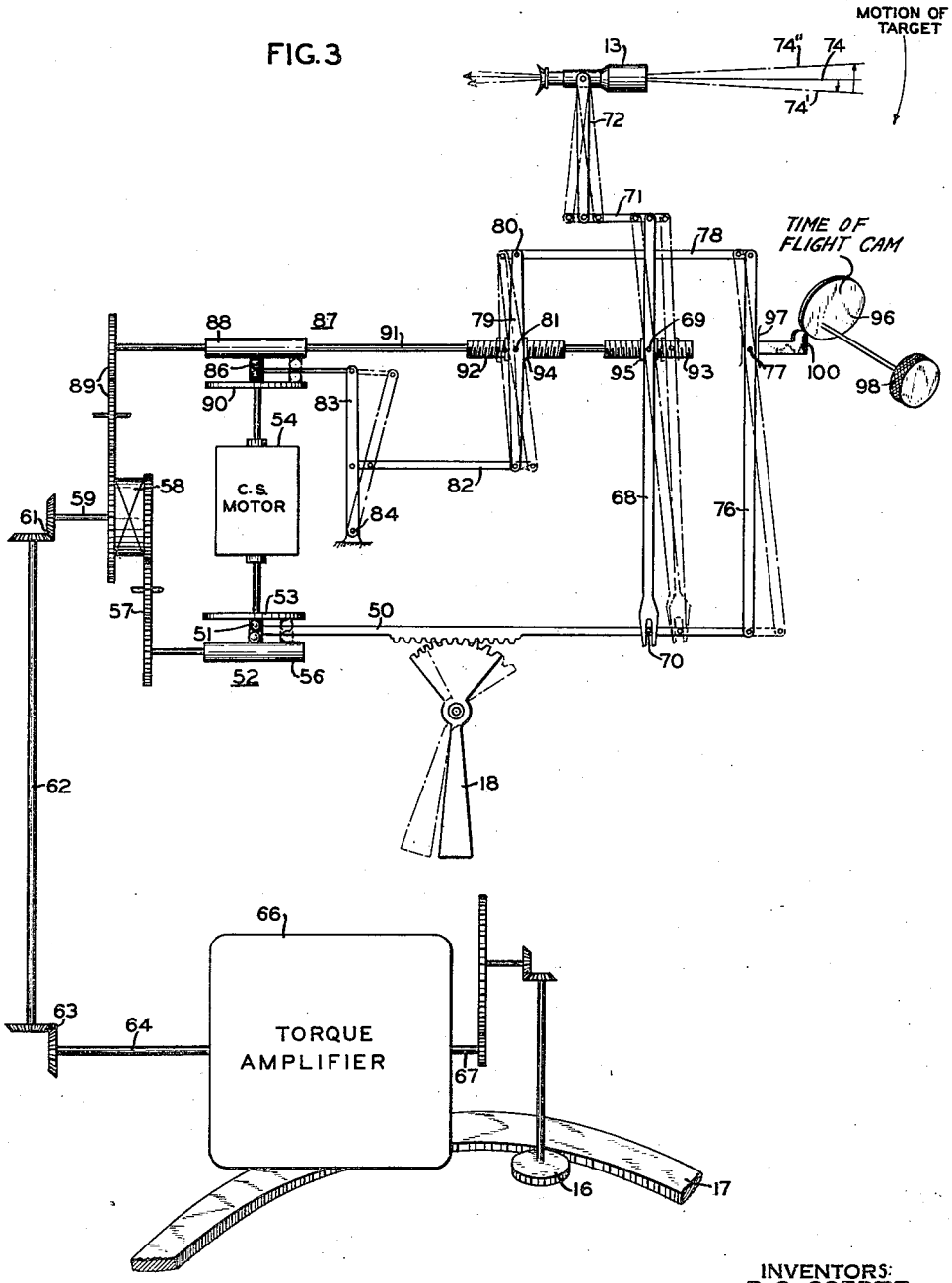
BY Paul B. Hunter.
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Dec. 1, 1953 R. C. GOERTZ ET AL 2,660,794

COMPUTING GUN SIGHT

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FIG. 3



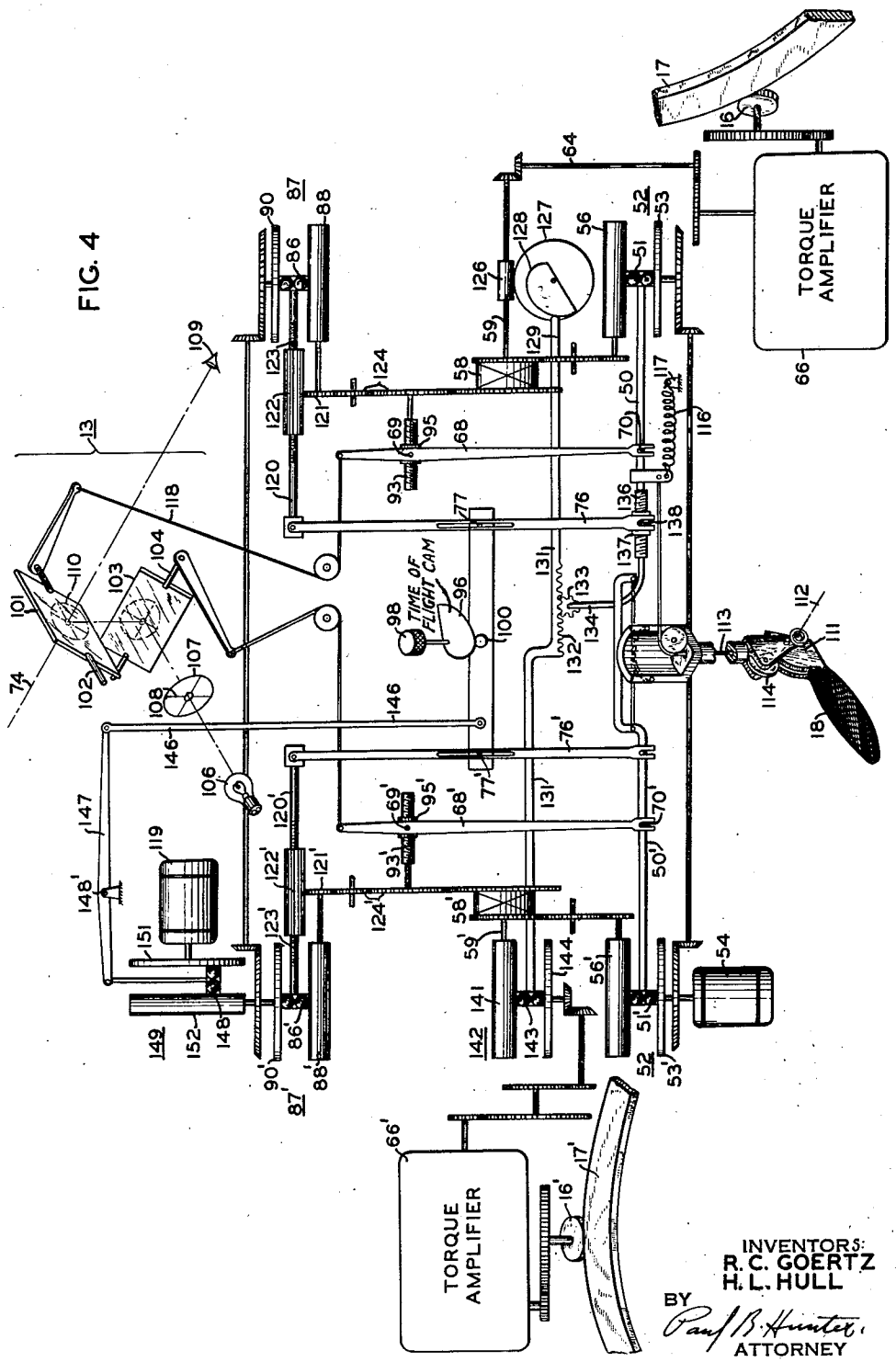
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FIG. 4



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UNITED STATES PATENT OFFICE

2,660,794

COMPUTING GUN SIGHT

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Application September 12, 1942, Serial No. 458,118

3 Claims. (Cl. 33—49)

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The present invention is related to the art including computing gun sights and gun turrets. The present invention is especially concerned with computing gun sights of the type in which the sight is carried by or moved in synchronism with the gun or turret and is offset or "disturbed" with respect to the gun by the amount necessary to give the proper lead angle of the gun with respect to the present orientation of the target defined by the line of sight of the sighting mechanism, to properly direct a projectile to the target.

Such a sighting device is shown in copending application Serial No. 358,382, for Computing Aircraft Gun Sight, filed September 26, 1940, in the names of C. G. Holschuh and O. A. Vielehr, now Patent 2,396,701, granted March 19, 1946. The computing gun sight of this prior application is intended for direct manual operation in an aircraft. The present invention constitutes an improvement of and a simplification of the gun sight of the prior application, including a manually controlled power means for rotating the guns and a simplified lead computing mechanism suitable for use either on aircraft or on the ground, against any moving targets.

Disturbed gun sights of the present type are subject to a type of instability which renders their efficient operation very difficult. This instability may be seen from the consideration that, if the line of sight should be lagging behind the target, and the gunner desires to move the line of sight up onto the target, his natural action is to increase the velocity of tracking of the gun and sight. In so doing, the lead angle also increases, since it has one component (prediction) proportional to the angular velocity of the guns, and therefore tends to drive the sight back with respect to the gun and away from the target. This constitutes an unnatural response to the natural tendency of the operator, and results in confusion and difficulty in acurately maintaining the line of sight in track with the target.

This objection to the disturbed sight is overcome by the present invention, and a further advantage in simplified tracking is obtained by providing a control of the sight which at the first instant in response to a change in velocity, moves the sight forward, namely, in the direction of the target, rather than reversely, as has formerly been the case. This temporary forward motion is then wiped out and reversed to provide the required lead angle after a time delay sufficient to prevent the unstable operation referred to above. In this manner an "aided tracking" type of control of the sight is obtained, which has been found

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to be advantageous in facilitating accurate tracking with a moving target.

In addition, the present invention provides the further feature that the orientation of the sight is rendered independent of the computing apparatus and is controlled solely by the manual control of the operator, whereby the effect of change in the lead angle does not impair the ease and effectiveness of control of the tracking.

Accordingly, it is an object of the present invention to provide improved computing gun sights of the "disturbed sight" type, eliminating the unstable operation of prior art systems.

It is a further object of the present invention to provide improved disturbed gun sights in which the sight is instantaneously actuated in a direction to follow the target upon a change of the position of a manual control, and is thereafter delayably moved in the opposite direction to introduce the required lead angle between the sight and the gun.

It is a still further object of the present invention to provide improved disturbed gun sights incorporating an aided tracking type of control of the sight.

It is another object of the present invention to provide improved disturbed gun sights in which the control of the orientation of the line of sight is made independent of the lead angle, whereby ease of tracking is greatly improved.

It is still another object of the present invention to provide improved disturbed gun sights including means for delayably offsetting the sight by the required lead angle to prevent unstable operation, the amount of delay being adjusted in accordance with the projectile time of flight to provide improved operation both with distant and with close-in targets.

It is a further object of the present invention to provide an electrically operated disturbed gun sight incorporating at least some of the advantages described above.

It is still another object of the present invention to provide a simplified mechanical construction for a disturbed gun sight also including these advantages.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 shows a schematic perspective view of a representative gun turret, such as may be used with the present invention.

Fig. 2 shows a schematic circuit diagram of an

electrical embodiment of the control for a disturbed gun sight according to the present invention, showing the control along one coordinate.

Fig. 3 shows a diagrammatic view of a mechanical embodiment of the present invention for controlling the device of Fig. 1.

Fig. 4 shows a schematic diagram of a complete mechanical embodiment of the present invention, including the features and advantages described above, and

Fig. 5 shows an improved form of the circuit of Fig. 2.

Fig. 1 shows a schematic perspective representation of one form of gun control and sight. In this case, the guns 11 are mounted on a platform 12 for rotation about a suitable axis, in this case illustrated as being a vertical axis, whereby the guns 11 may be rotated in azimuth. Also carried by platform 12 is the sighting device, illustrated schematically as being a telescope 13, which may be any type of device adapted to define a line of sight to a distant target.

By a sighting device in the present case is meant any device defining an axis and capable of indicating or determining when this axis is oriented toward a target, and may include radio, infra-red, photoelectric or other devices as well as the usual optical telescope or sight.

Platform 12 is adapted to be rotated in azimuth by means of a suitable servo device 14 which drives a pinion 16 engaging an internal fixed ring gear 17, whereby the platform 12 is caused to rotate by the interaction of pinion 16 and fixed internal gear 17. Servo 14 is controlled from a manual control member 18 by means of suitable control mechanism, indicated by the control box 19.

Manual control member 18 and its associated circuit are preferably of the type disclosed in Figs. 12A and 12B of copending application Serial No. 428,030 for Positional Control System, filed January 24, 1942, in the names of H. L. Hull, R. C. Goertz and W. C. Hartman, now Patent No. 2,526,665, or in Figs. 2–4 of copending application Serial No. 403,618 for Handle Control System, filed July 23, 1941, in the names of H. L. Hull, W. C. Hartman and R. C. Goertz, now Patent 2,414,102, granted January 14, 1947, and are adapted to produce an electrical voltage corresponding in sense and magnitude to the sense and magnitude of displacement of control member 18. As shown in copending application Serial No. 428,030 in its simplest form, the means employed for converting the displacement of control handle 18 into a corresponding electrical voltage signal may comprise merely a resistive potentiometer winding having its opposite terminals connected to a constant source of alternating or direct potential, and having a movable contact arm actuated by control handle 18. The voltage between the contact arm and the midpoint of the resistive winding then provides the required electrical control signal.

Fig. 2 shows one form of control circuit which may, for example, be included in control box 19 in Fig. 1, operative in response to the control signal produced by the control member 18 to orient the guns 11. Thus, the control signal derived from the manipulation of control handle 18 is connected to input terminals 21, and is thereby impressed across resistor 22. Resistor 22 is connected in series with a resistor 23, whose function will be described below, and the resultant series voltage across these two resistors is impressed upon the input of any suitable conventional type of amplifier 24. Amplifier 24 is preferably chosen to have a large amplification, whereby it may produce full output voltage for a very small input voltage. The output of amplifier 24 then actuates a suitable servo device 14. Servo 14 may be of the well-known Vickers variable-speed hydraulic transmission type, in which a predetermined input control signal voltage produces a corresponding and preferably proportional rate of turn of its output member 28 connected to pinion 16, shown in Fig. 1. If desired, any of the servo devices shown in Figs. 10A–10D of application Serial No. 428,030 may be used here.

Connected to be rotated simultaneously with platform 12 is a generator 29, shown for example as driven from a pinion 31 journaled in platform 12 and connected to generator 29 by any suitable mechanical means, indicated at 32. Generator 29 is preferably of the type which produces an output voltage directly proportional to the speed at which it is driven, and this voltage is impressed upon resistor 23 in series with condenser 33. This voltage is of the same type (alternating or unidirectional) as the signal voltage impressed across terminals 21. Preferably, generator 29 is of the permanent magnet direct current type, and the control signal is unidirectional or is converted suitably into a unidirectional voltage across resistor 23.

Neglecting for the moment the effect of condenser 33, it will be seen that the control signal voltage impressed on resistor 22 will serve to actuate servo 14, and thereby sets up a rate of turn of platform 12. This rotation of platform 12 produces a voltage by means of generator 29, which is impressed upon resistor 23 to oppose the voltage across resistor 22. By making amplifier 24 sensitive and responsive to small values of input voltage, an equilibrium condition will be reached in which the voltage input to amplifier 24 is just that necessary to produce a rotation of platform 12 and generator 29 such as to produce a voltage across resistor 23 differing from that across resistor 22 only by the small amount necessary to actuate amplifier 24 to maintain operation of the rest of the system. Since the voltage output of generator 29 is proportional to its speed and that of platform 12 and guns 11, it will be seen that in this way the control signal voltage impressed on terminals 21, and therefore, with condenser 33 omitted, the deflection of control member 18, will be substantially proportional to the angular velocity of the guns 11 and that, in effect, a "rate" type of control is provided, as described more in detail in application Serial No. 403,618, in which a predetermined deflection of manual control member 18 produces a corresponding angular velocity of guns 11 and platform 12.

Condenser 33 serves to provide a type of integrating or smoothing control. Thus, if the guns 11 and platform 12 are being rotated at a constant angular velocity, a constant voltage will be generated by generator 29 and will charge condenser 33 substantially up to this voltage. During the time condenser 33 is charging to full voltage, the voltage across resistor 23 will correspondingly decrease since the sum of the condenser voltage and the resistor voltage must continuously be equal to the voltage produced by generator 29, which generated voltage is constant if the platform has a constant angular velocity of rotation. The deflection of the control handle 18 necessary to maintain this constant angular

velocity of platform 12 will continuously decrease, since in order to maintain a constant angular velocity of platform 12 the displacement of control handle 18 must be always just sufficient to produce a control signal voltage across resistor 22 which differs from the voltage across resistor 23 by the small constant amount necessary to maintain this angular velocity. The required displacement will therefore decrease as condenser 33 charges and the voltage across resistor 23 decreases. Thus, after bringing the platform and guns up to the desired angular velocity, the control member 18 may be gradually returned to its neutral position without changing the angular velocity of the platform. In this way, condenser 33 operates to cause the platform 12 and guns 11 to continue to rotate at the same velocity even after manual controller 18 is returned to its neutral position.

Sighting device 13 is also carried by platform 12, but adjustable with respect thereto by means of servo 42, so that if the manual controller 18 is adjusted so that the line of sight defined by sighting device 13 is tracking with a target, it will be clear that the guns 11 are moving at the same angular velocity as that of the target relative to the gun position.

If a projectile is fired by the gun, it will take a predetermined time interval, known as the "time of flight," before reaching the target. During this time of flight the target will have advanced its position by an amount roughly equal to the angular velocity of the target relative to the gun position times the time of flight, which is termed the "prediction lead angle." Accordingly, in order to permit the gun to effectively direct the projectile, the orientation of the gun must be advanced with respect to the orientation of the target by an amount corresponding to this lead angle. In the present system, this is done by retarding the sighting device 13 relative to platform 12 on which it is carried and to the guns 11, thus producing a "disturbed gun sight."

For this purpose, it will be noted that the voltage produced by generator 29 is proportional to the angular velocity of the platform 12 and guns 11 and hence, when the sighting device 13 is tracking with the target, will also be substantially proportional to the angular velocity of the target.

To multiply this voltage by the time of flight, a potentiometer 34 is connected across the terminals of generator 29. It will be clear that the voltage derived between the variable arm 36 of potentiometer 34 and one of its fixed terminals will be proportional to the deflection of arm 36 from its end position and will also be proportional to the voltage impressed across the entire potentiometer 34, that is, will be proportional to the voltage of generator 29, which has already been shown to be proportional to the gun or target angular velocity during proper tracking conditions. Therefore, by suitably adjusting arm 36, as by means of a knob 37, proportionally to time of flight, the output voltage from potentiometer 34 may be taken as proportional to the product of target angular velocity and the time of flight. Since time of flight is approximately a function only of target range, knob 37 may be provided with a suitable scale calibrated directly in range.

The prediction voltage thus derived is impressed in series with a voltage produced from a follow-up potentiometer 38 energized from a battery 39, and the resultant voltage is impressed upon an amplifier 41, which controls a servo 42 driving the sight 13 with respect to platform 12. Servo 42 is also mechanically connected by a suitable coupling, indicated at 43, to the variable arm 44 of follow-up potentiometer 38.

In this way, servo 42 will continue to rotate until the voltage produced by follow-up potentiometer 38 exactly balances, that is, is equal and opposite to, the prediction voltage, and in this way the angular displacement of potentiometer arm 44, and hence of servo 42 and sight 13, will be proportional to the prediction voltage, which is in turn proportional to the prediction lead angle required between sight 13 and guns 11. By suitably choosing the gearing ratios and the voltage magnitudes, the sight 13 may be angularly displaced from the orientation of the guns 11 by exactly the proper lead angle to provide so-called "prediction correction" or prediction lead angle for the guns, to allow for the motion of the target relative to the guns.

It will be seen that if guns 11 are moving, for example, clockwise, in Fig. 1, sight 13 must be displaced in a counterclockwise sense with respect to platform 12. If the sight 13 is tracking behind the target, and the gunner attempts to accelerate the sight to "get on" the target, it will be seen that any increase in gun and platform velocity will produce a displacement of sight 13 tending to increase the lag between sight and target, and the more the gun velocity is increased, the greater lag is produced, although the gunner is attempting to decrease the lag. This action is characteristic of all disturbed sights, and renders tracking with the target very unnatural and difficult, thus preventing optimum utility of the device.

To overcome this defect, a condenser 46 and a resistor 47 are connected across the input terminals 21 supplied with the control signal, and the voltage across resistor 47 is inserted in series across the voltage output of the time-of-flight potentiometer 34 and is therefore added thereto. The values of condenser 46 and resistor 47 are chosen such that these elements form a differentiating circuit in a manner well known in the art, whereby the voltage derived across resistor 47 corresponds to the rate of change of the control signal impressed on terminals 21.

By adding this voltage to the lead angle voltage derived from time-of-flight potentiometer 34, the sight 13 is initially actuated in such a manner as to follow the target, rather than in the opposite sense as would otherwise be the case.

This action serves to overcome the tracking lag and the sight "catches up" to the target. At this instant, of course, the correct lead angle is not present, but this is immaterial since firing is done only while accurately tracking with the target. In this way, the sight responds as the operator would intuitively expect, and not oppositely, and the operator is enabled to "get on" the target much more quickly to place the sight in the proper tracking condition.

It will be seen that the rate voltage derived from resistor 47 will die out as the control signal persists, and that after a short time the actual lead angle between sight 13 and guns 11 will again become proportional to the lead angle voltage, as is required, whereupon accurate fire can be obtained once more. In this way a stable and easily operated disturbed gun sight system is provided, eliminating the instability characteristic of prior art devices.

The differentiating circuit 46, 47 also produces

a type of aided tracking control for the sight. As is known, in an aided tracking control, the controlled device is actuated so that its displacement θ from a predetermined neutral position is related to a constant displacement φ of the controlling member by a relation of the form

$$\theta = k_1\varphi + k_2\varphi t$$

where k_1 and k_2 are proportionality constants and t is the time the control displacement φ persists. In the present case, the motion of the guns and platform carrying the sight produces the second term of the right member of the above equation, while the differentiating circuit 46, 47 produces the first term, at least in transient fashion, during "getting on" the target, when aided tracking control is most useful and desirable.

It is to be noted that the device thus far described serves to supply only the prediction lead angle. Other lead angle components may also be provided by inserting voltages proportional thereto in series with the input to amplifier 41.

The system of Figs. 1 and 2 has been described with respect to motion about one axis only, illustrated as being the azimuth axis. It is to be understood that preferably the guns 11 and sight 13 are made rotatable also about a second axis, such as an elevation axis perpendicular to the azimuth axis, under the control of a suitable manual control member, which may be member 18, displaced about a second independent axis, as is shown below in Fig. 4. A similar control between the elevational motions of the sighting device 13 and guns 11 may be provided for motion about the elevation axis, as shown in Fig. 4, whereby the gun sight of the invention may be utilized with targets moving in three dimensions, such as aircraft.

The system of Fig. 2 still suffers the disadvantage that the gunner, in order to maintain the sight in track with the target, must actuate the sight (by means of his control of the guns and platform 12) to compensate for changes in lead angle. It is preferable, from the standpoint of simple and effective tracking, that the operator be able to manipulate the sight without adjusting for changes in lead angle. This is done in Fig. 3, which shows a modified type of control system similar in principle to that of Figs. 1 and 2, but entirely mechanical in operation. Here control handle 18 is coupled to arm 50 and displaces the ball carriage 51 of a variable speed drive 52, whose drive disc 53 is rotated at constant speed from a constant speed motor 54. In this way, the output cylinder 56 of variable speed drive 52 is rotated at an angular velocity proportional to the displacement of control 18. This rotation of cylinder 56 is led through suitable gearing 57 and a differential 58 to rotate an output shaft 59 which is connected by way of gearing 61, shaft 62, gearing 63, and shaft 64 to a torque amplifier 66 whose output 67 drives pinion 16 with respect to fixed ring gear 17 in the same manner as in Fig. 1. Torque amplifier 66 may be of any suitable type adapted to provide a high torque output from a relatively small torque input derived from shaft 64. Such amplifiers are well known in the art and are believed to require no further description here. One form of such torque amplifier is the well known Vickers hydraulic variable speed drive.

In this manner, displacement of manual control 18 sets up a corresponding angular velocity of platform 12 which carries all of the elements shown in Fig. 3, except the fixed ring gear 17, in a manner similar to that shown in Fig. 1, and hence provides a rate control of sight 13.

At the same time, the displacement of manual control 18 rotates a lever 68 about a pivot 69. Lever 68 is connected through a further linkage 71, 72 to the sight 13 and thereby displaces the line of sight 74, corresponding to the optical axis of telescope 13 in Fig. 1, by a proportional amount and in the same sense as the desired rotation of platform 12, as to a position 74' relative to the gun orientation which is along 74. This action therefore corresponds to the effect of condenser 46 and resistor 47 described in Fig. 2, since the sight 13 is thus initially displaced proportionally to the angular velocity of platform 12, and provides a resultant "aided tracking" control of sight 13, which has been recognized as a desirable type of control for efficient tracking.

At the same time, displacement of control member 18 moves another lever 76 about a pivot 77, which motion is transferred proportionately through a link 78, link 79 pivoted at 81, link 82, and lever 83 pivoted about pivot 84, to proportionately displace ball carriage 86 of a second variable speed drive 87 also actuated from motor 54.

The rotation of output cylinder 88 of variable speed drive 87 rotates a shaft 91 carrying oppositely threaded screws 92 and 93 cooperating with respective traveling nuts 94 and 95, upon which are mounted the pivots 81 and 69 described above. Thus, the rotation of shaft 91 serves to displace pivot 81, whereby lever 79 pivots about the new position of its pivot 80 and returns the ball carriage 86 to its neutral or centralized position to stop the rotation of shaft 91, which will then have rotated through an angle proportional to the deflection of member 18.

At the same time, rotation of shaft 91 operates to move the traveling nut 95 carrying pivot 69, whereby lever 68 pivots about its pivot 70 and turns the sight 13 oppositely to its original motion. The angular displacement of shaft 91, and hence the angular displacement of sight 13 thus produced, will be proportional to the displacement of manual control 18 and accordingly will be proportional to the angular velocity of platform 12, which will be equal to the angular velocity of the target during proper tracking.

It will be seen that this angular displacement of sight 13 and shaft 91 will depend upon the position of the pivot 77 about which lever 76 rotates. This pivot is made adjustable, as by means of a time-of-flight cam 96 and a slide 97 actuated by a range knob 98, and is set in accordance with the time of flight of the projectile, determined in the same manner as with respect to Figs. 1 and 2, from a suitable range finder. By adjusting pivot 77 in accordance with the time of flight, the angle through which sight 13 is turned by shaft 91 is made proportional to the time of flight plus a constant. Since the original deflection of sight 13 in the direction of motion of the guns was proportional to the angular velocity of the guns as determined by the angular displacement of control 18, this constant is chosen to be of such value that the resultant position of sight 13 will be displaced from the orientation of the guns by an amount equal to the desired prediction lead angle, or to the angular velocity of the guns times the time of flight, producing the same type of operation as in Figs. 1 and 2.

The motion of output cylinder 88 of variable speed drive 87 is also additively coupled to that

of cylinder 56 by way of gearing 89 and differential 58. In this way the input to torque amplifier 66 and the platform 12 are additionally displaced by a component corresponding to the prediction lead angle.

Since the sight 13 is thus displaced relative to platform 12 and guns 11 by the same amount as the guns and platform are oppositely displaced with respect to the target, it will be seen that sight 13 has no motion relative to the target due to the action of variable speed drive 87, which therefore sets in the proper lead angle without in any way impairing the ease of tracking. In other words, the gunner need not compensate for the lead angle, as he must in Fig. 2.

It will be seen that variable speed drive 87 acts to initially delay the control of sight 13 by the proper lead angle, so that easier and stable tracking is possible. This delay is controlled by the "settling time" of drive 87, which is the time it takes to resume a stable position after being displaced, and depends on the speed of motor 54 and the amount the ball carriage 86 is initially displaced, which latter in turn depends on the distance advantage of the lever system 83, 82, etc. This settling time, in the device of Fig. 3, is selected to have a value large enough to provide stable tracking by sight 13, and short enough to obtain quick setting of the sight and guns to the proper firing positions.

It will be clear here also that a similar control may be provided for motion about a second axis perpendicular to the axis of rotation of sight 13 and the guns, to provide three-dimensional control.

To provide control compensation for the lead angle in Fig. 2, this circuit may be modified in the manner shown in Fig. 5, by the addition of a generator 45 driven from the sight servo 42 synchronously with sight 13. Generator 45 is preferably of the same type as generator 29, and produces a voltage output proportional to the speed at which it is driven, which will therefore be proportional to the rate of change of the prediction lead angle. This prediction rate voltage is inserted in series with the other voltage input to control amplifier 24. As was seen in Fig. 2, the speed of the guns obtained from gun servo 14 is proportional to the input voltage derived across resistor 22. In Fig. 5, however, the gun rate will be proportional to the sum of the voltage across resistor 22 and the voltage derived from generator 45. Accordingly, the gun orientation derived by the device of Fig. 5 in response to a change in displacement of control 18, will be advanced from the corresponding orientation of the gun in Fig. 2 by an amount equal to the change in the lead angle, so that the sight and gun are displaced in opposite senses by the same angle, leaving the sight orientation unaffected by changes in the position of control 18, in a manner similar to that in Fig. 3.

Preferably also the voltage derived from generator 45 is connected in series with the input voltage to control amplifier 41, and thereby provides, in a well-known manner, a type of anti-hunting control for the sight servo 42, permitting more accurate positioning of sight 13 without lag or hunting in response to the voltages derived from potentiometer 34, resistor 47 and potentiometer 38, described in Fig. 2.

Fig. 4 shows a modification of the device of Fig. 3, including control along both elevation and azimuth coordinates and incorporating several improvements. It will be noted that the device of Figs. 2 and 3 is useful in obtaining the prediction lead angle allowing for the motion of the target, but does not provide the ballistic correction required to allow for variation of the projectile from the orientation of the gun. Such ballistic correction for a gun having a stationary location, such as on a truck or tank or a ship, can be considered to be in elevation only, namely, to be the so-called superelevation correction, and as a sufficiently good approximation may be considered to be proportional to the product of the cosine of the angle of elevation of the gun by the time of flight. Such a correction is incorporated in the device of Fig. 4, as will be described.

In addition, it has been found that the settling time discussed above should vary with the range of the target or the time of flight in order to provide optimum operation. Thus, for close-in targets having a short time of flight and range, it is desirable that a short settling time be provided in order to enable the gunner to quickly get into the accurate firing condition. For longer ranges and longer times of flight, a longer settling time is desirable to provide improved stability of operation and ease of tracking. This feature is also incorporated in the device of Fig. 4.

Referring to this figure, the sight 13 is shown as constituting a mirror 101 pivoted about an axis 102 preferably horizontally disposed and parallel to the elevation trunnions of the gun and cooperating with a second mirror 103 pivoted about an axis 104 disposed along the axis of the gun. A suitable source of light, indicated schematically as a lamp bulb 106, projects its light rays through a screen or masking member 107 having a suitable reticle 108 formed thereon, so that the image 110 of this reticle is reflected from mirror 103 into mirror 101, and thereby into the eye 109 of the gunner. Mirror 101 is preferably of the reflex type, also permitting direct transmission of light therethrough, such as along the line of sight 74. It will be seen that rotation of the mirror 103 will cause the image 110 of the reticle 108, as seen by the observer's eye, to move along axis 102 of mirror 101, so that the line of sight formed by the reticle image 110 and the gunner's eye 109 will move in the slant plane containing the elevation gun trunnions and the gun axis, and about an axis perpendicular to this plane. This may be termed motion in gun slant plane azimuth. Rotation of mirror 101 will cause this reticle image 110 to appear to move perpendicular to axis 102, producing motion of the line of sight in elevation. As will be seen, mirrors 101 and 103 are angularly displaced in accordance with the elevation and slant plane azimuth components of the lead angle required for proper operation, and therefore the optical system 13 is operated in a similar fashion to that of Figs. 2 and 3, having its line of sight offset or disturbed from the gun orientation by the amount and in the direction of the resultant lead angle.

In operation, the gunner will actuate the manual controller 18 to maintain the target centralized with respect to the reticle image 110, at which time the proper tracking condition for effective fire is obtained. Manual control member 18 in Fig. 4 is shown as being of the type having independent displacements about two independent axes, corresponding to the elevation axis and the azimuth axis of rotation of the gun and sight. Thus, fixed to control member 18 is a member 111 formed as a sector of a circle having its center along the pivot axis 112 of the manual control 18. Disposed along the circumfer-

ence of this circular member 111 is a cable 113 which is maintained in close contact with this circumference by means of an idler pulley 114. Upon motion of manual control 18 about axis 112, cable 113, operating against the pull of a spring 116, whose remote end is fixed as at 117, will serve to translate arm 50, and thereby displaces the ball carriage 51 of the variable speed drive 52 in the same manner as in Fig. 3. The rotation of the output cylinder 56 of the variable speed drive 52 is then led through differential 58 to output shaft 64 controlling a torque amplifier 66 driving the elevation pinion 16 engaging the elevation rack or ring gear 17 and thereby driving the entire apparatus here shown, together with the guns fixed with respect thereto, in elevation, at a rate proportional to the elevation displacement of manual controller 18. This action is exactly similar to that of Fig. 3.

At the same time, this motion of arm 50 moves a lever 68 about a pivot 69 and thereby displaces the elevation mirror 101, as by means of a suitable cable 118, or other mechanical coupling, to displace the line of sight determined by the reticle image 110 in the same direction as the guns are starting to move. In addition, the motion of arm 50 moves a lever 76 about a pivot 77 and thereby displaces the ball carriage 86 of variable speed drive 87, whose drive disc 90 is driven from motor 119 in the manner to be described. The output cylinder 88 of variable speed drive 87 drives a gear 121 meshing with an elongated pinion 122 which is rotatably mounted on a link 120 coupled to lever 76, and which is internally threaded to receive a threaded shaft 123 movable in translation together with the ball carriage 86. as cylinder 88 turns, pinion 122 is rotated and the screw shaft 123 is thereby screwed in or out in a sense to restore ball carriage 86 toward its neutral position. In this respect, the device of Fig. 4 is similar to the linkage system 83, 82, 79, 92, 94, 81 of Fig. 3, and serves to delayably rotate gear 121 by an amount proportional to the displacement of manual controller 18, and also proportional to the angular velocity of the guns, and hence of the target when tracking therewith.

Gear 121 also operates through suitable gearing 124 to rotate a screw 93 carrying the nut 95 which supports the pivot 69, and thereby delayably rotates mirror 101 by the amount necessary to withdraw the line of sight from its original advanced position and to displace it from the gun orientation by the proper prediction lead angle. Pivot 77 is made adjustable under the control of the range knob 98 and time-of-flight cam 96 in the same manner as in Fig. 3. Gear 121 also adds its motion to that of cylinder 56 in differential 58, also as in Fig. 3.

As thus far described, the present system is identical with that of Fig. 3, merely replacing the sight 13 by an equivalent sighting device 101, 103. In order to introduce the super-elevation component of the elevation lead angle, output shaft 59 of differential 58 operates through a worm 126 and a worm wheel 127 to rotate a cam 128, whose follower 129 is thereby translated in proportion to the cosine of the angular displacement of shaft 59, and therefore in accordance with the cosine of the angle of elevation of the gun. The displacement of follower 129 correspondingly displaces arm 131 carrying the rack 132 cooperating with a pinion 133, which is thereby rotated through an angle corresponding to the cosine of the angle of gun elevation. Pinion 133 actuates a flexible shaft 134, which in turn rotates a screw shaft 136 rotatably mounted upon arm 50. Screw 136 in this manner translates a nut 137 mounted thereon, which carries the pivot 138 for lever 76. Thus, the displacement of lever 76 produced by manual control 18 is modified by an additive component proportional to the cosine of the angle of elevation. This modification of the displacement of lever 76 produces a corresponding modification of the resultant angular displacement of output cylinder 88 of variable speed drive 87, which thus operates through screw 93 and nut 95 to modify the lead angle of mirror 101, which is thus controlled both in accordance with the prediction lead angle and the superelevation lead angle to provide the proper resultant lead angle in elevation for effective fire.

Shaft 59 is coupled to torque amplifier 66 driving pinion 16 with respect to fixed elevation rack 17, similar to the arrangement of Fig. 3.

The control of the azimuth mirror 103 is exactly similar to that of the elevation mirror 101 and need not be further described, similar elements being given similar reference characters, but primed. It is to be noted, however, that the angular motion of the line of sight produced by azimuth mirror 103 occurs in the slant plane determined by the gun orientation and the pivot axis 102 of mirror 101 parallel to the gun elevation trunnions. The azimuth control of the guns, however, is generally about a fixed vertical axis, as in Fig. 1, or in a horizontal plane. In order to properly control the guns, therefore, it is necessary to convert angular displacements in azimuth in the slant plane into the corresponding azimuth angular displacements in the horizontal plane. As is well known, this conversion may be performed by multiplying the slant plane azimuth values by the secant of the angle of elevation, or by dividing by the cosine of the elevation angle. For this purpose, output shaft 59′ of differential 58′, corresponding to output shaft 59 of Figs. 2 and 3, which is angularly displaced in accordance with the gun slant plane azimuth, serves to actuate the drum cylinder 141 of a variable speed drive 142, whose ball carriage 143 is translated in proportion to the cosine of the angle of gun elevation by means of arm 131. By so doing, the disc 144 of variable speed drive 142 is actuated in accordance with the ratio of the displacement of cylinder 141 to that of ball carriage 143, and will therefore be displaced in proportion to the product of the displacement of shaft 59′ by the secant of the angle of elevation. The output derived from disc 144 is then led to a torque amplifier 66′, similar to that of Figs. 2 and 3, and serves to actuate the azimuth drive pinion 16 cooperating with the azimuth ring gear 17′ to rotate the entire apparatus in azimuth.

As thus far described, the present device of Fig. 4 has added the superelevation control and the correction for slant plane data to the device of Fig. 3. In order to adjust the settling time in accordance with the time of flight, range knob 98 and cam 96 actuate a link 146, which in turn is pivoted to a lever 147 having a fixed fulcrum at 148′. In this manner, lever 147 adjusts the ball carriage 148 of a further variable speed drive 149, whose drive disc 151 is driven at constant speed from constant speed motor 119, in accordance with time-of-flight. The output cylinder 152 of variable speed drive 149 then drives the drive discs 90 and 90′ of variable speed drives 87 and 87′. In this manner, the settling time of the variable speed drives 87 and 87′ is adjusted

in accordance with the time of flight or range of the target, so that optimum performance may be obtained both for close-in targets and for distant targets.

The apparatus of Fig. 2 may be adjusted similarly to allow for close-in or remote targets by adjusting the value of resistor **47** or condenser **46**. Preferably, for reasons of simplicity, resistor **47** is made adjustable for this purpose.

Although the above modifications have been described as using the friction disc type of variable speed drive, it is to be noted that any other type of device yielding an output rate of turn corresponding to an input displacement may be used.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A computing gun sight comprising a sighting device mounted on and adapted to be moved with a gun, means for producing a control voltage corresponding to a desired angular velocity of said gun, means responsive to said voltage, and including a speed generator adapted to produce a speed voltage proportional to the angular velocity of said gun, for driving said gun and sighting device at said desired angular velocity, and means for offsetting the orientation of said sighting device from that of said gun in a direction opposite to the motion of said gun and in proportion to said angular velocity, comprising means for displacing said sighting device relative to said gun in proportion to said speed voltage, whereby said sighting device lags said gun by the prediction lead angle.

2. A computing gun sight as in claim 1 further including means for momentarily further displacing said sighting device relative to said gun in the same sense as the motion of said gun and in proportion to the rate of change of said control voltage whereby an aided tracking control of said sighting device is provided so that it may be more readily tracked with a target.

3. A computing gun sight as in claim 1, further including means responsive to a change in said control voltage for initially displacing said sighting device relative to said gun in the same sense as the motion of said gun and for delayably removing said initial displacement, whereby said sighting device may be stably and easily tracked with a target.

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