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Sept. 1, 1959 W. H. NEWELL ET AL 2,902,212
TRUNNION TILT CORRECTOR
Filed April 13, 1954 5 Sheets-Sheet 1

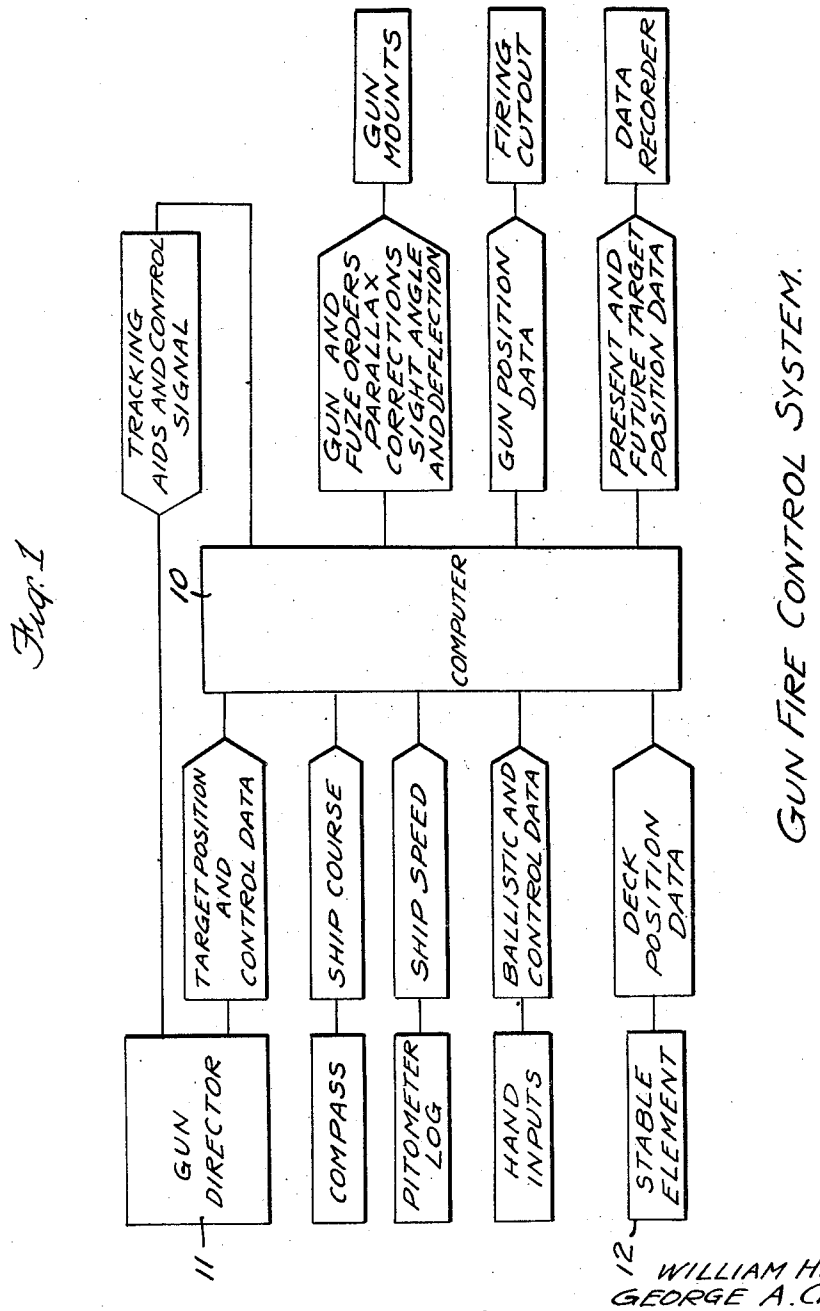


Fig. 1

GUN FIRE CONTROL SYSTEM.

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TRUNNION TILT CORRECTOR

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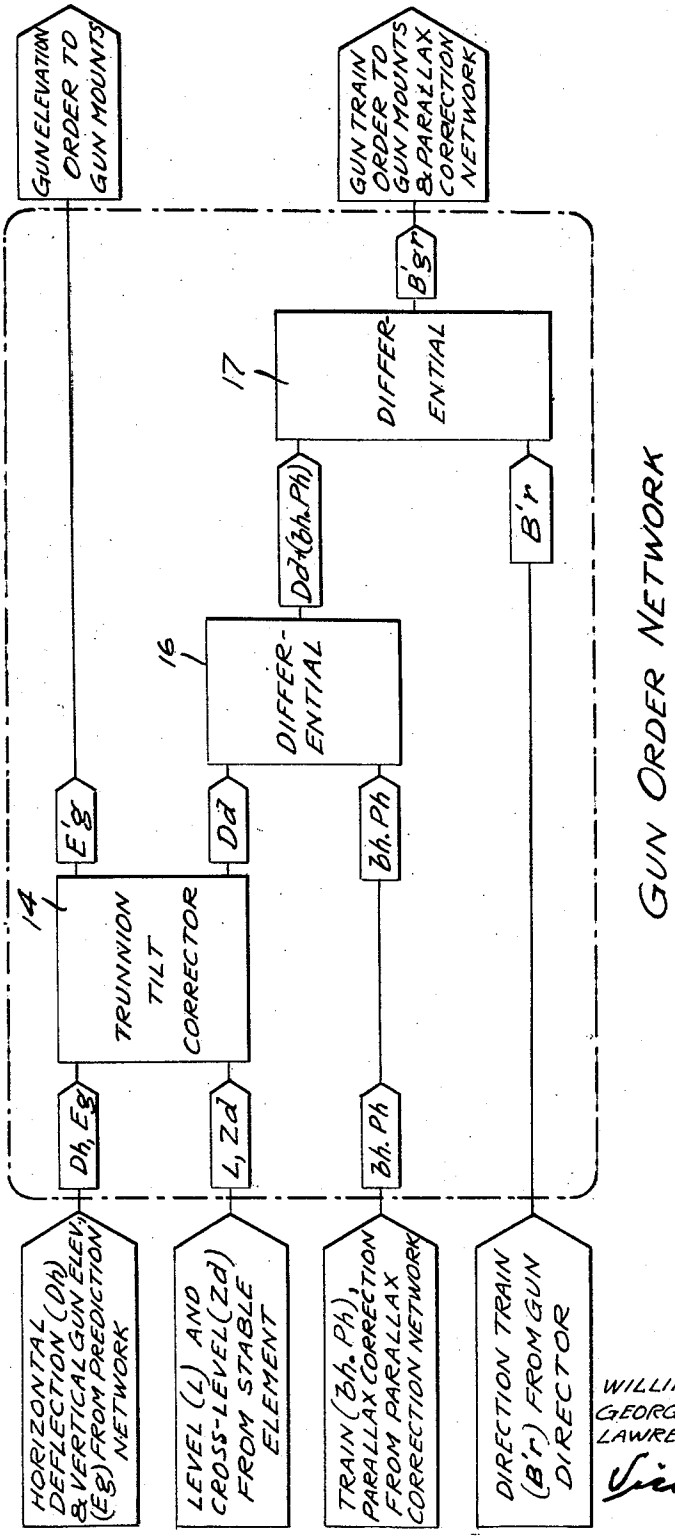


Fig. 2.

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TRUNNION TILT CORRECTOR

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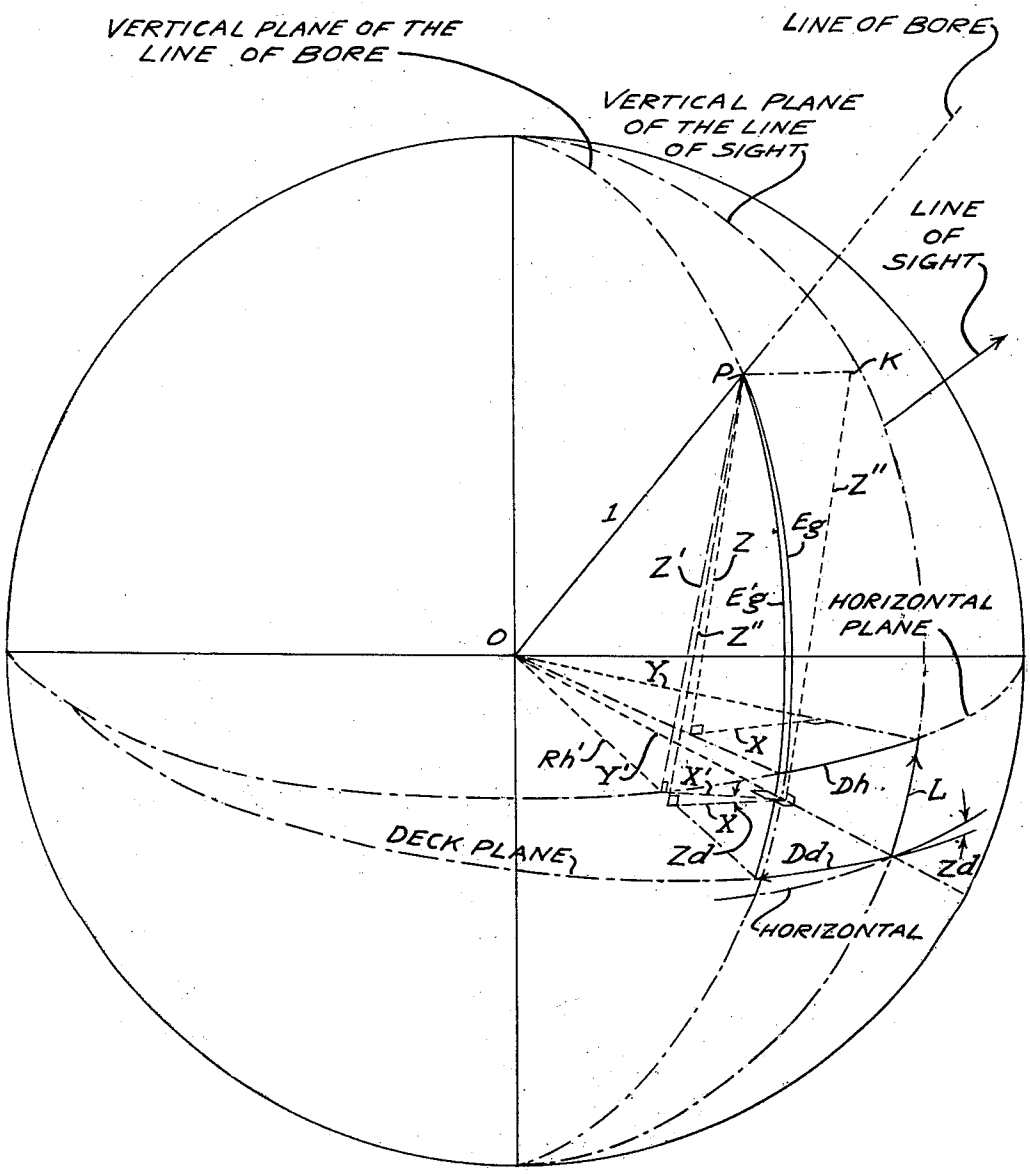


Fig. 3.

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TRUNNION TILT CORRECTOR

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Fig. 4

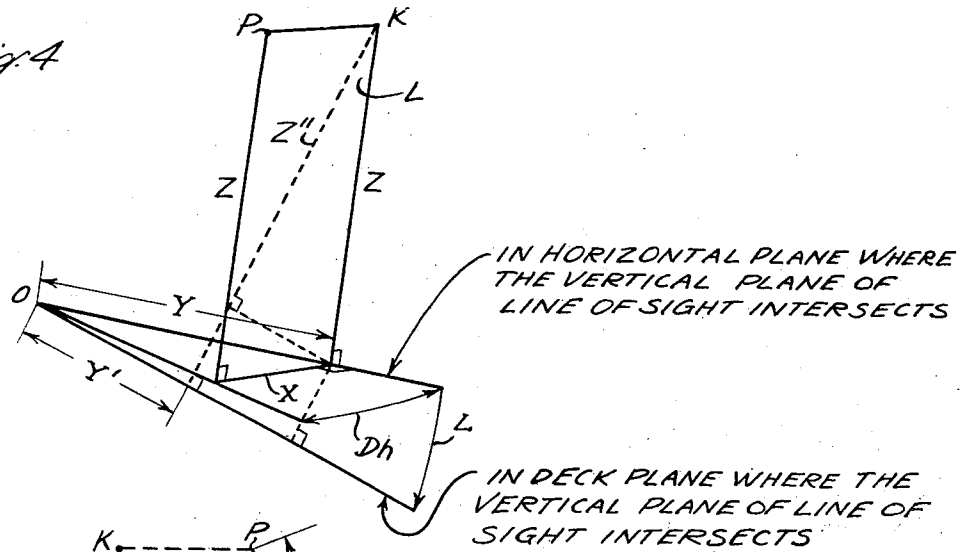


Fig. 5

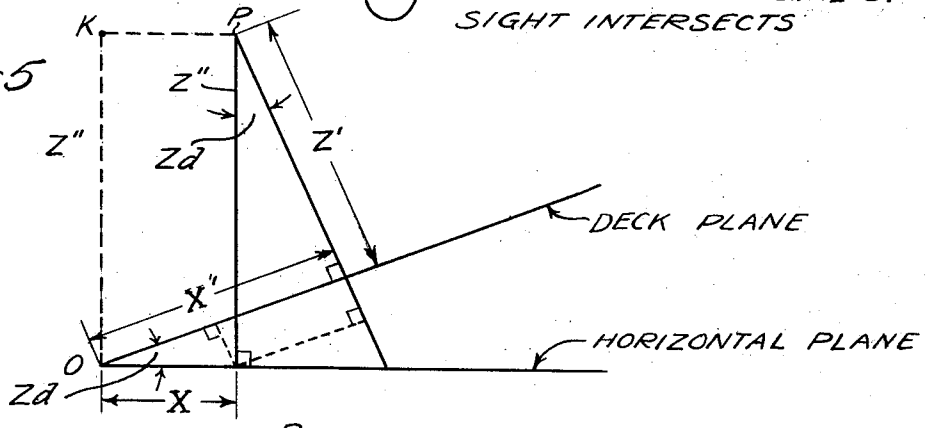
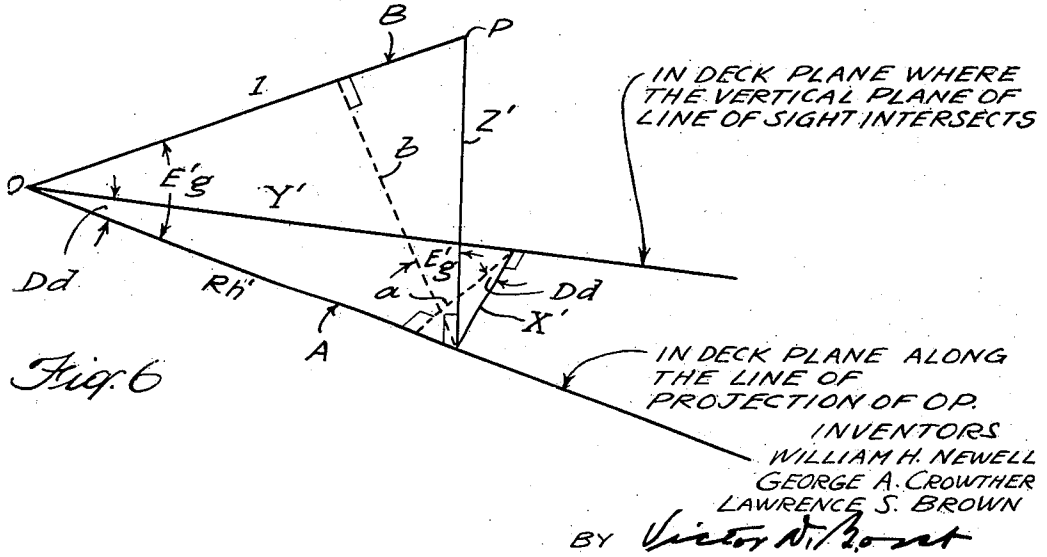


Fig. 6

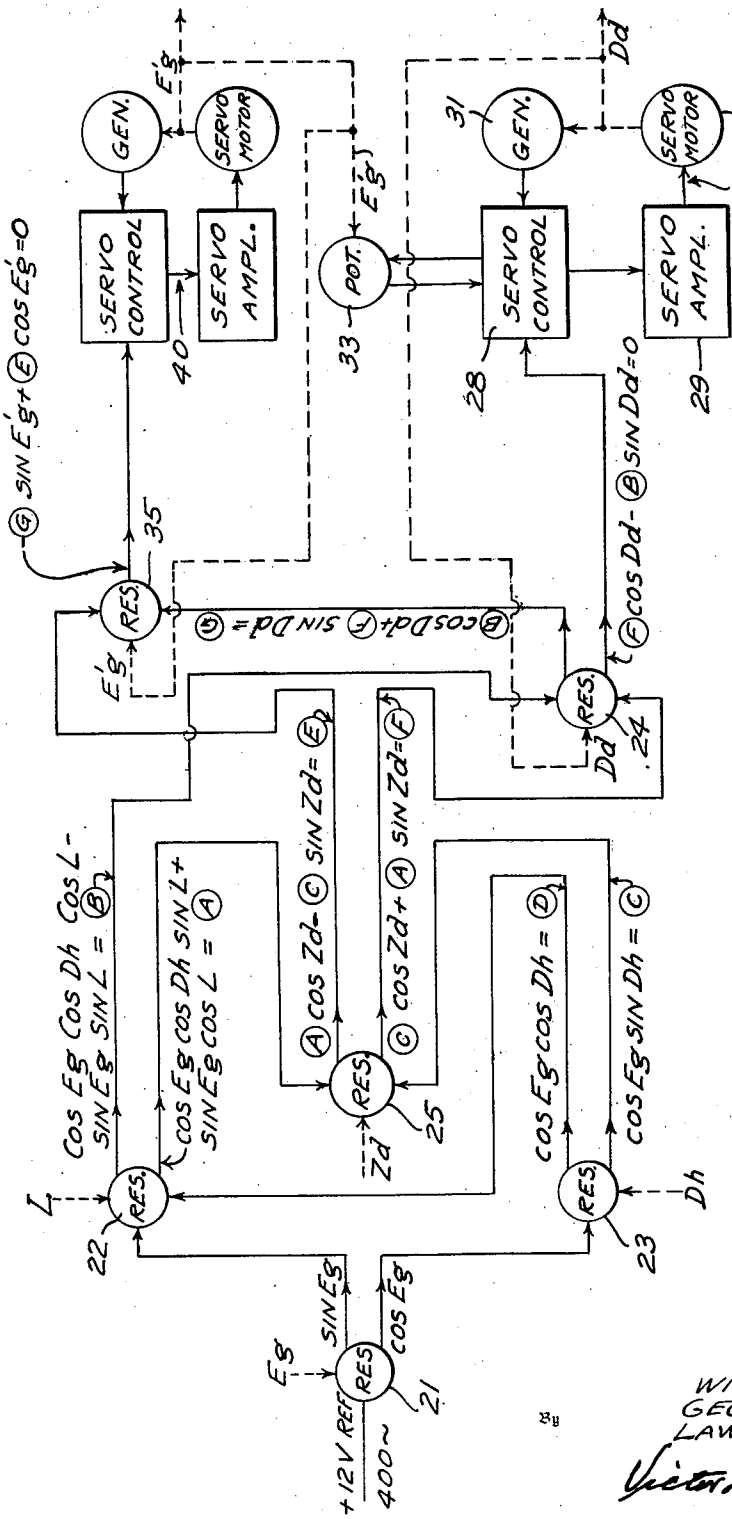


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TRUNNION TILT CORRECTOR

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$$\textcircled{G}\sin E'g + \textcircled{E}\cos E'g = 0$$

$$\textcircled{B}\cos Dd + \textcircled{F}\sin Dd = \textcircled{G}$$

$$\textcircled{F}\cos Dd - \textcircled{B}\sin Dd = 0$$

$$\cos Eg \cos Dh \cos L - \sin Eg \sin L = \textcircled{B}$$

$$\cos Eg \cos Dh \sin L + \sin Eg \cos L = \textcircled{A}$$

$$\textcircled{A}\cos Zd - \textcircled{C}\sin Zd = \textcircled{E}$$

$$\textcircled{C}\cos Zd + \textcircled{A}\sin Zd = \textcircled{F}$$

$$\cos Eg \cos Dh = \textcircled{D}$$

$$\cos Eg \sin Dh = \textcircled{C}$$

$$Dd: \sin Dd[(\cos Eg \cos Dh \cos L - \sin Eg \sin L)\cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]$$

$$Eg: \sin E'g\{[\cos Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L) + \sin Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]\}$$

$$= \cos E'g[\cos Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L) - \cos Eg \sin Dh \sin Zd]$$

Fig. 7.

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United States Patent Office 2,902,212 Patented Sept. 1, 1959

2,902,212

TRUNNION TILT CORRECTOR

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Application April 13, 1954, Serial No. 422,845

3 Claims. (Cl. 235—61.5)

The present invention relates to the art of determining, in a gunfire control system supported on a movable deck, gun position data, referred to said deck and thereby corrected for trunnion tilt, to assure accurate aiming of the gun.

The invention is particularly useful in connection with a fire control system, in which a gun or like ordnance to be controlled is supported on a movable platform such as a ship's deck. Since the ship will roll and pitch, angles measured in the deck plane usually vary in phase with the ship's angular movement and hence must be corrected to determine certain fire control quantities. The so-called "computer" in a fire control system provides a continuous solution for the train and elevation of a particular target and must operate relative to the horizontal plane. However, the line of sight (involving either optical or radar tracking) is determined by the director of the fire control system, relative to the deck plane. The conversion of director information to define the line of sight relative to the horizontal plane is accomplished by the deck tilt corrector. It is necessary, for accurate firing, to convert the line of bore (gun axis) coordinates in the horizontal plane as determined by the computer, back to coordinates relative to the deck plane, by means of a trunnion tilt corrector.

One object of the present invention is to provide a new and improved method and instrument, by which the necessary values of gun positioning angles corrected for trunnion tilt are accurately and continously computed with a minimum of instrumental complexities and with the aid of servomechanisms affording maximum of stability and minimum of variation in sensitivity.

Another object of the invention is to provide a method and trunnion tilt corrector, by which the gun elevation order angle, i.e., the ordered angle between the line of gun bore or line of fire (gun axis) and its projection on the deck plane, is computed by means of a servo system in which the sensitivity is constant (not affected by the roll and pitch of the suporting platform or deck).

A further object is to provide a method and trunnion tilt corrector, by which the deck sight deflection angle, i.e., the angle between the vertical plane through the line of sight and the plane perpendicular to the deck plane through the line of gun bore as measured in the deck plane, is computed by means of a servo system in which the sensitivity of said system is automatically maintained constant by variation of the gain to the servo control.

As a feature of the present invention, there are derived true solution formulas for certain gun positioning angles expressed in terms of available quantities and corrected for trunnion tilt, to convert the computed gun position referred to the horizontal plane to gun position referred to in the deck plane. From the main computing section of the fire control system, there is available: (1) the elevation angle Eg between the line of gun bore and its projection on the horizontal plane; (2) the horizontal

sight deflection angle Dh, the angle between the vertical plane through the line of sight and the vertical plane through the line of bore, measured in the horizontal plane; (3) the level angle L between the horizontal plane and the deck plane measured in the vertical plane through the line of sight; and (4) the cross-level angle Zd between the vertical plane through the line of sight and a plane perpendicular to the deck plane through the projection of the line of sight on the deck plane. From these four available quantities, true solution formulas are derived in accordance with the present invention for (1) the deck sight deflection angle Dd between the vertical plane through the line of sight and the plane perpendicular to the deck plane through the line of gun bore, as measured in the deck plane, and (2) the vertical gun elevation angle E'g between the line of gun bore and its projection on the deck plane.

The positioning data for the gun aiming point P with reference to the horizontal plane are available in the form of polar coordinates Eg and Dh. In deriving the true solution formulas described, these available polar coordinates are transformed to a system of rectangular cartesian coordinates X, Y and Z, which system is then rotated through the level angle L and then through the cross-level angle Zd, to obtain the X', Y' and Z' cartesian location of point P with respect to the deck plane. These X', Y' and Z' coordinates are then translated into polar coordinates with respect to the deck plane by means of two mutually perpendicular right triangles, the solution of which is servoed in the mechanization of the solution formulas, to obtain the polar gun angles Dd and E'g. One of these triangles contains the angle E'g at an origin point, a side Rh' adjacent to said angle and representing the line from said origin point to the point corresponding to the projection of the gun aiming point on the deck plane, a side Z' opposite said angle representing one of the rectangular coordinates of the gun aiming point with respect to the deck plane and the vertical plane containing the line of sight, and a hypotenuse indicated as r, the value of which will be described. In such a triangle, if a perpendicular is drawn from the right angle point to the hypotenuse, r, it will divide the triangle into two smaller right triangles. Calling this perpendicular b, we have

$$\sin E'g=\frac{b}{Rh'}$$

or

$$b=Rh' \sin E'g$$

and

$$\cos E'g=\frac{b}{Z'}$$

or

$$b=Z' \cos E'g$$

Therefore, we have the control equation

$$Z' \cos E'g=Rh' \sin E'g$$

from which the value E'g can be obtained.

In the servo system for solving the control equation for the quantity E'g, a motor rotates computing elements to balance the quantities Z' cos $E'g$ and Rh' sin $E'g$. This motor is controlled by comparing electrical voltages corresponding to the quantities Z' cos $E'g$ and Rh' sin $E'g$ respectively, in such a way that the sum of the two voltages is zero or a null. In order to achieve stable servo action, it is necessary that the control voltage corresponding to a given increment of error be constant for any value of the angle E'g. In accordance with the present invention, the stabilizing of the servomechanism is achieved in solving for the angle E'g, by designing the control equation in such a way that the

derivative of the error with respect to the angle E'*g* to be computed is a constant and is achieved in solving for the angle D*d* by providing a compensating correction in the gain of the amplifier.

In solving for the angle E'*g*, if we consider

$$Z' \cos E'g - Rh' \sin E'g = \text{error}$$

then

$$\frac{d(\text{error})}{d(E'g)} = Z' \sin E'g + Rh' \cos E'g$$

$$= r(\text{hypotenuse})$$

In accordance with the present invention, the length *r* in the equation for the solution of E'*g* is chosen as unity. Hence, the sensitivity of the servomechanism employed in this solution is a constant.

The other of the mutually perpendicular right triangles contains the angle D*d* at the origin point, the hypotenuse R*h'*, the side Y' adjacent to said angle, representing one of the rectangular coordinates of the gun aiming point with respect to the deck plane and the vertical plane containing the line of sight and the side X' opposite said angle representing another of the rectangular coordinates of the gun aiming point with respect to the deck plane and the vertical plane containing the line of sight. From this right triangle is derived in the manner similar to that in connection with the angle E'*g*, the control equation

$$X' \cos Dd = Y' \sin Dd$$

The servomechanism for solving this equation for the quantity D*d* is maintained in stable condition, by adjusting the gain of the servomechanism by a compensating correction, which in the specific example of the present invention, corresponds to a function of the cos E'*g*.

Various other objects, features and advantages of the present invention are apparent from the following particular description and from inspection of the accompanying drawings, in which:

Fig. 1 is a simplified block diagram showing the functional relationship between different components of a suitable gunfire control system into which the trunnion tilt corrector of the present invention may be incorporated;

Fig. 2 is a simplified block diagram showing a gun order device or network which forms part of the fire control system of Fig. 1 and which includes the trunnion tilt corrector of the present invention;

Fig. 3 is a spherical diagram of the trunnion tilt problem solved in accordance with the present invention;

Fig. 4 is a diagram by which polar coordinates of the gun aiming point with respect to the horizontal plane and the vertical plane containing the line of sight are converted into an X, Y, Z, rectangular cordinate system with respect to said planes in the process of deriving true solution formulas for gun positioning angles corrected for trunnion tilt and shows said system rotated through the level angle L as the first step in converting the X, Y, Z system into the X', Y', Z' rectangular coordinate system with respect to the deck plane and the vertical plane containing the line of sight;

Fig. 5 is a diagram showing the X, Y, Z rectangular coordinate system of Fig. 4 rotated through the cross-level angle Z*d* as the second step in converting the X, Y, Z system into the X', Y', Z' rectangular coordinate system in the process of deriving true solution formulas for gun positioning angles corrected for trunnion tilt;

Fig. 6 is a diagram by which the X', Y', Z' rectangular coordinate system is converted into the polar coordinate system with respect to the deck plane in the process of deriving true solution formulas for gun positioning angles corrected for trunnion tilt; and

Fig. 7 is a simplified block diagram of the trunnion tilt corrector embodying the present invention.

The present application is a continuation-in-part of copending application Serial No. 370,256, filed July 27, 1953.

Glossary

A tabulation of symbols and terms used in the derivation of formulas herein, in the drawings and in the description, is submitted herein.

B*gr*—Gun train order: Angle between the vertical plane through own ship centerline, and the normal plane through the line of fire, measured in the deck plane. Positive angles measured clockwise from own ship centerline.

B'*r*—Director train (stabilized sight): Angle between the vertical plane through own ship centerline, and the vertical plane through the line of sight, measured in the deck plane. Positive angles measured clockwise from own ship centerline.

bh.P*h*—Train parallax correction: Correction for gun director's horizontal base from the reference point of the fire control system.

D*d*—Deck deflection: Angle between the vertical plane through the line of sight, and the vertical plane through the line of fire (line of bore of the gun), measured in the deck plane from the vertical plane through the line of sight.

D*h*—Horizontal deflection: Angle between the vertical plane through the line of sight and the vertical plane through the line of fire, measured in the horizontal plane from the vertical plane through the line of sight.

E*g*—Vertical gun elevation: Angle between the horizontal plane and the line of fire, measured in the vertical plane through the line of fire. Positive angles measured upward from the horizontal plane.

E'*g*—Gun elevation order: Angle between the deck plane and the line of fire. Positive angles measured upward from the deck plane.

L—Level: Angle between the deck plane and horizontal plane measured in the vertical plane through the line of sight, this angle being positive when the portion of the deck towards the target is down.

Z*d*—Cross-level: Angle between the vertical plane to the deck plane through the line of sight, and the normal plane through the intersection of the vertical plane through the line of sight and the deck plane, measured about the axis which is the intersection of the vertical plane through the line of slight and the deck plane. Positive direction is clockwise when viewed along axis inward from target.

Fire control system

A suitable fire control system capable of solving gunfire control problems, both anti-aircraft and surface, is illustrated in simplified form in Fig. 1. This fire control system may comprise a computer assembly **10**, a gun director **11**, and a stable element **12**. The computer assembly **10** includes a prediction network for determining horizontal sight deflection D*h* and vertical gun elevation E*g*, a parallax correction network for determining train parallax corection (*bh*.P*h*) and a gun order device or network shown in simplified form in Fig. 2. This gun order device or network may comprise a trunnion tilt corrector **14**, which is the subject of the present invention and which operates in conjunction with adding components or differentials **16** and **17** to make up the gun orders from: (1) the D*h* and E*g* outputs from the prediction network; (2) the *bh*.P*h* output from the parallax correction network; (3) the L and Z*d* outputs from the stable element **12** (Fig. 1); and (4) the B'*r* output from the gun director **11** (Fig. 1). The trunnion tilt corrector **14** in this gun order network has inputs D*h*, E*g*, L and Z*d* and outputs E'*g* and D*d*.

Derivation of the solution formulas for gun positioning angles Dd and E'g

In accordance with the present invention, true solutions for the trunnion tilt problems are employed, thereby eliminating errors, such as those which would be inherent, if empirical solutions were employed. As a result of the procedure of the present invention, true solution formulas are obtained for trunnion tilt-corrected angles D*d* (deck deflection) and E'*g* (gun elevation order angle), in terms of the available quantity E*g* (elevation order), D*h* (deflection order), L (level) and Z*d* (cross-level). These formulas are solved for the quantities E'*g* and D*d* by servo or null seeking systems, which so position the E'*g* and D*d* lines, that a balance is obtained between the quantities represented by the right and left hand terms of each equation.

The trunnion tilt correction problems are indicated in the spherical diagram shown in Fig. 3. In this diagram, the sphere is assumed to be of unit radius, the deck plane is assumed to pass through the center of said sphere and the point P, which is the gun aiming point, is assumed to be located on the surface of said sphere. The spherical diagram of Fig. 3 shows the polar coordinates E*g* and D*h* of the gun aiming point P and the rectangular coordinates X, Y and Z of said point P with respect to a horizontal plane passing through the center O of the sphere and with respect to the vertical plane of the line of sight passing through said center. The center O of the sphere serves as the origin of the X, Y, Z coordinate system and of the polar coordinate system, and the point K in said coordinate system represents the projection of the gun aiming point P upon the vertical plane of the line of sight.

In deriving the true formulas for the quantities E'*g* and D*d*, the polar coordinates E*g* and D*h* of the gun aiming point P are converted to rectangular coordinates X, Y and Z with respect to the horizontal plane, and this coordinate system is rotated first through the level angle L and then through the cross-level angle Z*d*, to obtain the X', Y' and Z' location of said point P with respect to the deck plane and to the vertical plane of the line of sight.

Fig. 4 is a diagram of the X, Y, Z, coordinate system of the gun aiming point P, rotated through the level angle L. From this diagram, the following relationships are obtained:

$$Y'=Y\cos L-Z\sin L \quad (1)$$
$$Z''=Y\sin L+Z\cos L \quad (2)$$

Fig. 5 is a diagram of the X, Y, Z, coordinate system of Fig. 4 observed along the Y' axis with the origin O nearest to the observation point and after said system is rotated through the level angle L and then through the cross-level angle Z*d*. From this diagram of Fig. 5, the following relationships are obtained:

$$X'=Z''\sin Zd+X\cos Zd \quad (3)$$
$$Z'=Z''\cos Zd-X\sin Zd \quad (4)$$

After the X', Y' and Z' coordinates are obtained as described, these coordinates are converted to polar coordniates with respect to the deck plane, in terms of the desired quantities D*d* and E'*g*. For that purpose, a diagram is constructed from X', Y' and Z' rectangular coordinates, as well as polar coordinates D*d* and E'*g*, to produce two mutually perpendicular right angles A and B, as shown in Fig. 6. In this diagram, the angle of the triangle A at the origin O is D*d*, the hypotenuse is R*h*', produced by projecting the gun aiming point P on the deck plane and the side of this triangle opposite the angle D*d* is the coordinate X'. By drawing a perpendicular line *a* from the apex of the right angle to the hypotenuse R*h*' to divide this triangle into two component right triangles, and by equating those values of this perpendicular line derived trigonometrically from these component triangles, there is obtained the following control equation from which the value of D*d* may be determined:

$$Y'\sin Dd=X'\cos Dd \quad (5)$$

The other right triangle B in the diagram of Fig. 6 has the angle E'*g* at the origin O, an hypotenuse from said origin to the point P of unit value, a side adjacent to its right angle equal to the coordinate Z' and the other side adjacent to this right angle, equal to R*h*' and common with the hypotenuse of the right triangle A. A perpendicular line *b* from the apex of the right angle in the triangle B to the unit hypotenuse, divides this triangle into two component right triangles. By equating those values of this perpendicular line derived trigonometrically from these component triangles, there is obtained the following control equation, from which the value of E'*g* may be determined:

$$Rh'\sin E'g=Z'\cos E'g \quad (6)$$

Referring back to right triangle A and to its two component right triangles in Fig. 6, it is found that

$$Rh'=Y'\cos Dd+X'\sin Dd \quad (7)$$

and by referring back to the spherical diagram of Fig. 3, it is found that

$$X=\cos Eg\sin Dh \quad (8)$$
$$Y=\cos Eg\cos Dh \quad (9)$$
$$Z=\sin Eg \quad (10)$$

By making the proper substitution in the control Equation 5 from Equations 1, 2, 3, 8, 9 and 10, an equation is obtained in terms of the available quantities D*h*, E*g*, L and Z*d*, and the quantity D*d* to be determined, which equation can be solved effectively by mechanization to obtain the quantity D*d* continuously. This solvable equation is as follows:

$$\sin Dd(\cos Eg\cos Dh\cos L-\sin Eg\sin L)=\cos Dd[\cos Eg\sin Dh\cos Zd+\sin Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)] \quad (11)$$

By making the proper substitution in the control Equation 6, from Equations 1, 2, 3, 4, 7, 8, 9 and 10, an equation is obtained in terms of the available quantities D*h*, E*g*, L and Z*d* and the quantity E'*g* to be determined, which equation can be solved effectively by mechanization to obtain the quantity E'*g* continuously. This solvable equation is as follows:

$$\sin E'g\{\cos Dd(\cos Eg\cos Dh\cos L-\sin Eg\sin L)+\sin Dd[\cos Eg\sin Dh\cos Zd+\sin Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)]\}=\cos E'g[\cos Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)-\cos Eg\sin Dh\sin Zd] \quad (12)$$

In the servo system for solving for the angle E'*g*, a motor rotates computing elements to balance the quantities Z cos E'*g* and R*h*' sin E'*g* on opposite sides of the control Equation 6. Control of this motor is effected by comparing electrical voltages corresponding to Z' cos E'*g* and R*h*' sin E'*g* respectively in such a manner, that the sum of the two quantities is zero or a null. In order to achieve stable servo action, the control voltage corresponding to a given increment of error is made constant for any value of the angle E'*g*. Since

$$Z'\cos E'g-Rh'\sin E'g=\text{error}$$

$$\frac{d(\text{error})}{d(E'g)}=Z'\sin E'g+Rh'\cos E'g$$

$$=\text{the hypotenuse in the triangle B of Fig. 6}$$

To achieve stable servo action, the derivative of the error with respect to the angle E'*g* is made a constant. To that end, the hypotenuse in the triangle B of Fig. 6 employed to derive the control Equation 6 is chosen as unity, so that the sensitivity of the servomechanism employed to solve for E'*g* is a constant.

In the solution for D*d*, however, since in the right triangle A containing the angle D*d*, the hypotenuse is R*h'* equal to cos *E'g*, the sensitivity of the servomechanism employed in the mechanization of the Equation 11 in acquiring the gun order D*d* is affected by changes in E'*g*. Hence, the gain of the servomechanism must be adjusted to vary the gain proportional to a function of the cos *E'g*, to correct for effects of level, cross-level and for changes in elevation of the target and to achieve stable servo action. Since E'*g* is obtained in the mechanization of Equation 12, accurate control in the sensitivity of the servomechanism operating on Equation 11 is assured.

It should be noted that the solution Equation 11 for obtaining the quantity D*d*, involves the following two main channels, the algebraic sum of which is equal to zero:

Chan. 1

$$\sin Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L)$$

Chan. 2

$$\cos Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]$$

In a similar manner, the solution Equation 12 for obtaining the quantity E'*g* involves the following two main channels, the algebraic sum of which is equal to zero:

Chan. 3

$$\sin E'g\{\cos Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L) + \sin Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]\}$$

Chan. 4

$$\cos E'g[\cos Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L) - \cos Eg \sin Dh \sin Zd]$$

The computer for solving the Equation 11 is essentially one in which quantities in the form of the proper functions of input and output quantities are added, subtracted and multiplied in each of the channels of computations 1 and 2. From Equation 11, it is seen that the summation of these two channels 1 and 2, should be zero. Consequently, the output of an adding device is used as a servo input to drive a line in accordance with the quantity D*d*. When the servo nulls the output of this adding device, the equation of this solution has been satisfied.

Similarly, the two channels of computations 3 and 4 are fed as inputs into an adding device to obtain an output which is used as a servo input and which, when nulled, satisfies the Equation 12, thereby producing a line drive according to the quantity E'*g*.

The trunnion tilt corrector employed for the mechanization of Equations 11 and 12 is made up of a series of components, which may be of any suitable design, and which, per se, form no part of the present invention. Fig. 7, therefore, shows this trunnion tilt corrector diagrammatically in block form. The specific corrector shown as an example is essentially an electrical one, the solid lines indicating electrical connections and the dotted lines indicating mechanical lines or movements arising, for example, from shaft rotations.

The specific trunnion tilt corrector shown in Fig. 7 utilizes 400 cycles per second current as a computing reference, with an input level of 12 volts, the representation of data by the 400-cycle voltage being such, that the root mean square value of each voltage is proportional to the quantity represented. For the purpose of discussion, this reference voltage is regarded as (+1). The different computed quantities are indicated in Fig. 7 without parametric coefficients. These coefficients are a function of the reference voltage (12 volts) and the characteristics of the constituent elements of the networks or loops involved and are constant for any one mechanism.

The main components employed in the mechanization of Equations 11 and 12, aside from the servomechanisms, are angle function computers or resolvers. As far as the present invention is concerned, these resolvers may be of any suitable type, as, for example, of the magnetic type disclosed in U.S. Patent #2,646,218, issued July 21, 1953. The function of these resolvers is to produce an output voltage proportional to a sine or cosine function of an angle which is introduced mechanically. The circuit of such a resolver resembles a synchro control transformer in construction, except for the number and distribution of windings, and comprises essentially of a stator having two separate distributed windings arranged in space quadrature and constituting primary windings and a rotor having two separate distributed windings in space quadrature constituting secondary windings.

In operation, the specific magnetic resolver described acts as a single-phase transformer with a variable coupling between primary and secondary. As the rotor turns, the voltage across each secondary winding changes. Construction of the resolver is such that the secondary voltages vary as the sine or cosine of the angle through which the rotor turns.

In operation, the angle as a mechanical quantity turns the rotor. A voltage energizes the stator. Assuming the stator to be fixed, voltages corresponding to the product of the stator energizing voltage and sine and cosine of the angle are computed at the rotor windings.

Where two voltages are improved upon the resolver in conjunction with the mechanical input whose trigonometric function is to be computed, these two voltages are algebraically added in the resolver by a suitable adding network. It should, therefore, be understood that resolvers indicated in the trunnion tilt corrector of Fig. 7 may include therein adding networks or devices to add quantities for resolution into the trigonometric functions.

Since it is impracticable to design a computing resolver that has no output voltage wave-shape distortion and therefore no appreciable error, the basic resolver circuit described gives only approximate results. Reduction of the error to a negligible amount may be accomplished by an error compensating loop described in the aforesaid U.S. Patent No. 2,646,218. This error compensating loop attenuates the distortion by introducing a high gain amplifier ahead of the computing resolver and connecting an error compensating resolver in parallel with the computing resolver and to the output of the amplifier. This error compensating resolver may be identical electrically and magnetically with the computing resolver and the two resolvers may have a common primary (stator). The output of the error compensating resolver is fed back as a negative feed-back to the input of the amplifier. The rotor of this error compensating resolver is set by adjustment and clamped to obtain correct output voltages from the computing resolver.

The resolvers employed in the trunnion tilt corrector may be of the general type described, or of any other well-known suitable type.

Mechanization for Dd

In the mechanization for computation channel 1, a reference voltage, for example, 12 volts, and mechanical elevation quantity E*g* as computed in the prediction network of the fire control system, are fed as inputs into a resolver **21**. The sin *Eg* voltage output of this resolver **21** and the mechanical level quantity L obtained from the stable element of the ship are fed as inputs into a resolver **22**, and the cos *Eg* voltage output of the resolver **21** and the mechanical horizontal sight deflection quantity D*h* as computed in the prediction network of the fire control system are fed as inputs into a resolver **23**. One voltage output (cos *Eg* cos *Dh*) of this resolver **23** is fed to the resolver **22** as an input, and this latter resolver incorporating an adding network produces as one of its output voltages the algebraic sum

$$(\cos Eg \cos Dh \cos L - \sin Eg \sin L)$$

This latter voltage is fed into a resolver **24** in conjunction with the mechanical input D*d* obtained from the

servomechanism to be described, to obtain a voltage quantity corresponding to that of the computation channel 1, namely,

$$\sin Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L)$$

In the mechanization for computation channel 2, the other voltage output of resolver 23, namely

$$(\cos Eg \sin Dh)$$

and the other voltage output of resolver 22, namely $(\cos Eg \cos Dh \sin L + \sin Eg \cos L)$, are fed into a resolver 25, in conjunction with the mechanical cross-level (Zd) input obtained from the stable element on the ship. This resolver 25, incorporating an adding network therein, produces as one of its voltage outputs the quantity

$$\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)$$

This latter voltage is fed into the resolver 24 to obtain therefrom a voltage quantity corresponding to that of the computation channel 2, namely,

$$\cos Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]$$

Since the resolver 24 incorporates therein an adding network, two of the voltage outputs of said resolver corresponding in values to those of computation channels 1 and 2 are algebraically added therein. The sum so obtained should be zero in accordance with Equation 11.

One of the outputs of the resolver 24 constituting the summation of channels 1 and 2 is

$$\cos Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)] - \sin Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L) = 0$$

in accordance with Equation 11. If the conditions of Equation 11 are not satisfied, an error is produced at the output of resolver 24, which, in the case of a system which is mainly electrical, such as that of Fig. 7, is a voltage having the proper polarity to drive the servo motor of a servomechanism 27 of the known type, to produce a null in the error voltage. When this null is achieved, the value of Dd converted into a mechanical quantity, such as a shaft rotation, becomes one of the trunnion tilt correction quantities required.

A servomechanism, such as the servomechanism 27, is an automotive drive which positions a mechanical load in accurate correspondence with an input, without placing an appreciable load upon this input. The input can be either mechanical or electrical (in Fig. 7, this input is electrical), but the output is always mechanical.

The basic components of the specific servomechanism shown in Fig. 7 comprises a servo control 28, a servo amplifier 29, a servo motor 30 and an induction generator 31, all connected in a double loop circuit with a control network which, in the present case, is the resolver 24. Essentially, the control network 24 computes a voltage proportional to the error between a function of the input and a function of the output. This error voltage is converted to a frequency of 60 cycles by the servo control 28, amplified by the servo amplifier 29 and finally supplied to the servo motor 30 for its control. The servo motor 30 furnishes the mechanical output and drives the induction generator 31. From this generator 31, a voltage proportional to the output velocity is supplied to the servo control 28. After being modified by computing elements in the servo control 28, the modified voltage is combined with the error voltage to improve the operation of the servomechanism 27.

As was already pointed out, the sensitivity of the servomechanism 27 is affected by changes in $E'g$. Hence, the gain of the servomechanism must be adjusted proportional to the function of the cos $E'g$, to assure constant sensitivity and high stability. For that purpose, the gain achieved through the servo amplifier 29 is adjusted by means of a potentiometer 33 having a mechanical input equal to the quantity $E'g$ obtained in the manner to be described, and an electrical output controlled by said input and corresponding in value to a function of the cos $E'g$, this electrical output being applied to the servo amplifier 29 through the servo control 28 to control the gain of the servomechanism to the desired extent and to maintain thereby substantially constant servo sensitivity.

The output mechanical quantity Dd from the servomechanism 27 is fed back as a mechanical input into the resolver 24, for the purpose already indicated.

Mechanization for E'g

In the mechanization of computation channels 3 and 4, the resolver 24, incorporating therein an adding network as described, produces in addition to the voltage output previously indicated, a voltage output equal to

$$\cos Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L) + \sin Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]$$

This voltage is imposed upon a resolver 35.

The resolver 25 incorporating therein an adding network as described, produces, in addition to the voltage output previously described, a voltage output equal to

$$\cos Dd(\cos Eg \cos Dh \sin L + \sin Eg \cos L) - \cos Eg \sin Dh \sin Zd$$

which is imposed as an input upon the resolver 35 in conjunction with a mechanical output equal to $E'g$ and which is combined through an adding network in said resolver 35 with the voltage output of resolver 24 described. The summation trigonometrically resolved in the resolver 35 produces a voltage output in said resolver, equal to

$$\sin E'g\{\cos Dd(\cos Eg \cos Dh \cos L - \sin Eg \sin L) + \sin Dd[\cos Eg \sin Dh \cos Zd + \sin Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L)]\} - \cos E'g[\cos Zd(\cos Eg \cos Dh \sin L + \sin Eg \cos L) - \cos Eg \sin Dh \sin Zd] = 0$$

corresponding to the summation of channels 3 and 4 and to Equation 12.

Theoretically, according to Equation 12, the summation of the computations 3 and 4 should be zero. If the conditions of the Equation 12 are not satisfied, an error is produced at the output of the resolver 35, which, in the case of an electrical system, such as that of Fig. 7, is a voltage having the proper polarity to drive the servo motor of a servomechanism 40, similar to the servomechanism 27 to produce a null in the error voltage. When this null is achieved, the value of $E'g$ converted into a mechanical quantity (shaft rotation) becomes one of the gun positioning angles required. This quantity $E'g$ is fed back to the resolver 35 for the reason indicated, and is available to adjust the gain achieved through the servo amplifier 29 of the servomechanism 27, for the purposes described.

As was already pointed out, the control Equation 6 $Z' \cos E'g = Rh' \sin E'g$ for the solution of $E'g$ was derived from a triangle whose hypotenuse was assumed to be unity. Therefore, the sensitivity of the servomechanism 40 is constant and is not affected by changes in Dd. Consequently, there is no need to adjust the gain of the servomechanism 40 as in the case of servomechanism 27.

While the invention has been described with particular reference to a specific embodiment, it is to be understood that it is not to be limited thereto, but is to be construed broadly and restricted solely by the scope of the appended claims.

What is claimed is:

1. A device for continuously computing the gun elevation order angle ($E'g$) in a gunfire control system and for rendering the computed angle continuously available as a physical quantity, comprising means for receiving

input physical quantities corresponding to the vertical gun elevation angle (E*g*), horizontal sight deflection angle (D*h*), level angle (L) and cross-level angle (*Zd*) respectively, a mechanizing computing device operable in response to said input quantities for deriving continuously two physical quantities $Rh'\sin E'g$ and $Z\cos E'g$, the algebraic sum of which is theoretically equal to zero in accordance with the control equation

$$Rh'\sin E'g=Z'\cos E'g$$

wherein Z' is one side of a right triangle and corresponds to a rectangular coordinate with respect to the deck plane of the gun aiming point assumed to be located at unit distance from a vertex of said triangle, whereby the length of the hypothenuse of said triangle is assumed to be of corresponding unit value, E'*g* is the angle of said triangle at said vertex opposite the side Z' and R*h*' is the third side of said triangle from said vertex to the point corresponding to the projection of said gun aiming point on the deck plane, a servo system having a constant gain for its full range and thereby constant sensitivity, and means for continuously imposing the two physical quantities $Rh'\sin E'g$ and $Z'\cos E'g$ upon said servo system to null the algebraic sum of said physical quantities and to obtain continuously a physical quantity corresponding to said gun elevation order angle (E'*g*).

2. A device for continuously computing the gun elevation order angle (E'*g*) in a gunfire control system and for rendering the computed angle continuously available as a physical quantity, comprising means for receiving input physical quantities corresponding to the vertical angle (E*g*), horizontal sight deflection angle (D*h*), level angle (L), cross-level angle (*Zd*) and deck sight deflection angle (D*d*) respectively, a mechanizing computing device operable in response to said input quantities for deriving continuously two physical quantities

$$\begin{aligned}\text{Sin } E'g\{&\cos Dd(\cos Eg\cos Dh\cos L-\sin Eg\sin L)+\\&\sin Dd[\cos Eg\sin Dh\cos Zd+\\&\sin Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)]\}\end{aligned}$$

and

$$\begin{aligned}\cos E'g[&\cos Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)-\\&\cos Eg\sin Dh\sin Zd]\end{aligned}$$

a servo system having a constant gain for its full range and thereby constant sensitivity, and means for continuously imposing the said two physical quantities upon said servo system to null the algebraic sum of said two physical quantities and to obtain continuously a physical quantity corresponding to said gun elevation order angle (E'*g*).

3. A device for continuously computing the gun elevation order angle E'*g* and the deck sight deflection angle (D*d*) in a gunfire control system and for rendering the computed angles continuously available as physical quantities, comprising means for receiving input physical quantities corresponding to the vertical gun elevation angle (E*g*), horizontal sight deflection angle (D*h*), level angle (L) and cross-level angle (*Zd*) respectively, a first mechanizing computing device operable in response to said input quantities for deriving continuously the first two physical quantities

$$\sin Dd(\cos Eg\cos Dh\cos L-\sin Eg\sin L)$$

and

$$\begin{aligned}\cos Dd[&\cos Eg\sin Dh\cos Z+\\&\sin Zd(\cos Eg\cos Dh\sin L+\\&\sin Eg\cos L)]\end{aligned}$$

a first servo mechanism, means for continuously imposing the said two physical quantities upon said servo mechanism to null the algebraic sum of said two physical quantities and to obtain continuously a physical quantity corresponding to the deck sight deflection angle (D*d*), a second mechanizing computing device operable in response to said input quantities and to the physical quantity corresponding to the deck sight deflection angle (D*d*) obtained from said first servo mechanism for deriving continuously the second two physical quantities

$$\begin{aligned}\sin E'g\{&\cos Dd(\cos Eg\cos Dh\cos L-\sin Eg\sin L)+\\&\sin Dd[\cos Eg\sin Dh\cos Dd+\\&\sin Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)]\}\end{aligned}$$

and

$$\begin{aligned}\cos E'g[&\cos Zd(\cos Eg\cos Dh\sin L+\sin Eg\cos L)-\\&\cos Eg\sin Dh\sin Zd]\end{aligned}$$

a second servo mechanism having a constant gain for its full range and thereby constant sensitivity, means for continuously imposing said second two physical quantities upon said second servo mechanism to null the algebraic sum of said second two physical quantities and to obtain continuously a physical quantity corresponding to said gun elevation order angle (E'*g*), and means for converting the quantity (E'*g*) obtained from the output of said second servo mechanism to a quantity corresponding to cos E'*g* and for applying the latter quantity to control the gain of said first servo mechanism in accordance with the variation in cos E'*g*.

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