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CONTROL APPARATUS

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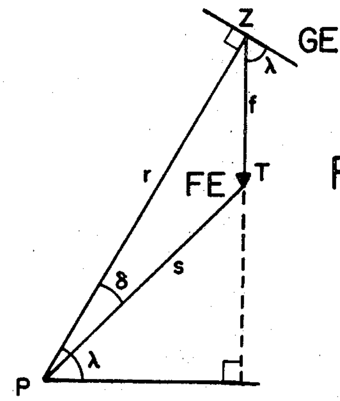
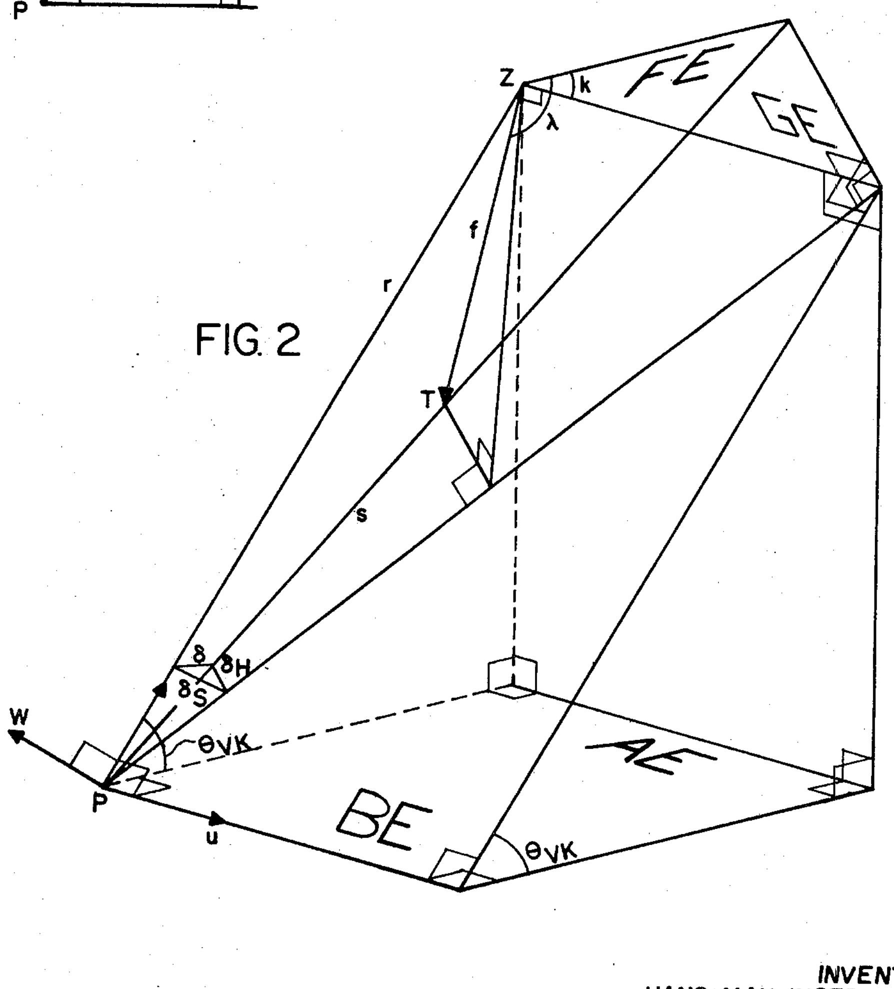


FIG. 1

FIG. 2



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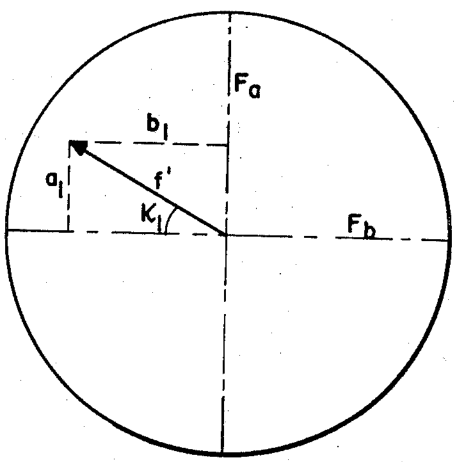

FIG. 3A

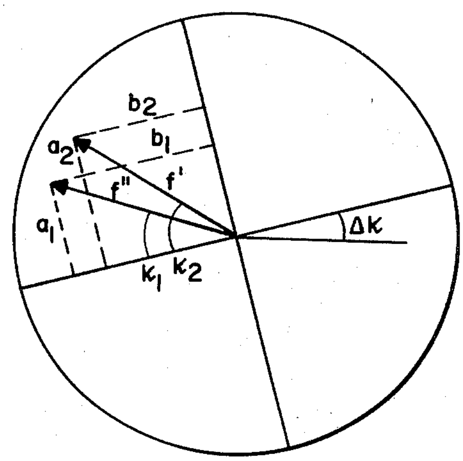

FIG. 3B

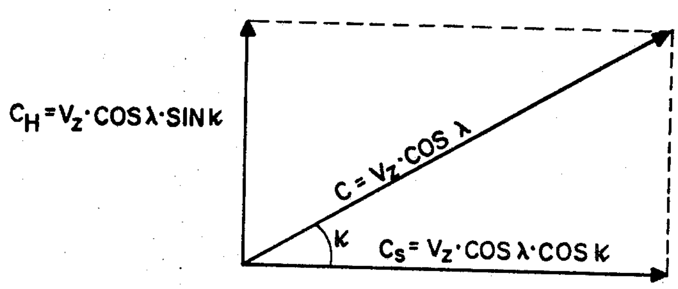

FIG. 4

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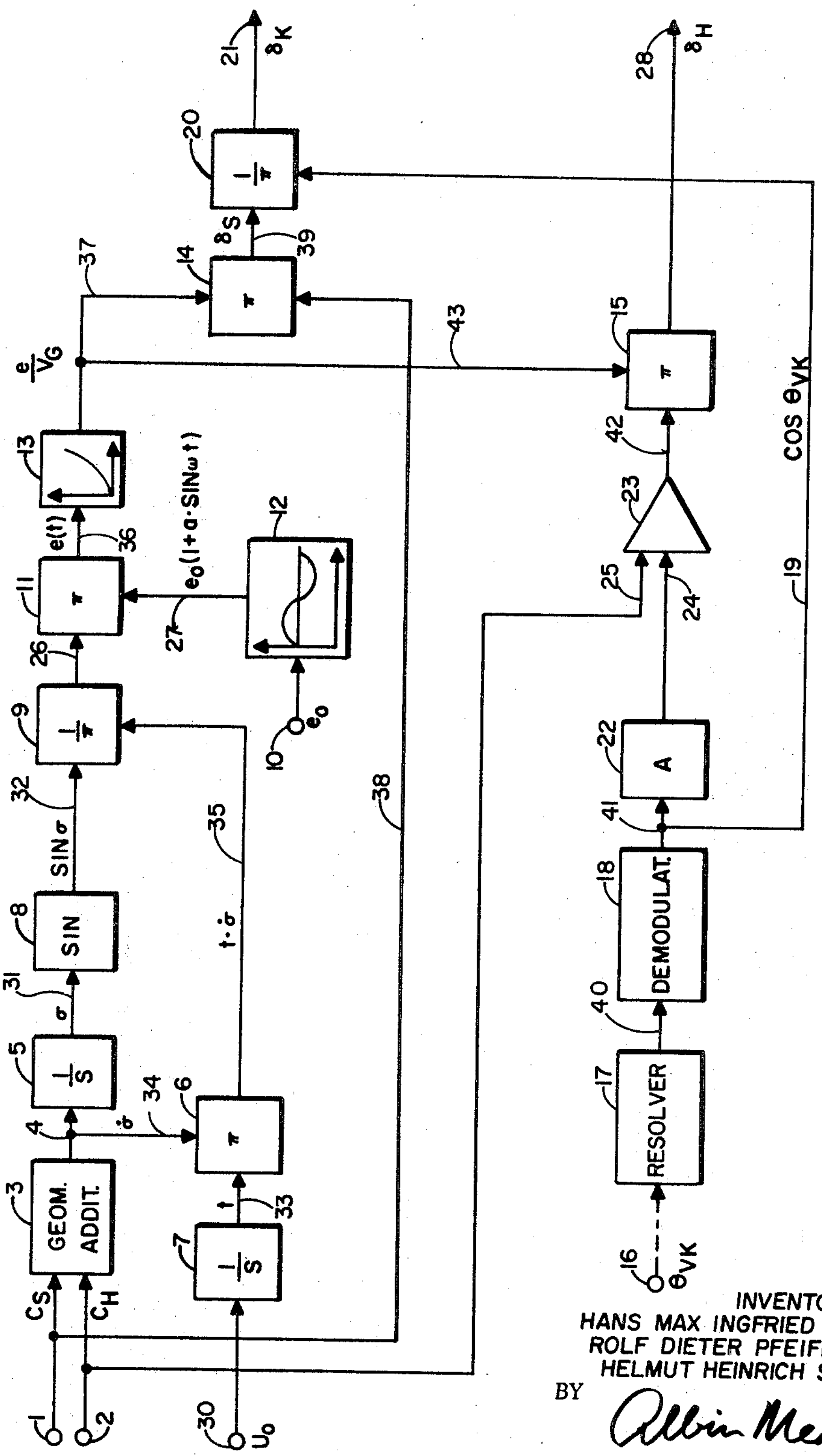

FIG. 5

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CONTROL APPARATUS

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U.S. Cl. 235—61.5 **11 Claims**

ABSTRACT OF THE DISCLOSURE

A dynamic biaxial lead computer for the lateral and vertical lead angles of tank-mounted anti-aircraft guns.

SUMMARY OF THE INVENTION

The present invention pertains to the field of geometrical instruments and, more particularly, to automatic gun movement compensators.

The present invention is intended for use with fire control systems including a biaxially directionable weapon and a biaxially directionable sight or fire director, both mounted on a mobile platform such as a tank or ship, and interconnected electrically as by servo systems such that the sight line determines the weapon line of fire.

The present disclosure concerns a lead angle computer to be interposed in the electrical interconnections to automatically provide an angle of lead between the weapon line of fire and the sight line to compensate for target speed, direction, projectile speed, and projectile ballistics or trajectory.

The present invention provides a lead angle computer especially suited to anti-aircraft guns, mounted on tanks or ships, which are directed toward and which follow a moving target. The invention evaluates the necessary lead angles with respect to the sight line. The lead angle can be computed by using the lateral lead angle together with the vertical lead angle or the lateral lead angle together with the whole elevation angle. The target may be aligned with the sight by means of a directioning handle positioned by the operator. Movements of the supporting frame as would be found with ship or tank mounting can be compensated for by an automatically operating target holding system.

The automatic target holding system would be a necessary element in an application of the present invention wherein an anti-aircraft weapon is mounted on a rotatable turret containing a primary weapon. For this embodiment, it is desired that the secondary weapon be turned and elevated without regard to the motion of the turret which directs the primary weapon. The fire director or sight is also mounted on the turret. The stabilization system provides that the line of sight remains stable with respect to a space reference in spite of turret or vehicle movements without requiring corrections by the gun operator.

It is, of course, also desired that the method of stabilization not affect operation and direction of the weapon by the operator. To this end, the preferred embodiment utilizes direct stabilization of the fire director which in turn maintains the weapon in alignment. The system consists of a directioning handle affected by gyros necessary for stabilization controlling the fire director or sight. The lead angle computer is connected between the fire director and the weapon directing mechanism.

The lead angle is computed in two components, the lateral lead angle δ_S and the vertical lead angle δ_H. For purposes of determination it is assumed that the target moves with a constant V_Z along a straight line path and that the projectile follows a straight line path with a decreasing speed, determinable from a firing table for the particular kind of ammunition used. Curvature of the path of the projectile under the influence of gravity is compensated for by enlarging δ_H to allow for the ballistic super elevation $\Delta\theta$.

The average projectile speed V_G, due to the decreasing instantaneous speed, depends on the distance e_G which the projectile must travel to reach the target.

According to the invention, transducers generate signals proportional to the angular rates of the sight line in the lateral direction (C_S) and the vertical direction (C_H). In one embodiment of the invention, the signals are produced by a rate gyro firmly aligned with the sight line. The rate gyro for the lateral angular speed simultaneously follows the turning motion in the vertical direction. An alternate embodiment derives the signals from a directioning handle for the sight line.

The angular rate signals are combined with signals proportional to the target distance e along the sight line r and the average projectile speed V_G for determination of the vertical and lateral lead angles δ_H and δ_S of the weapon with respect to the sight line which is assumed to be constantly directed to the target. The lateral and vertical lead angle equations are

$$\sin\delta_H = C_H\cdot\frac{e}{V_G} \tag{1}$$

and

$$\sin\delta_S\ C_S\frac{e}{V_G}\cdot\frac{1}{\cos\delta_H} \tag{2}$$

For small lead angles:

$$\sin\delta_H \approx \delta_H$$

$$\cos\delta_H \approx 1$$

$$\sin\delta_S \approx \delta_S$$

The equations for the lateral and vertical lead angles therefore become

$$\delta_H = C_H\cdot\frac{e}{v_G} \tag{1a}$$

and

$$\delta_S = C_S\cdot\frac{e}{v_G} \tag{2a}$$

In the usual mechanization, the lateral directioning signal works on a turret carrying the vertically elevatable weapon rather than on the weapon itself. The lateral lead angle δ_K of the turret with respect to the sight line, therefore, has to be evaluated according to the equation

$$\sin\delta_K = \frac{\sin\delta_S}{\cos\theta_{SK}} \tag{3}$$

For small angles

$$\delta_K = \frac{\theta_S}{\cos\theta_{SK}} \approx \frac{\delta_S}{\cos\theta_{VK}} \tag{3a}$$

θ_{SK} is the elevation angle of the weapon with respect to the turning plane of the turret and θ_{VK} is the elevation angle of the sight line with respect to the turning plane of the turret.

The invention provides a method of continuous evaluation of the target distance e. An integration arrangement is used wherein the initial distance e_0 is adjusted and the distance thereafter is computed depending on the angle σ of the sight line r with respect to the line at the time of initial distance estimate. The instantaneous distance with respect to the initial distance is computed according to the equation

$$e = e_0\cdot\frac{\sin\sigma}{C\cdot t} \tag{4}$$

wherein

$$\sigma=\int_0^t C dt \quad (4a)$$

and

$$C=\sqrt{C_S^2+C_H^2} \quad (4b)$$

An important feature of the present invention lies in the fact that evaluation of the lead quantities not only considers motions of the sight line in following the target but also that when the target is kept along the sight line, the lead quantities are automatically corrected for rotational motions of the vehicle around the sight line. Turning motions of the vehicle around other axes are taken care of by the stabilization system.

An additional feature of the present invention lies in the modification of the vertical lead angle δ_H of the weapon to allow for the ballistic super-elevation $\Delta\theta$ of the munition:

$$\Delta\theta=\frac{g}{2}\cdot\cos\theta_{VK}\cdot\frac{e}{V^2_G} \quad (5)$$

wherein

g=earth's acceleration,
θ_{VK}=the elevation angle of the sight line with respect to the turning plane of the turret carrying the weapon,
e=target distance along the sight line r, and
v_G=average projectile speed along the projectile path.

With consideration of the ballistic super-elevation, the total vertical lead angle δ_H becomes

$$\sigma_H=\sigma_H+\Delta\theta \quad (6)$$

It is evident from Equations 1 and 2 that the target diestance enters proportionally into the evaluated lead angles. Errors in distance (dependent on measurement of the initial distance e_0) affect the lead angle in their full magnitude. The present invention provides an improvement whereby the hit probability may be increased to allow for inaccuracies in the distance measurements. A periodically varying signal is heterodyned to the calculated lead signals. The periodically varying signal is of such an amplitude to cause sweeping of the target area to allow for errors in distance measurement.

The objects of the present invention are:

To provide apparatus for and methods of fire control for ordnance devices, particular anti-aircraft ordnance.

To provide apparatus for and methods of computation of lead angles for anti-aircraft weapons.

To provide a lead computer having means for continuous evaluation of the target distance.

To provide a lead computer which corrects for rotational motions of a gun platform about the axis of the sight line.

To provide means for modification of the vertical lead angle to allow for the ballistic super-elevation of the munition.

To provide means for increasing the hit probability to allow for inaccuracies in distance measurements.

Other advantages of the present invention will become apparent from the specification taken in connection with the drawings.

In the drawings the following reference symbols are used to facilitate an understanding of the invention.

Z position of the target at the moment of firing
r sight line at the moment of firing
e target distance along the sight line
P position of the weapon
T point at which the projectile contacts the target
s projectile path
e_G projectile flight distance along s
t_G projectile flight time
v_G average projectile speed
v_Z target speed (assumed constant)
AE turning plane of turret

BE reference plane defined by sight line r and a line perpendicular to the line r, at point P, in plane AE. This plane is seen as a line parallel to the turning plane AE of the turret when viewed along the sight line r. (horizontal line in a cross hair sight)
σ angle passed by sight line with respect to sight line position at time of initial distance C_0 input
FE plane defined by target path f and weapon position
λ angle between target path f and field of view plane GE
θ_{VK} elevation angle of sight line with respect to turning plane of turret
δ total lead angle between projectile path s and sight line r
δ_S lateral lead angle component
δ_H vertical lead angle component
θ_{SK} elevation angle of weapon with respect to the turning plane of the turret
κ inclination angle of projection of target path f on plane GE with respect to reference plane BE.

FIG. 1 is a view perpendicular to plane FE;

FIG. 2 is a spatial representation of the pertinent geometry necessary for an explanation of the invention;

FIGS. 3A and 3B represent the field of view of the gun pointer as seen through the sight with mutually perpendicular cross hairs F_a and F_b;

FIG. 4 is a vector diagram illustrating the geometrical addition of two perpendicular components of the directioning signal C; and,

FIG. 5 is a block diagram of the preferred embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred embodiment shown in FIG. 5, a signal C_S proportional to the lateral angular speed of the sight line is applied to an input terminal **1**. A signal C_H proportional to the vertical angular speed of the sight line is connected to an input terminal **2**. Inputs **1** and **2** are further connected to the input of a geometrical addition circuit **3** having an output lead **4**. Output lead **4** is further connected to the input of an integrator circuit **5** having an output connected to a sine transformer **8** by lead **31**. The output of sine transformer **8** is connected by lead **32** to a first input of a divider circuit **9** having an output lead **26** and a second input.

An input terminal **30** is connected to a constant signal source U_0. Input terminal **30** is connected to the input of an integrator circuit **7**, the output of which is connected by means of a lead **33** to one of two inputs of a multiplier circuit **6**. A lead **34** connects output terminal **4** of circuit **3** to the second input of the multiplier circuit **6**. The output of multiplier circuit **6** is connected through a lead **35** to the second input of divider circuit **9**. The output of divider circuit **9** is connected to a first input of a multiplier circuit **11** through a lead **26**.

An input terminal **10** is connected to a signal e_0 proportional to the initial range of the target. Input terminal **10** is further connected to a sine modulator **12** having an output lead **27** connected to a second input of multiplier circuit **11**. The output of multiplier circuit **11** is connected to the input of a non-linear circuit **13** by means of lead **36**. The output of non-linear circuit **13** is connected to a first input of a multiplier circuit **14** (having a second input) through a lead **37**. A lead **38** connects input terminal **1** to the second input of a multiplier circuit **14**. The output of multiplier circuit **14** is connected to an input of a divider circuit **20** through a lead **39**.

A mechanical input **16** to a resolver **17** is driven by the elevation mechanism of the sight. The output of resolver **17** is coupled to a demodulator circuit **18** through a lead **40**. The demodulator circuit **18** output is connected to an amplifier circuit **22** through a lead **41**. The output of demodulator circuit **18** is also coupled through a lead **19** to a second input of divider circuit **20**. The output of divider circuit **20** is conducted through a lead **21** to the turret drive to align the weapon with reference to the sight line in accordance with the calculated lateral lead angle.

The output of amplifier **22** is connected through a lead **24** to an input of a summing amplifier **23**. A second input of summing amplifier **23** is connected to the second input terminal for the vertical angular speed signal through a lead **25**. The output of summing amplifier **23** is connected through a lead **42** to an input of a multiplier circuit **15**. A second input to multiplier circuit **15** is connected to the output of non-linear amplifier **13** through a lead **43**. The output of multiplier circuit **15** is conducted through a lead **28** to the elevation mechanism for the weapon to control the elevation with respect to the sight line in accordance with the calculated vertical lead angle.

OPERATION

With reference to FIG. 1, the distance f traveled by the target during the time of projectile flight along the path s and the average projectile speed v_G may be computed in the following equations:

$$f=|\overline{ZT}|=v_Z \cdot t_G \tag{7a}$$

$$v_G=\frac{e_G}{t_G} \tag{7b}$$

Referring to FIG. 2, the following lead angle relations can be derived:

$$\sin \delta_H=\frac{v_Z}{v_G} \cdot \cos \lambda \cdot \sin \kappa \tag{8}$$

$$\sin \delta_S=\frac{v_Z}{v_G} \cdot \cos \lambda \cdot \cos \kappa \cdot \frac{1}{\cos \delta_H} \tag{9}$$

It will be noted that Equations 8 and 9 for the lead angles δ_H and δ_S have no dependence upon the position of the weapon or the elevation angle θ_{VK}.

When following a target through the optical sight, the target speed vector v_Z is projected on the field of view plane GE. The apparent velocity as seen through the optical sight is therefore v_Z, $\cos \lambda$ where λ is the angle of the target path with respect to the view plane GE. The angular speed of the sight line is determined by dividing the projection of the speed on the view plane by the associated radius distance, in other words, the target distance e. The angular speed therefore becomes

$$\frac{v_Z \cdot \cos \lambda}{e}$$

and must be proportional to the total directioning signal C for the weapon to track the target:

$$C=\frac{v_Z \cdot \cos \lambda}{e} \tag{10}$$

The total control signal consists of the two components C_H (vertical) and C_S (lateral). FIG. 4 is a representation of the directioning signal components as seen through the optical sight. It will be seen in FIG. 4 that the vertical component of the target velocity vector is v_Z. $\cos \lambda$. $\sin \kappa$ and the lateral component of the vector is v_Z. $\cos \lambda$. $\cos \kappa$. The component angular speeds are obtained by dividing these values by the radius or the target distance e. The equations for the directioning signal components are, therefore,

$$C_H=\frac{v_Z \cdot \cos \lambda \sin \kappa}{e} \tag{11}$$

$$C_S=\frac{v_Z \cdot \cos \lambda \cos \kappa}{e} \tag{12}$$

Rearrangement of these equations yields:

$$v_Z.\ \cos \lambda.\ \sin \kappa=C_H.e \tag{11a}$$

$$v_Z.\ \cos \lambda.\ \cos \kappa=C_S.e \tag{12a}$$

Equations 11*a* and 12*a* may be substituted into the lead angle Equations 8 and 9:

$$\sin \sigma_H=C_H \frac{e}{v_G} \tag{1}$$

and

$$\sin \delta_S=C_S \cdot \frac{e}{v_G} \cdot \frac{1}{\cos \delta_H} \tag{2}$$

Because the lead angles are small, the following approximations can be made:

$\sin \delta_H=\delta_H$;
$\cos \delta_H=1$;
and
$\sin \delta=\delta_S$

The final equations for the lead angle components are then

$$\delta_H=C_H \cdot \frac{e}{v_G} \tag{1a}$$

and

$$\delta_S=C_S \cdot \frac{e}{v_G} \tag{2a}$$

It is evident from these equations that in order to calculate the lead angle certain input information is required: control signals C_H and C_S for the vertical and lateral directioning respectively, projectile speed v_G, and the distance e of the target with respect to the weapon position measured along the sight line.

In the absence of a means for instantaneously measuring the target distance e, the distance must be evaluated by the lead computer. The following equations provide the instantaneous distance:

$$e=e_0 \frac{\sin \delta}{C \cdot t} \tag{4}$$

where

e_0=initial distance,
t=time,
C=total directioning signal composed of two perpendicular components, and
σ=total angle passed by the sight line since the beginning of calculation.

The total angle through which the sight line is rotated is

$$\sigma=\int_0^t C dt \tag{4a}$$

The total directioning signal C is

$$C=\sqrt{C_s^2+C_H^2}| \tag{4b}$$

The initial distance e_0 corresponds to an amplification factor in the computer. When the initial value of the distance is available, the amplification factor is adjusted and the distance calculation starts at the time $t=0$.

Still unknown in the speed angle equation is the projectile speed v_G, dependent on the kind of ammunition and on the distance e_G the projectile must travel. For a particular kind of ammunition, the projectile speed v_G will depend on the target distance e along the sight line, the position λ of the target path with relation to the weapon position and the speed v_Z of the target. A reasonable approximation formula for the relation between the sight line distance e and the projectile speed v_G arrived at through calculations of the projectile speed for realistic values of e, v_Z and λ is

$$\frac{e}{v_G} \approx f(e) \tag{13}$$

The left side of the equation can be divided into two factors:

$$\frac{e}{v_G}=\frac{e}{e_G}\cdot\frac{e_G}{v_G} \quad (13a)$$

The second factor will be recognized as representing the projectile flight time t_G given by

$$\frac{e}{v_G}=\frac{e}{e_G}\cdot t_G(e_G)$$

For the particular type of ammunition used, t_G can be taken from firing tables and can be closely represented by the function:

$$t_G=\frac{e_G}{v_0-e_G}$$

where

v_0=firing speed

ω=constant with dimensions of $\frac{1}{\text{time}}$

Values of the ratio $\frac{e}{e_G}\left(\frac{\text{sight distance}}{\text{projectile path distance}}\right)$ less than 1 will not be considered as this would only be the case when the target was departing from the weapon position. The practical maximum value m for the ratio is 1.25 which results at the greatest distance $\hat{e}$ with maximum target speed and a direct approach ($\lambda=90°$). It is therefore reasonable to represent e/e_G by a function having a value between 1 and the maximum value m for the greatest distance e diminishing towards 1 at decreasing distance e. For instance:

$$\frac{e}{e_G}\approx 1+e\cdot\frac{m-1}{2\hat{e}}$$

Substituting this equation into Equation 12a:

$$\frac{e}{v_G}=\frac{e}{e_G}\cdot\frac{e_G}{v_0-\omega e_G}=\frac{e}{v_0-\omega e_G}$$

further resulting in

$$\frac{e}{v_G}\approx\frac{e}{v_0-\cfrac{e\cdot\omega}{1+\cfrac{e(m-1)}{2\hat{e}}}}=\frac{2[2e+e(m-1)]}{2\hat{e}v_0+e[(m-1)v_0-2\hat{e}\omega]} \quad (13)$$

If the left side of the above equation is plotted with respect to e, a smooth, slightly curved function will result which may be duplicated electronically.

Equations have thus been provided for calculation of the desired vertical and lateral lead angles in a computer from the directioning signals C_H and C_S and the initial distance e_0.

Consideration must now be given to the target path rectangular speed components as viewed through the optical sight. The relationship between the two components determine the direction of the resulting motion of the sight line necessary to follow the target due to the inclination of the target path plane. Components of the inertial angular speed of the sight line necessary for target tracking indicate the inclination κ of the target path plane by:

$$\tan\kappa=\frac{C_H}{C_S} \quad (14)$$

FIG. 3*a* is a representation of the target path as seen through the optical sight under normal conditions, i.e., the supporting means for the weapon in a level condition. In this condition, of course, cross hair F_a will be vertical (along a radius line of the earth) and cross hair F_b will be horizontal (tangent to the earth's surface).

In following the target with the cross hair the inertial angular speeds of the sight line in the two orthogonal directions are indicative of the instantaneous inclination angle at any point. For target movement in the field of sight plane GE in the direction f', the orthogonal inertial angular speeds generated by movement of the sight line in the direction f' are indicative of the inclination angle κ_1.

As previously mentioned, the two orthogonal angular speed components of the sight line may be generated by means of a single rate gyro fixedly mounted along the axis of the sight line.

It is also possible to derive the angular speed signals from the control voltages generated by the sight optic drive. For example, stabilization systems utilizing integrating rate gyros to correct for changes in orientation of the turning plane of the weapon (due to a tank-mounted weapon traversing hilly ground, for example) require that the control signals to the sight drive be proportional to the angular speed of the sight line. The inclination angle of the target path plane may therefore be evaluated according to the Equation 14 using these signals.

It is also necessary that the lead computer give the correct values when the weapon is in motion. As the normal target is an airplane and the weapon is mounted on a surface craft, the relative speed between target and weapon is almost entirely determined by the speed of the target. The speed of the weapon may be neglected. Rotation of the weapon support vehicle can be taken as a vector consisting of three components in mutually perpendicular planes. The axes of rotation for the three components are the sight line r, a line u perpendicular to r and parallel to the turning plane AE, and the axis w which is perpendicular to both r and u. Rotational components around axes other than the sight line r may be easily compensated for by a stabilization system. The system is not explained in detail here since it is not a part of the present invention. In general, rotation around the sight line r is not of interest for stabilization purposes. Therefore, no sensing means (gyro) is provided for this purpose. Rotation of the weapon support vehicle around the sight line r can be expected to cause no reaction by the stabilization system.

In the absence of the lead computer, the weapon would be directed in a line parallel to the sight line. With the interconnection of the lead computer, the axis of the weapon has a lead angle inclination with respect to the sight line. Rotation of the craft around the sight line axis causes the axis of the weapon to trace a cone shaped shell around the sight line. As long as the target is maintained in the cross hair by the gun pointer, this condition has no effect. This is explained with reference to the drawings.

FIG. 3*a* represents the view through the optical sight with the horizontal cross hair F_b (parallel to turning plane AE) in a horizontal position with respect to the earth. To maintain the target at the point of intersection of the cross hairs, the sight must be moved along the line f' at an angle κ_1 with respect to the horizontal F_b. For the condition illustrated in FIG. 3*a*, that is, horizontal cross hair F_b (which is parallel to the turning plane of the weapon) level, the inertial angular speeds in the vertical and lateral direction for maintaining the target at the intersection of the cross hairs will have the ratio

$$\frac{a_1}{b_1}=\frac{C_H}{C_S}=\tan\kappa_1$$

Referring now to FIG. 3*b*, a roll motion through the angle $\Delta\kappa$ around the sight line causes the cross hairs of the optical sight to be positioned relative to a horizontal line as shown. Moving the optical sight along the previously correct line as determined by the angle κ_1 would lose the target moving along the line f'. To maintain the sight on target, the gun pointer must change the relationship of the angular speeds of the sight line so that the sight line again moves along the line f'. The line f' is now defined in position by the relationship

$$\frac{a_2}{b_2}=\frac{C_H}{C_S}=\tan\kappa_2$$

This change in the angle κ necessary for following of the target is automatically calculated within the lead computer. The lead computer therefore not only computes the necessary lead angle but also the absolute direction of the lead for any position of the weapon turning plane (e.g., tank traversing hilly ground or ship in rolling seas) and automatically adjusts the weapon position according to the calculations.

The signals which are generated with a change of the directioning handle by the gun pointer correspond to new nominal values of the angular rotation speeds C_H and C_S of the weapon which are fed to the lead computer. Signals proportional to the inertial angular speeds may be taken from a rate gyro which is fixedly aligned with respect to the line of sight. Rolling motion of the sight optic around the sight line does not change the ratio of the inertial angular speed components because, with the change of orientation of the rate gyro, the turning speed of the sight line as represented by two orthogonal components also changes.

With reference to FIG. 5, the operation of the preferred embodiment of the lead computer will be described. As previously described with respect to Equations 1*a* and 2*a*, evaluation of the lead angle requires that the quantities C_H, C_s, and e/v_G be fed into the lead computer. The signal C_s is proportional to the angular speed $\dot{\psi}_V$ of the sight line in the lateral direction and the signal C_H is proportional to the angular speed $\dot{\theta}_{Vk}$ in the vertical direction. Utilizing Equation 4*a* for the total directioning handle signal C the resultant angular speed is given by

$$\dot{\delta}=\sqrt{\dot{\psi}_V^2+\dot{\theta}_{VK}^2} \tag{4c}$$

FIG. 5 does not show the source of the signals which are proportional to the angular speeds. The block diagram begins with the signals applied to terminals **1** and **2** in the form of electrical control signals. It has previously been explained with reference to FIG. 4*a* that these signals representing the two components of the total directioning handle signal C can be used to calculate the total directioning signal C by geometrical addition according to Equation 4*b*. In FIG. 5, the two signals C_s and C_H are geometrically added in the circuit **3** providing on output lead **4** the signal C. The method of geometrical addition is not important and can be achieved in different ways as by squaring the input signals with subsequent adding and taking the square root or by addition of two AC voltages subjected to a ninety degree phase shift and rectification.

The signal on output lead **4** is representative of the angular speed of the sight line as shown in Equations 4*b* and 4*c*. This signal is integrated in circuit **5** and is also multiplied by a time proportional signal t in multiplier circuit **6**. Generation of the signal t is accomplished in integrator circuit **7** which is fed by constant signal U_o. On lead **31** at the output of integrator **5** the signal σ is available which in a subsequent sine transformer **8** is transformed to the signal $\sin\sigma$ appearing on lead **32**. We now have available the dividend $\sin\sigma$ and the divisor $t\cdot C$ of the fraction in the Equation 4*a* which are fed to a divider circuit **9** to derive the quantity

$$\sin\sigma/C\cdot t$$

on lead **26**. It is necessary to have a signal which is proportional to the initial distance e_0 along the sight line as shown in Equation 4*a*. Multiplication circuit **11** is fed with an initial distance signal e_0 which is multiplied with the signal on lead **26**.

It will be realized that the hit probability of the weapon system will be increased with a periodically varying signal corresponding to distance heterodyned with the lead signals. In the present embodiment, this is accomplished through modulation of the signal corresponding to the initial distance e_0 before it is fed to the multiplication circuit **11**. e_0 is applied to terminal **10** which is connected to the input of a modulation circuit **12** providing on output lead **27** the signal corresponding to the equation

$$e_0'=e_0(1+a\cdot \sin t) \tag{15}$$

The output of multiplier circuit **11** on lead **36** is now a function of time wherein e is proportional to the target distance along the sight line.

Reference to the Equations 1*a* and 2*a* necessary for the calculation of the lead angles δ_H and δ_s show that the signal e must still be divided by the averaged projectile speed v_G and subsequently be multiplied by the respective directioning handle signal C_H and C_S.

As previously noted, the average projectile speed v_G depends on several quantities and, for the lead angle calculations, the speed is not needed explicitly, but only together with the target distance in the fraction e/v_G.

The dependence of v_G and e/v_G on the different parameters was investigated. It was found that the function

$$\frac{e}{V_G}=f(e)$$

can be represented by a group of curves approximated by third degree parabolas. It is therefore possible to determine the desired quantity e/v_G, without evaluating the average projectile speed v_G, using only the target distance e. This is accomplished by feeding the signal $e(t)$ to a non-linear circuit **13** having the characteristic transfer function $f(e)$. The output of non-linear circuit **13** appears on lead **37**: the signal e/v_G, previously modulated in circuit **12**.

In accordance with Equations 1*a* and 2*a*, it is necessary to multiply the signal with the associated directioning signals C_H and C_s to arrive at the signal corresponding to the lead angle of the weapon in the vertical and lateral directions respectively. It is to be remembered that the lead angles of the weapons are always with reference to the sight line which is directed towards the target. Two multiplication circuits are provided in **14** and **15**. Multiplier circuit **14** has as inputs the quotient e/v_G and the lateral directioning signal C_s, providing at the output on lead **39** the lateral lead signal of the weapon

$$\delta_s=C_S\cdot\frac{e}{V_G}$$

It would be possible to feed this signal directly to the weapon, however, as the weapon itself cannot be turned in a lateral direction, but only can be elevated within a rotatable turret, it is necessary to recalculate the lead signal with respect to the lateral lead angle δ_K of the turret according to Equation 3*a*. Equation 3*a* shows that the elevation angle θ_{VK} of the sight line with respect to the horizontal turning plane of the turret must be known. To provide this input information, the input of resolver **17** is coupled mechanically to provide a signal proportional to the elevation angle θ_{VK}. The resolver **17**, provided with an alternating voltage of constant frequency and amplitude, provides an output signal modulated in accordance with the cosine of the elevation angle θ_{VK}. The resolver output signal is fed to a demodulator **18** through lead **40** where it is rectified to provide $\cos\theta_{VK}$ on lead **41**. $\cos\theta_{VK}$ is also fed to the division circuit **20** through lead **19**, providing on lead **21** at the output of divider circuit **20** the lateral lead angle δ_K of the turret according to the Equation 3*a:*

$$\delta_K=\frac{\delta_S}{\cos\theta_{SK}}$$

Having provided the lateral lead angle δ_K, our attention is now turned to the calculation of the vertical lead angle δ_H. It will be realized that the directioning handle signal C_H and the magnitude e/v_G, already present, are sufficient for calculation of δ_H. However, the embodiment of the present invention as shown in FIG. 5 considers not only the lead quantities which are necessary due to the relative motion between the weapon and the target, but also automatically calculates directly the needed ballistic superelevation according to the Equation 5*a*

$$\Delta\theta=\frac{g}{2}\cdot\frac{\cos\theta_{VK}}{v_G'}\cdot\frac{e}{v_G}$$

It will be noted with reference to the previously cited Equation 5 that the factor e/v_G has been extracted from the product. The quantity v_G remains as a factor in the denominator of the fraction. In the above equation it has been designated v_G' which has an average value corresponding to the average projectile speed at the main battle distance. Due to this simplification, the calculation of $\Delta\theta$ requires only that the signal cos θ_{VK} (already calculated in the circuits **17** and **18**) and the value of e/v_G (at the output **37** of circuit **13**) be multiplied with a constant factor $g/2v_G'$. The angle δ_H^* including the ballistic superelevation is determined by adding Equations 1*a* and 5*a* resulting in:

$$\delta_H^* = \frac{e}{v_G}\left(C_H + \frac{g}{2v_G'}\cdot\cos\theta_{VK}\right)\cdot$$

The signal cos θ_{VK} is multiplied by constant factor

$$A = \frac{g}{2v_G'}$$

in amplifier **22**. At one input of summing amplifier **23** on lead **24** a signal

$$\frac{g}{2v_G'}\cdot\cos\theta_{VK}$$

is present while on the other input line **25**, the directioning signal C_H in the vertical direction is applied from input terminal **2** through lead **25**. The sum of the two input signals is connected to multiplication circuit **15** through lead **42**. The signal e/v_G is multiplied with the sum of the two signals providing, on lead **28** at the output of the multiplier circuit, the vertical lead signal δ_H^* including the ballistic superelevation according to the Equation 4*a*. The signal δ_H^* determines the lateral lead of the weapon with respect to the sight line. The lateral lead angle δ_K of the turret determines the angle between the turret and the sight line. Due to the modulation of the initial distance signal e_0, the lateral lead angle as well as the vertical lead angle vary in accordance with the amplitude of the modulation, which is dependent on the initial distance e_0.

It is to be realized in accordance with the present invention, that the modulation may be omitted completely or it may be introduced at another point in the circuit. In the embodiment shown in FIG. 5, the lateral variation and the vertical variation of the lead angles are always at an equal percentage. This appears to be the desirable situation, however it can be modified.

In accordance with the invention, it shall be noted that the computations accomplished with the embodiment shown in FIG. 5 can also be realized with other electrical circuits. The equations could be solved, for example, by means of an analog computer. The trigonometric transformation could be accomplished by resolvers or coordinate changers or a sine or cosine potentiometer. The servo-circuits are not to be limited to operation on alternating currents but also can be operated using direct current. The operation with DC causes a change of rotational direction of the motors in response to a change in polarity of the applied current. With AC operation, the change of the motor direction is achieved by altering the phase of the carrier frequency in relation to a reference phase. In both cases it is desirable to introduce a low frequency alternating current to the direct current or the carrier frequency. The present invention provides a system for computation of the lead angle but is not to be limited in scope by the embodiment shown. Various modifications of the system will be evident to those skilled in the art while maintaining the essence of the present invention. It is our intention to be limited in scope only by the appended claims.

We claim:

1. A weapon fire control system wherein a biaxial directionable weapon and a biaxial directionable sight mounted on a movable platform are interconnected electrically, including a lead angle computer interposed in the electrical interconnection whereby, in accordance

with electrical signals processed in said lead computer, said weapon is directed toward a target seen through said sight, said lead computer comprising:

first and second input means for receiving a signal proportional to the inertial angular speed of the sight line in a lateral and vertical direction respectively;

time dependent input;

geometrical addition means connected to said first and second input means, having an output, for computing the geometrical sum of said signals;

integrator means connected to said time dependent input, having an output, for providing a signal proportional to time which is the integral of a signal applied to said time dependent input;

computer means, connected to said output of said geometrical addition means and to said output of said integrator means, having an output for providing a signal directly proportional to the sine of said signal at said output of said geometrical addition means and inversely proportional to the product of said signals at said output of said integrator and said output of said geometrical addition means;

first multiplier circuit having a first input connected to said output of said computer means and having a second input, further having an output;

initial distance input means for receiving an electrical signal proportional to the target distance, connected to said second input of said first multiplier circuit, whereby said output of said multiplier circuit provides a signal directly proportional to the product of the signal applied to said first input and said signal applied to said initial distance input means;

non-linear circuit means with a predetermined transfer characteristic having input and output whereby a signal at said input provides an output signal at said output in accordance with a predetermined non-linear function approximating a parabola of the third degree, whereby the signal at said output means of said non-linear circuit means is directly proportional to the distance of the target and inversely proportional to the average speed of the projectile;

second multiplier circuit having first and second input further having an output, said first input connected to said output of said non-linear circuit means and said second input connected to said first input means for receiving a signal proportional to said inertial angular speed of said sight line in said lateral direction, whereby a signal is provided at said output of said second multiplier circuit proportional to the desired lateral lead angle of the weapon with respect to the sight line;

resolver means having a mechanical input connected to said sight, further having an electrical output, whereby the signal at said electrical output is proportional to the cosine of the elevation angle of said sight;

first divider means connected to said output of said second multiplier circuit and further connected to said output of said resolver means, having an output coupled to the lateral directioning apparatus of said weapon whereby the signal at said output is directly proportional to said signal at said output of said second multiplier circuit and is inversely proportional to said signal at said electrical output of said resolver means;

amplifier means, having an input and an output, said input connected to said output of said resolver means, for providing a signal at said output of said amplifier means directly proportional to a signal at said input in accordance with a predetermined multiplication factor;

summing amplifier having first and second inputs and an output, said first input connected to said second input means for receiving a signal proportional to the inertial angular speed of said sight line in a vertical direction, said second input connected to said output of said amplifier means, said output of said summing amplifier providing a signal equal to the sum of the signals at said first and second inputs; and

third multipler circuit means, having a first input connected to said output of said non-linear circuit means, having a second input connected to said output of said summing amplifier, having an output connected to the vertical directioning apparatus for said weapon, for providing a signal to position said weapon in the vertical direction with respect to said sight line, whereby the combination of said lateral and said vertical directioning signals provides direction of the weapon with respect to said sight line at the correct angle for maximum bit probability.

2. Apparatus as recited in claim **1** including means for modulating said lateral and said vertical directioning signals.

3. Apparatus as recited in claim **1** wherein said predetermined multiplication factor of said amplifier means is adjusted in accordance with the ballistic super elevation needed for a projectile fired from said weapon.

4. A lead computer for an electrically positioned antiaircraft weapon system including a biaxially directionable weapon and a biaxially directionable sight line comprising:

input means for receiving signals proportional to the inertial angular speeds C_S and C_H of said sight line;

initial distance input means for receiving a signal proportional to target distance at first contact;

first signal processing means, connected to said initial distance input means and to said input means, for evaluating the instantaneous target distance e;

second signal processing means, connected to said input means and to said first signal processing means, for evaluating the vertical lead angle δ_H of said weapon using the equation

$$\sin \delta_H = C_H \cdot \frac{e}{v_G}$$

where v_G is the average projectile speed;

third signal processing means, connected to said input means and to said first signal processing means, for evaluating the lateral lead angle δ_S of said weapon using the equation

$$\sin \delta_S = C_S \cdot \frac{e}{v_G} \cdot \frac{1}{\cos \delta_H}$$

and

output means connected to said weapon, further connected to said first and second signal processing means, whereby said weapon is positioned with respect to said sight line in accordance with the evaluated lead angles.

5. Apparatus as recited in claim **4** wherein said output means connected to said weapon includes means for electrically indicating the elevation angle θ_{VK} of said sight line for computing the lateral lead angle δ_K of a

turret carrying said weapon in accordance with the equation

$$\sin \delta_K = \frac{\sin \delta_S}{\cos \theta_{VK}}$$

6. Apparatus as recited in claim **4** wherein said second signal processing means and said third signal processing means include non-linear circuit means for calculating the ratio e/v_G.

7. Apparatus as recited in claim **4** including modulating means for modulating said vertical lead angle and said lateral lead angle.

8. Apparatus as recited in claim **7** wherein said modulating means is connected to said initial distance input means for modulating said signal proportional to target distance at first contact.

9. Apparatus as recited in claim **4** wherein said signals proportional to the inertial angular speeds C_S and C_H of said sight line are generated by a rate gyro fixedly mounted with respect to said sight line.

10. Apparatus as recited in claim **4** wherein said signals proportional to the inertial angular speeds C_S and C_H of said sight line are derived from an electric directioning handle for said sight line.

11. Apparatus as recited in claim **4** wherein said vertical lead angle δ_H of said weapon is evaluated according to the approximate equation for small lead angles

$$\delta_H = C_H \cdot \frac{e}{v_G}$$

and said lateral lead angle δ_S of said weapon is evaluated according to the approximate equation for small lead angles

$$\delta_S = C_S \cdot \frac{e}{v_G}$$

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89—1, 41