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Nov. 29, 1949 E. LAKATOS 2,489,907

ARTILLERY COMPUTER

Filed Feb. 19, 1944 3 Sheets-Sheet 1

FIG. 1

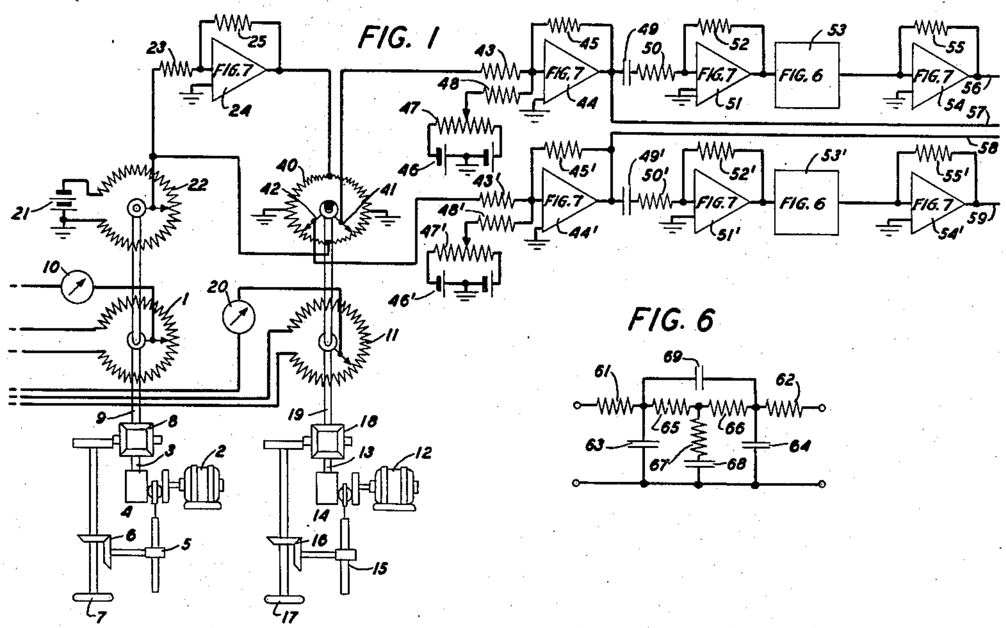


FIG. 6

FIG. 5

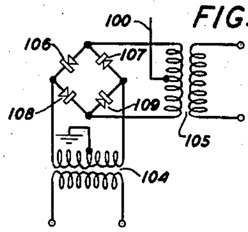
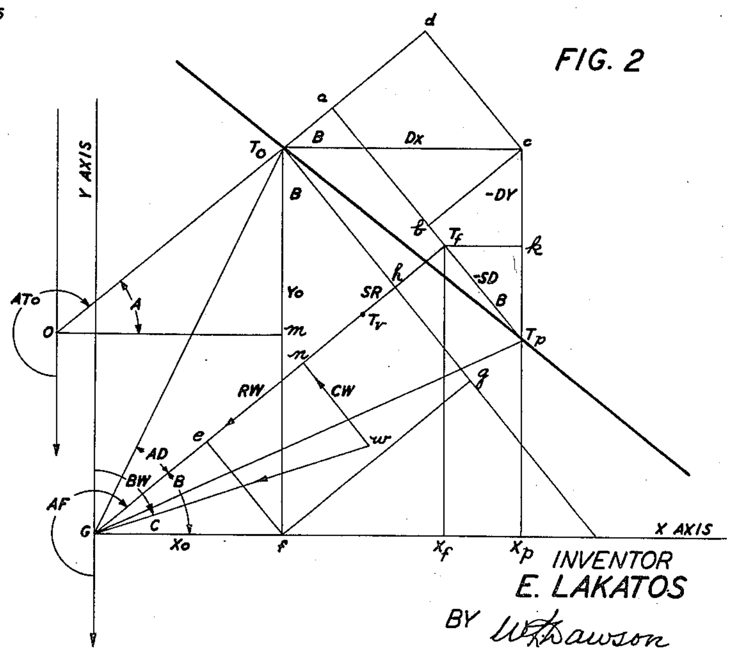


FIG. 2



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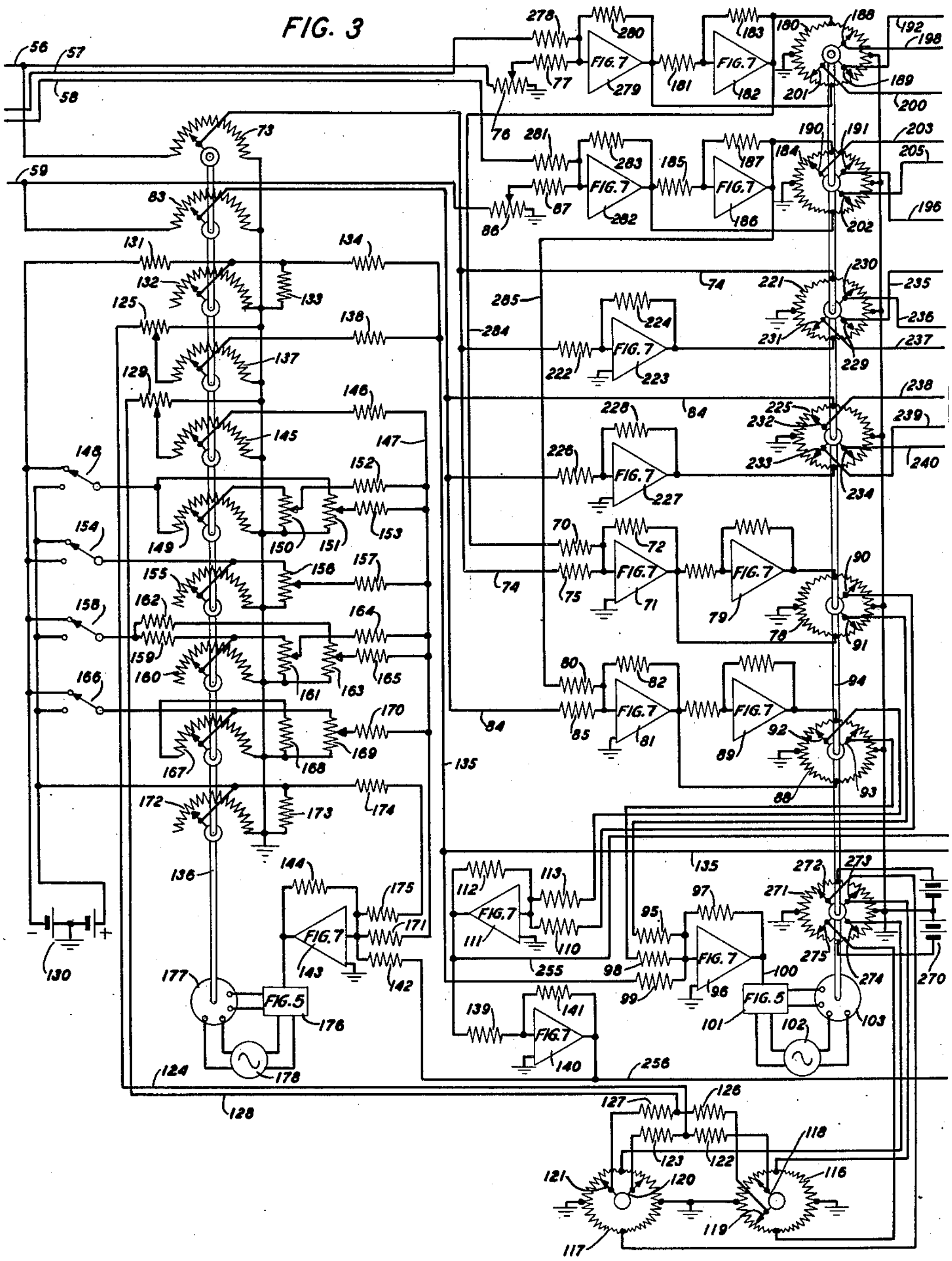
3 Sheets-Sheet 2

FIG. 3



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Filed Feb. 19, 1944 3 Sheets-Sheet 3

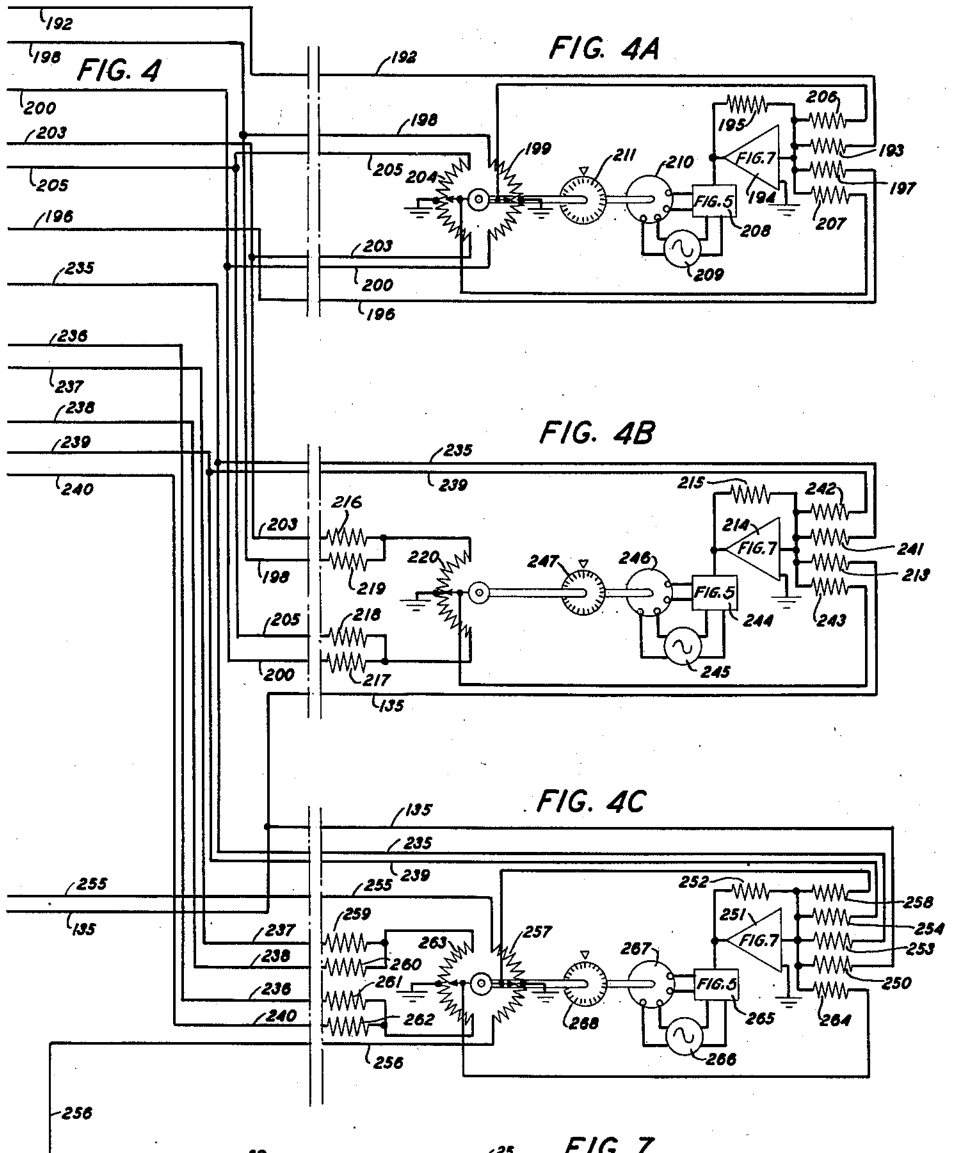
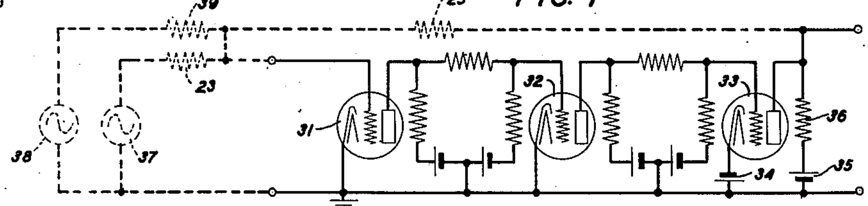


FIG. 7



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UNITED STATES PATENT OFFICE

2,489,907

ARTILLERY COMPUTER

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Application February 19, 1944, Serial No. 523,171

9 Claims. (Cl. 235—61.5)

1

This invention relates to artillery computers and particularly to computers in which some of the data are represented by electrical quantities.

The object of the invention is a method and means for computing and indicating the deflection angle, or angle at the gun by which the line of fire leads the present position of the target.

In the drawings:

Fig. 1 discloses a prediction system;

Fig. 2 shows the geometrical relationships involved;

Fig. 3 discloses a ballistic correction system associated with the system of Fig. 1;

Figs. 4A, 4B, 4C disclose alternative forms of the invention associated with the system of Fig. 3;

Fig. 5 shows a phase controlling network used in the systems of Figs. 3, 4A, 4B, 4C;

Fig. 6 shows a smoothing network used in the system of Fig. 1; and

Fig. 7 shows a summing amplifier used in the systems of Figs. 1, 3, 4A, 4B, 4C.

In Fig. 2, the line T_o, T_p represents the course of a moving target. From an observation station O, the distance OT_o and the azimuth AT_o, between the South axis and the line OT_o, are continuously measured. These observations are transmitted to the computer, and from them and the known coordinates of the gun with respect to the point of observation the computer continuously produces electrical quantities proportional to the rectangular coordinates, X_o and Y_o, from the gun to the target. From these coordinates and the rates of change of these coordinates, the computer approximately determines the values of the coordinates of the position of the target at which a hit is predicted, and also selects the values of the range and azimuth of the line of fire to a virtual target that, corrected for ballistic range and deflection effects will cause a shell to hit approximately at the predicted position of the target. The two values for the predicted position of the target are automatically compared and, if there is a discrepancy, the values of both approximations are changed to produce coincidence of the predicted positions at the correct value.

In Fig. 2, T_p is the correct predicted position of the target. The range and azimuth of the line of fire is directed to a virtual target T_v such that the shell, fired at T_v and influenced by the total ballistic range effects SR and the total ballistic deflection effects SD will burst at T_p. In the present disclosure, ballistic effects which increase the range are represented by positive quantities and ballistic effects which deflect the shell to

2

the left of the virtual position of the target are also represented by positive quantities. The total range $R+SR$ may be designated as the firing range R_F. The firing range R_F is usually comparable with, but slightly less than the map range GT_p.

The azimuth AF of the line of fire GT_f is, as usual, in terms of the angle traced clockwise from the South. The angle $B=270°-AF$. Let angle T_oGT_f be AD the angle of deflection, that is, the angle by which the line of fire leads the present position of the target.

First method

Draw T_of parallel to the Y axis, then $T_of=Y_o$ and $Gf=X_o$.

$$\tan(AD+B)=\frac{Y_o}{X_o}$$

$$\tan AD=\frac{-X_o\sin B+Y_o\cos B}{X_o\cos B+Y_o\sin B}$$

$$=-\frac{X_o\cos AF-Y_o\sin AF}{X_o\sin AF+Y_o\cos AF}$$

$$\tan AD.X_o\sin AF+\tan AD.Y_o\cos AF+X_o\cos AF-Y_o\sin AF=0 \quad (1)$$

Second method

Draw T_od, bc, and fg parallel to GT_f; ef, T_og, aT_f and dc perpendicular to GT_f; T_oc parallel to the X axis and cT_p parallel to the Y axis.

T_oc is the change in the X coordinate from the present to the predicted position of the target and will be designated DX; cT_p is the change in the Y coordinate and will be designated DY, and as this change is in the negative direction, $cT_p=-DY$.

Angles fT_og, dT_oc, bT_pc, equal angle T_fGx or angle B.

$$\begin{aligned}Gh&=Ge+eh\\&=Ge+fg\\&=+X_o\cos B+Y_o\sin B\\&=-X_o\sin AF-Y_o\cos AF\end{aligned}$$

$$\begin{aligned}T_oh&=ab+bT_p-T_fT_p\\&=dc+bT_p-T_fT_p\\&=DX\sin B-DY\cos B+SD\\&=-DX\cos AF+DY\sin AF+SD\end{aligned}$$

$$\tan AD=\frac{T_oh}{Gh}$$

$$=-\frac{SD-DX\cos AF+DY\sin AF}{X_o\sin AF+Y_o\cos AF}$$

$$\tan AD(X_o\sin AF+Y_o\cos AF)+SD-DX\cos AF+DY\sin AF=0 \quad (2)$$

Third method

$$T_oh = -DX \cos AF + DY \sin AF + SD$$
$$Gh = GT_f - hT_f = GT_f - T_od + ad = GT_f - T_od + bc$$
$$= R_f - DX \cos B - DY \sin B$$
$$= R_f + DX \sin AF + DY \cos AF$$
$$\tan AD = \frac{-DX \cos AF + DY \sin AF + SD}{R_f + DX \sin AF + DY \cos AF}$$
$$\tan AD.R_f + \tan AD(DX \sin AF + DY \cos AF) - SD + DX \cos AF - DY \sin AF = 0 \quad (3)$$

In Fig. 2 $T_og = Y_o \cos B$; $hg = ef = X_o \sin B$, thus $Y_o \cos B - X_o \sin B = T_oh, = +X_o \cos AF - Y_o \sin AF$, the rectangular coordinate of the present position of the target with respect to the gun perpendicular to the line of fire.

Also $Ge = X_o \cos B$; $fg = eh = Y_o \sin B$, thus $X_o \cos B + Y_o \sin B = Gh \equiv (X_o \sin AF + Y_o \cos AF,)$ the rectangular coordinate of the present position of the target with respect to the gun in the line of fire.

$T_oh = aT_f = ab + bT_p - T_fT_p = DX \sin B - DY \cos B + SD = -DX \cos AF + DY \sin AF + SD$, the rectangular coordinate of the present position of the target with respect to the gun, perpendicular to the line of fire.

$Gh = GT_f - hT_f = GT_f - (T_od - bc) = R_f - DX$

$\cos B - DY \sin B = R_f + DX \sin AF + DY \cos AF$, the rectangular coordinate of the present position of the target with respect to the gun in the line of fire.

Thus, in each of the three methods, the tangent of the deflection angle is equal to the quotient of the rectangular coordinate of the present position of the target with respect to the gun perpendicular to the line of fire and the rectangular coordinate of the present position of the target with respect to the gun in the line of fire.

The present computer is primarily intended for the control of substantially horizontal fire, such as coast defense fire against maritime vessels or land fire against vehicles. The target is continuously observed by known means, such as a simple theodolite and a range finder.

The observations of the distance to and azimuth of the present position of the target are continuously transmitted to the computer by some convenient data transmission system, such as the system shown in U. S. Patent 1,483,235, February 12, 1924, R. V. Morse. The complete data may be transmitted by such a system, or, for greater accuracy, the even hundreds of yards of distance and degrees of azimuth may be telephoned to the operator of the computer at regular intervals, and the divisions of the hundreds of yards and degrees transmitted by the data transmission system.

In Fig. 1, the potentiometer **1** is the receiving potentiometer of the distance data transmission system. A constant speed motor **2** drives the shaft **3** through the variable speed drive **4**, of any suitable type, such as the drive shown in U. S. Patent 1,448,490, March 13, 1923, H. Moakley. In this drive the motor **2** drives a disc which, through an interposed ball, drives a cylinder fixed to shaft **3**. The speed ratio is determined by the position of the ball on the disc.

The position of the ball is varied by the rack and pinion **5**, attached to the ball race and adjusted through the gears **6** by the hand-wheel **7**.

The shaft **3** drives the shaft **9**, rotating the brush of potentiometer **1**, through a differential gear **8**. The ring gear of differential gear **8** may be rotated by the hand-wheel **7**.

Rotation of the hand-wheel **7** will thus cause an angular movement of the brush of potentiometer **1** and will also change the speed of shaft **9**.

The operator adjusts the hand-wheel **7** to balance the data transmission system and set the speed of the brush of potentiometer **1** to maintain the system balanced, as indicated by the meter **10**.

Potentiometer **11** is the receiving potentiometer of the azimuth data transmission system. The brush of potentiometer **11** is driven by motor **12** under the control of hand-wheel **17**, and unbalance of this system is indicated by meter **20**.

Elements **13**, **14**, **15**, **16**, **18**, **19** operate similarly to elements **3**, **4**, **5**, **6**, **8**, **9**.

A source of voltage **21**, having its positive pole grounded, is connected across the winding of potentiometer **22**. The brush of potentiometer **22** is rotated by shaft **9** to select a voltage proportional to the distance to the present position of the target, OT_o, Fig. 2.

In order to show the circuit connections more clearly, the potentiometers **1** and **22** have been shown as if they were rotated 90 degrees with respect to the shaft **9**. The other potentiometers in the system have been similarly rotated with respect to the shafts rotating the brushes.

The windings of all the potentiometers in the system may conveniently be in the form of close even windings of resistance wire on thin flat cards having one straight edge. The card is supported in the arc of a circle concentric with the shaft driving the brushes. The resistance wire is bared on the straight edge of the card to form a good contact for the brush. The other edge of the card is shaped so that the width of the card will vary in such manner as to produce the desired variation of the voltage selected by the brush with the angular position of the brush. The width of the card will vary approximately as the derivative of the voltage function, corrected, if necessary, for the load connected to the brushes.

Potentiometers which vary during a run have been represented by circular potentiometers; and potentiometers which are handset to a constant value by straight potentiometers. The handset potentiometers may also be circular, if desired.

The voltage selected by the brush of potentiometer **22** is applied through resistor **23** to the input circuit of an amplifier **24** having a feedback resistor **25**. The amplifier **24** may be any stable high gain amplifier, such as the amplifier shown in Fig. 7.

The amplifier shown in Fig. 7 is of the type shown in United States Patent 2,401,779, June 11, 1946, by K. D. Swartzel and assigned to the assignee of the present application. The amplifier may conveniently include three high gain vacuum tubes **31**, **32**, **33**, coupled by any suitable interstage networks, such as the networks shown in U. S. Patent 1,751,527, March 25, 1930, H. Nyquist. Though for convenience, the vacuum tubes **31**, **32**, **33** have been shown as triodes, other types of tubes, such as pentodes, may be used with appropriate changes in the power supplies.

The negative pole of a source of voltage **34** is connected to the cathode of vacuum tube **33** and the positive pole grounded. The positive pole of a source of voltage **35**, having its negative pole grounded, is connected through resistor **36** to the anode of vacuum tube **33**. The voltages of the sources **34**, **35**, and the resistances of resistor **36** and the anode-cathode path of vacuum tube 33 are adjusted so that, in the absence of an applied signal, they form a balanced bridge, and no voltage is supplied to the output circuit.

If a source of positive voltage 37 be connected through a resistor 23 to the control grid of vacuum tube 31, it will tend to make the control grid of vacuum tube 31 positive with respect to ground, thus tending to make the control grid of vacuum tube 32 negative with respect to ground and the control grid of vacuum tube 33 positive with respect to ground. The positive voltage on the control grid of vacuum tube 33 will reduce the resistance of the anode-cathode path of vacuum tube 33, increasing the current flowing in the vacuum tube 33 and resistor 36, unbalancing the bridge and applying a negative voltage to the output terminals and load. Similarly, a negative voltage applied to the control grid of vacuum tube 31 will tend to make the control grid of vacuum tube 33 negative with respect to ground decreasing the current flowing in the vacuum tube 33 and applying a positive voltage to the output terminals and load. The amplifier thus reverses the polarity of a voltage applied to the input circuit.

A resistor 25 may be connected from the anode of vacuum tube 33 to the control grid of vacuum tube 31. If a source of positive voltage 37 be connected through a resistor 23 to the control grid of vacuum tube 31, this source will tend to cause a current to flow through resistor 23, resistor 25, and anode-cathode path of vacuum tube 33 back to the source. The amplified positive voltage on the control grid of vacuum tube 33 will cause the anode current of vacuum tube 33 to increase to carry the current flowing in resistor 25 and will produce a negative voltage across the output circuit equal to the voltage drop in the resistor 25. If the voltage amplification of the amplifier is large, this current will attain a value such that all the voltage of the source 37 is used to force the current through the resistor 23, reducing the potential difference between the control grid of vacuum tube 31 and ground substantially to zero. The input circuit of the amplifier, from the control grid of vacuum tube 31 to ground, will appear to be of low impedance.

Under these conditions, as the same current flows in resistors 23 and 25, the voltage of the source 37 will be to the output voltage as the resistance of resistor 23 is to the resistance of resistor 25; in other words, the voltage gain for the source 37 is the ratio of the resistances of the resistors 25 and 23.

If the source 37 applies a negative voltage to the control grid of vacuum tube 31 the direction of current flow through source 37, and resistors 23, 25 will be reversed, but the same gain and polarity relationships will be produced.

If a second source of a positive voltage 38 be connected through resistor 39 to the control grid of vacuum tube 31, this source will also tend to cause a current to flow in resistor 25. The output voltage will rise, increasing the voltage drop in resistor 25 until the potential difference between the control grid of vacuum tube 31 and ground is reduced substantially to zero. The output voltage will then be equal to the voltage drop in resistor 25 due to the algebraic sum of the currents from the two sources. The voltage gain for the voltage from the source 38 is the ratio of the resistances of the resistors 25 and 39, and is independent of the gain for the source 37. The output voltage is the algebraic sum of the amplified voltages from the sources 37, 38.

Let a capacitor be connected between the source 37 and resistor 23, then an increasing positive voltage from the source 37 will cause a current to flow towards the control grid of vacuum tube 31 and will produce a negative output voltage proportional to the derivative or time rate of change of the applied voltage multiplied by the ratio of the resistances of resistors 25 and 23. A decreasing positive voltage from the source 37 will cause a current to flow from the control grid of vacuum tube 31 and will produce a positive output voltage; an increasing negative voltage from the source 37 will cause a current to flow from the control grid of vacuum tube 31 and will produce a positive output voltage; a decreasing negative voltage from the source 37 will cause a current to flow towards the control grid of vacuum tube 31 and will produce a negative output voltage.

In Fig. 1, the resistances of resistors 23, 25 are selected so that the voltage selected by the brush of potentiometer 22 is reversed in polarity but unchanged in magnitude. The positive voltage from the output of amplifier 24 is applied to a tap in the potentiometer winding 40. The negative voltage selected by the brush of potentiometer 22 is applied to a tap in the winding 40 diametrically opposite to the first tap. The equidistant, intermediate taps of the winding 40 are grounded.

The brushes 41, 42 are located at right angles and insulated from the shaft 19 and from each other. Assuming zero azimuth at the left-hand grounded tap of the winding 40 and clockwise rotation of the brushes 41, 42 for increasing azimuth, the brush 41 will select a voltage proportional to the positive sine of the azimuth AT_o and brush 42 will select a voltage proportional to the positive cosine of the azimuth AT_o. But, as shown in Fig. 2, the azimuth AT_o equals $270° - A$, thus $+\sin AT_o$ equals $-\cos A$ and $+\cos AT_o$ equals $-\sin A$. As the voltage selected by the brush of potentiometer 22 is proportional to OT_o, the voltage selected by brush 41 will be proportional to $-OT_o \cos A$, that is, the minus x coordinate Om; and the voltage selected by the brush 42 will be proportional to $-OT_o \sin A$, that is, the minus y coordinate T_om.

The voltages selected by the brushes 41, 42 are thus proportional to the rectangular coordinates of the present position of the target with respect to the point of observation. These voltages may be converted into voltages proportional to the rectangular coordinates of the present position of the target with respect to the gun, by adding thereto voltages proportional to the gun parallax, that is, the rectangular coordinates of the gun with respect to the point of observation.

The voltage selected by the brush 41 is applied through resistor 43 to the input circuit of an amplifier 44, of the type shown in Fig. 7, having a feedback resistor 45. A source of voltage 46, having an intermediate point grounded, is connected across the winding of a potentiometer 47. The brush of potentiometer 47 is adjusted to select a voltage proportional to the x coordinate of the gun with respect to the point of observation, which is applied through resistor 48 to the input circuit of the amplifier 44. The output voltage of amplifier 44 will then be proportional to $+X_o$, the coördinate of the target with respect to the gun.

The output voltage of amplifier **44** is applied through capacitor **49** and resistor **50** to the input circuit of an amplifier **51**, of the type shown in Fig. 7, having a feedback resistor **52**.

As the brush **41** is rotating clockwise for increasing azimuth, the voltage selected by the brush **41** is increasing. Thus, the positive output voltage of amplifier **44**, applied to capacitor **49**, is increasing. The output voltage of amplifier **51** will thus be of negative polarity with respect to ground, and proportional to $-\dot{X}$, the time derivative of X_o, or the speed of the target in the direction of the X axis.

The output circuit of the amplifier **51** is connected to a smoothing network **53**, which may be of the type shown in Fig. 6.

The network shown in Fig. 6 includes the series resistors **61**, **62**, shunt capacitors **63**, **64** and the bridged T section formed by series resistors **65**, **66**, bridged by capacitor **69**, and shunt arm comprising resistor **67** and capacitor **68**. The complete network produces a smoothed weighted average of the applied values of $-\dot{X}$.

The network **53** is connected to the input circuit of an amplifier **54** having a feedback resistor **55**. The output of amplifier **54** will then be proportional to $+\dot{X}$.

The voltage selected by the brush **42** is similarly combined with the voltage selected by the brush of potentiometer **48'**, to produce a voltage from the output of amplifier **44'** proportional to $+Y_o$. The output circuit of amplifier **44'** is connected through capacitor **49'** to the input circuit of amplifier **51'**. As the brush **42** is rotating clockwise for increasing azimuth, the voltage selected by the brush **42** is decreasing. Thus, the positive output voltage of amplifier **44'** applied to capacitor **49'** is decreasing. The output voltage of amplifier **51'** will thus be of positive polarity. The output circuit of amplifier **51'** is connected through network **53'** to the input circuit of amplifier **54'**. The output voltage of amplifier **54'** will thus be proportional to $-\dot{Y}$, the time derivative of Y_o, or the speed of the target in the direction of the Y axis. Under the conditions shown in Fig. 2, the target is moving in the direction which decreases the Y coordinate, thus the speed of the target in this direction is negative.

Elements in the channel connected to brush **42** having similar functions to the elements in the channel connected to brush **41** have similar reference characters, distinguished by a prime.

Thus, the voltages with respect to ground of the connections **56**, **57**, **58**, **59**, are respectively proportional to $+\dot{X}$, $+X_o$, $+Y_o$ and $-\dot{Y}$.

If the gun is fired at the instant that the target passes through T_o, Fig. 2, the shell will take a time, TF, the time of flight, to travel from the gun G to T_p, the predicted position of the target. During this time interval, the change DX in the x coordinate of the position of the target, that is, the distance T_oc, Fig. 2, will be $\dot{X}.TF$; and the change $-DY$ in the y coordinate, that is, the distance T_pc, Fig. 2, will be $-\dot{Y}.TF$. The predicted position of the target will then have the coordinates $X_o+\dot{X}TF$ and $Y_o-\dot{Y}TF$.

In some cases, the data transmission system may be disabled, and only the values, telephoned at regular intervals, are available at the computer. These data are of a time in the past equal to the average time interval, TD, required by the operator to set in the data, which may be called the dead time. In some cases, the predicted position of the target will have the coordinates $X_o+\dot{X}(TF+TD)$ and $Y_o-\dot{Y}(TF+TD)$. The value of TF is, as yet, unknown and must be determined by the computation.

Connection **56** is connected through the winding of potentiometer **73** to ground. The brush of potentiometer **73** is moved, as explained hereinafter, to select a voltage proportional to $+\dot{X}TF$, and is connected, by connection **74** and resistor **75** to the input circuit of amplifier **71**, of the type shown in Fig. 7, having a feedback resistor **72**. The gains of amplifiers **51**, **54**, Fig. 1, are adjusted so that the change $\dot{X}TF$ has the same scale of yards per volt as X_o.

Connection **57**, Fig. 3, is connected through resistor **278** to the input circuit of an amplifier **279**, of the type shown in Fig. 7, having a feedback resistor **280**.

Connection **56** is connected through the winding of potentiometer **76** to ground. The brush of potentiometer **76** is adjusted to select a voltage proportional to $\dot{X}TD$. The brush of potentiometer **76** is connected through resistor **77** to the input circuit of amplifier **279**. The output voltage of amplifier **279** will then be proportional to $-(X_o+\dot{X}TD)$.

The output circuit of amplifier **279** is connected through resistor **181** to the input circuit of the polarity reversing amplifier **182**, of the type shown in Fig. 7, having a feedback resistor **183**. The output voltage of amplifier **182** will be proportional to $+X_o+\dot{X}TD$.

The output circuit of amplifier **182** is connected by connection **284** through resistor **70** to the input circuit of amplifier **71**.

The output circuit of amplifier **71** is connected to the lower tap of potentiometer winding **78**, and, through the polarity reversing amplifier **79**, of the type shown in Fig. 7, to the diametrically opposite upper tap. Intermediate, equidistant taps of the winding **78** are grounded. The winding **78** has a sinusoidal variation of resistance.

Connection **58** is connected through resistor **281** to the input circuit of an amplifier **282**, of the type shown in Fig. 7, having a feedback resistor **283**.

Connection **59** is connected through the winding of potentiometer **86** to ground. The brush of potentiometer **86** is adjusted to select a voltage proportional to $-\dot{Y}TD$ and is connected through resistor **87** to the input circuit of amplifier **282**. The gains of amplifiers **51'**, **54'** are adjusted so that $-\dot{Y}TD$ has the same scale of yards per volt as Y_o. The output voltage of amplifier **282** will then be proportional to $-Y_o+\dot{Y}TD$. The output circuit of amplifier **282** is connected through resistor **185** to the input circuit of a polarity reversing amplifier **186**, of the type shown in Fig. 7, having a feedback resistor **187**. The output circuit of amplifier **186** is connected by connection **285**, through resistor **80** to the input circuit of amplifier **81**.

Connection **59** is connected through the winding of potentiometer **83** to ground. The brush of potentiometer **83** is moved by shaft **136** to select a voltage proportional to $-\dot{Y}TF$ and is connected by connection **84** through resistor **85** to the input circuit of amplifier **81**.

The output voltage of amplifier **81** is proportional to $-Y_p$, the Y coordinate of the predicted position of the target.

The output circuit of amplifier **81** is connected directly to the lowest tap in the potentiometer winding **88**, and, through a polarity reversing amplifier **89**, of the type shown in Fig. 7, to a diametrically opposite tap. The intermediate, equidistant taps of winding **88** are grounded.

In Fig. 2, let the coordinates of the point T_f be X_f and Y_f.

$$X_f \sin B - Y_f \cos B = 0$$
$$-X_f \cos AF + Y_f \sin AF = 0$$

But

$$-X_f = -(X_p + SD \sin B) = -(X_p - SD \cos AF)$$
$$Y_f = Y_p - SD \cos B = Y_p + SD \sin AF$$

Thus

$$-(X_p - SD \cos AF) \cos AF + (Y_p + SD \sin AF) \sin AF = 0$$
$$-X_p \cos AF + Y_p \sin AF + SD = 0. \quad (4)$$

In Fig. 3, the brushes **90** and **91** are mutually at right angles and are insulated from the shaft **94** and from each other. The brushes **90** and **91** are moved by the shaft **94** to select voltages proportional to $+X_p \sin AF$ and $-X_p \cos AF$.

Similarly, the brushes **92** and **93** are at right angles, insulated from the shaft **94** and from each other and select voltages proportional to $+Y_p \cos AF$ and $+Y_p \sin AF$.

The brush **91** is connected through a resistor **95** to the input circuit of an amplifier **96** having a feedback resistor **97**. The brush **93** is connected through resistor **98** to the input circuit of amplifier **96**.

As explained hereinafter, a source of voltage proportional to +SD is connected to resistor **99**. The output voltage of the amplifier **96** will thus be proportional to $+X_p \cos AF - Y_p \sin AF - SD$.

The output circuit of amplifier **96** is connected by connection **100** to a phase controlling network **101**, of the type shown in Fig. 5. One phase of a two-phase source of power **102** is also connected to the phase controlling network **101** and the other phase of the two-phase source is connected to one phase winding of a two-phase motor **103**. The output of the phase controlling network **101** is connected to the other phase winding of the two-phase motor **103**.

The phase controlling network of Fig. 5 includes an input transformer **104** connected to one phase of the source of supply, an output transformer **105** connected to one phase winding of the motor and a bridge made up of the elements **106**, **107**, **108**, **109**, the conjugate vertices of the bridge being respectively connected to the transformers **104** and **105**. The elements **106**, **107**, **108**, **109** are equal non-linear resistors, such as copper-copper-oxide couples. When no current is supplied by the connection **100**, the bridge is balanced, no power is transmitted by the network and the motor is at rest. When current of one polarity is supplied by the connection **100**, the bridge is unbalanced and power of one phase angle is supplied to the motor, causing the motor to rotate in one direction. When current of the opposite polarity is supplied by the connection **100**, power of another phase angle is supplied to the motor, causing the motor to rotate in the opposite direction.

Thus, in Fig. 3, if the output of the amplifier **96** is not zero, the motor **103** will run, rotating the shaft **94** until the output of amplifier **96** is zero. Equation 4 is thus satisfied, and shaft **94** has rotated to the correct azimuth AF.

In Fig. 2, let $R_f = R_v + SR$, then $X_f = R_f \cos B$ and $Y_f = R_f \sin B$, thus, $X_p = R_f \cos B - SD \sin B$ and $Y_p = R_f \sin B + SD \cos B$.

Hence

$$X_p = -R_f \sin AF + SD \cos AF$$
$$Y_p = -R_f \cos AF - SD \sin AF$$

Multiplying by sin AF and cos AF, respectively, and adding

$$X_p \sin AF + Y_p \cos AF = -R_f \quad (5)$$

In Fig. 3, brush **90** selects a voltage proportional to $+X_p \sin AF$ and is connected through resistor **110** to the input circuit of an amplifier **111**, of the type shown in Fig. 7, having a feedback resistor **112**. Brush **92** selects a voltage proportional to $+Y_p \cos AF$ and is connected through resistor **113** to the input circuit of amplifier **111**. The output voltage of amplifier **111** will thus be proportional to $+R_f$.

At regular intervals, data is sent to the computer giving the weighted average value of the magnitude of the wind and the bearing, measured from north clockwise, of the direction from which the wind is blowing.

In Fig. 2, let *wG* be the wind vector of magnitude W at a bearing BW. Angle $B = 270 - AF$ and angle $C = 90 - BW$.

In the present computer, a ballistic effect which produces a decrease in range is represented by a negative voltage and an effect which tends to drift the shell to the left is represented by a positive voltage.

The cross-wind CW is represented by the vector *wn*.

$$CW = W \sin (B - C)$$
$$= W \sin (270 - AF - 90 + BW)$$
$$= W \sin (AF - BW)$$
$$= W (\sin AF \cos BW - \cos AF \sin BW) \quad (6)$$

The range wind is represented by the vector *n*G.

$$RW = W \cos (B - C)$$
$$= W \cos (270 - AF - 90 + BW)$$
$$= -W \cos (AF - BW)$$
$$= W(-\cos AF \cos BW - \sin AF \sin BW) \quad (7)$$

In Fig. 3, a source of voltage **270**, with midpoint grounded, has the positive pole connected to the upper tap in a potentiometer winding **271** and the negative pole connected to the lower diametrically opposite tap, the equidistant, intermediate taps being grounded. The potentiometer winding **271** has a sinusoidal variation in resistance.

The brushes **272**, **273**, **274**, **275** are mutually at right angles, insulated from the shaft **94** and from each other, and are rotated by the shaft **94** to the angle AF.

The brush **273** selects a voltage proportional to $+ \sin AF$ and the brush **275** selects a voltage proportional to $- \sin AF$. The brush **273** is connected to the upper tap of potentiometer winding **116**, the brush **275** is connected to the diametrically opposite lower tap of winding **116**, the intermediate, equidistant taps being grounded.

The brush **272** selects a voltage proportional to $+ \cos AF$ and the brush **274** selects a voltage proportional to $-\cos AF$. The brush **274** is connected to the upper tap of potentiometer winding **117**, the brush **272** is connected to the diametrically opposite lower tap of winding **117**, the intermediate, equidistant taps being grounded.

The brushes **118**, **119** are at right angles and insulated from each other and the shaft. Similarly, brushes **120**, **121** are at right angles and insulated from each other and the shaft. The two shafts are conveniently ganged together, or, the potentiometers may be superposed, with a common shaft, so that, the brushes 118, 119, 120, 121 are simultaneously manually rotated through the angle BW, clockwise from the right-hand tap.

Brush 118 is connected through resistor 122 to connection 124, and brush 120 is connected through resistor 123 to connection 124. The resistors 122, 123 reduce reactions between the circuits associated with brushes 118 and 120.

Brush 118 applies to connection 124 a voltage proportional to $+\sin AF \cos BW$; and brush 120 applies to connection 124 a voltage proportional to $-\cos AF \sin BW$. Connection 124 is connected to ground through the winding of potentiometer 125. The brush of potentiometer 125 is manually adjusted to the magnitude W of the wind. The voltage selected by the brush of potentiometer 125 will thus be proportional to $W(\sin AF \cos BW - \cos AF \sin BW)$, which, from Equation 6, is the cross-wind.

Brush 119 is connected through resistor 126, and brush 121 is connected through resistor 127 to connection 128. The resistors 126, 127 reduce reactions between the circuits connected to brushes 119 and 121.

Brush 119 applies to connection 128a voltage proportional to $-\sin AF \sin BW$; and brush 121 applies to connection 128 a voltage proportional to $-\cos AF \cos BW$. Connection 128 is connected to ground through the winding of potentiometer 129. The brush of potentiometer 129 is manually adjusted to the magnitude W of the wind, and may be ganged with the brush of potentiometer 125. The voltage selected by the brush of potentiometer 129 will thus be proportional to $W(-\sin AF \sin BW - \cos AF \cos BW)$ which, from Equation 7 is the range wind.

A source of voltage 130, with mid-point grounded, has the negative pole connected through resistor 131 to the brush of variable resistor 132; through resistor 133 to ground; and through resistor 134, connection 135 and resistor 99 to the input circuit of amplifier 96. The lower end of the winding of variable resistor 132 is grounded. The brush of variable resistor 132 is insulated from shaft 136 and is rotated by shaft 136, as explained hereinafter, proportionally to the quadrant elevation of the gun. The variable resistor 132 is in parallel with resistor 133 and the winding has a variation of resistance such that the voltage applied to connection 135 is proportional to the lateral correction for the drift of the shell.

The brush of potentiometer 125 is connected to one end of the winding of potentiometer 137, the other end being grounded. The brush of potentiometer 137 is insulated from shaft 136, is rotated by shaft 136 proportionally to the quadrant elevation of the gun, and is connected through resistor 138 with connection 135. The resistance of the winding of potentiometer 137 has a variation such that the voltage applied to connection 135 is proportional to the lateral correction for the cross-wind.

The voltage of connection 135 will thus be proportional to +SD, the sum of the deflection corrections and, as previously described, connection 135 is connected through resistor 99 to the input circuit of amplifier 96.

The output circuit of amplifier 111 is connected through resistor 139 to the input circuit of an amplifier 140, of the type shown in Fig. 7, having a feedback resistor 141. The output voltage of amplifier 140 will be proportional to $-R_f$. The output circuit of amplifier 140 is connected through resistor 142 to the input circuit of amplifier 143, of the type shown in Fig. 7, having a feedback resistor 144.

In Fig. 2, the range R_f is the distance GT_f and this range must be diminished by SR, the sum of the ballistic range corrections to give the range GT_v to the virtual target, as the quadrant elevation must be the value which will direct the shell to the virtual target.

Ballistic effects which act to increase the required range have positive polarity, while effects which act to decrease the range have negative polarity. Thus, the effect RW, Equation 7, which is shown as a headwind is of negative polarity.

The wiper of potentiometer 129 is connected through the winding of potentiometer 145 to ground. The wiper of potentiometer 145 is rotated by shaft 136, but is insulated therefrom and is connected through resistor 146 to connection 147.

If the projectile weight is greater than normal, switch 148 is set on the lower contact, connecting to the positive pole of source 130. If the weight is less than normal, switch 148 is moved to the upper contact connecting to the negative pole of source 130.

The lever of switch 148 is connected to ground through the winding of potentiometer 149 and through the winding of potentiometer 151. The brush of potentiometer 149 is connected to ground through the winding of potentiometer 150. The brushes of potentiometers 150, 151 are respectively connected to connection 147 through resistors 152, 153, are manually adjusted to the setting for the projectile weight and may be ganged together.

If the temperature of the air is higher than normal, switch 154 is set on the lower contact connecting to the negative pole of source 130; if the temperature is below normal, switch 154 is moved to the upper contact connecting to the positive pole.

The lever of switch 154 is connected to the brush of variable resistor 155 and through the winding of potentiometer 156 to ground. The brush of potentiometer 156 is connected through resistor 157 to connection 147. The brush of resistor 155 is moved by shaft 136, and the brush of potentiometer 156 is set to the value of the temperature.

If the muzzle velocity of the gun is above normal, switch 158 is set on the lower contact connecting to the positive pole of the source 130; if the muzzle velocity is below normal, switch 158 is moved to the upper contact connecting to the negative pole of the source 130.

The lever of switch 158 is connected through resistor 159 to the brush of variable resistor 160 and to the winding of potentiometer 161; and through resistor 162 to the winding of potentiometer 163. The brush of resistor 160 is moved by shaft 136. The brushes of potentiometers 161, 163 are respectively connected through resistors 164, 165 to connection 147, are set to the value of the muzzle velocity and may be ganged together.

If the density of the air is greater than normal, switch 166 is set on the upper contact connecting to the negative pole of source 130; if the density is less than normal, switch 166 is moved to the lower contact connecting to the positive pole of source 130.

The lever of switch 166 is connected to the brush of potentiometer 167 and through the winding of potentiometer 169 to ground. The winding of potentiometer 167 is shunted by a resistor 168. The brush of potentiometer 167 is moved by the shaft 136. The brush of potentiometer 169 is connected through resistor 170 to connection 147.

Similar potentiometers may be controlled by shaft 136 to supply voltages to the connection 147 varying with other ballistic range effects, such as the height of site, earth rotation, etc.

The voltage with respect to ground of connection 147 will be proportional to SR, the sum of the ballistic range effects. Connection 147 is connected through resistor 171 to the input circuit of amplifier 143.

The brush of variable resistor 172 is connected to the positive pole of source 130, through resistor 173 to ground and through resistors 174, 175 to the input circuit of amplifier 143.

The resistance of the winding of variable resistor 172 varies in such a way that the positive voltage applied to amplifier 143 varies with the functional relationship between range and quadrant elevation as given in the range tables for the particular gun and ammunition considered.

The output circuit of amplifier 143 is connected to a phase controlling network 176, of the type shown in Fig. 5. A source of two-phase power 178 is connected directly to one phase winding of the two-phase motor 177 and, through the phase controlling network 176 to the other phase winding of the motor 177.

The negative voltages applied to the input circuit of amplifier through resistors 142, 171 are balanced by the positive voltage applied through resistor 175. If there is an unbalance, the output current of amplifier 143 unbalances the phase controlling network 176, starting motor 177 which rotates shaft 136 until balance is attained. The position of shaft 136 will indicate the quadrant elevation for the gun.

The cards for the windings of potentiometers 145, 149, 167 and variable resistors 155, 160 are shaped so that, combined with their respective associated networks, these elements will apply voltages to connection 147 varying in accordance with the respective functions as given in the range tables. The differences in the forms of the various circuits are found to reduce the amount of shaping of the cards required by the various functions.

Similarly, the cards of potentiometers 73, 83, 137 and resistor 132 are shaped so that the proper voltage variations with quadrant elevation will be applied to the associated circuits.

In so far as the present invention is concerned, the above-described apparatus, under the control of observations of the target, provides voltages proportional to the rectangular coordinates of the present position of the target and the predicted changes in the coordinates during the flight of the shell; voltages proportional to the firing range and ballistic deflection corrections; and a motion proportional to the firing azimuth. The present invention is not limited to the specific apparatus described above and may be embodied in any artillery director, or other computing system, mechanical or electro-mechanical, from which these, or analogous factors, may be obtained.

First method

The output circuit of amplifier 279, Fig. 3, is connected to the lower tap of a potentiometer winding 180, and the output circuit of amplifier 182 is connected to the upper diametrically opposite tap of winding 180. The equidistant intermediate taps of winding 180 are grounded. The winding 180 has a sinusoidal variation of resistance.

The output circuit of amplifier 282, Fig. 3 is connected to the lower tap of potentiometer winding 184, and the output circuit of amplifier 186 is connected to the upper diametrically opposite tap of winding 184. The equidistant intermediate taps of winding 184 are grounded. The winding 184 has a sinusoidal variation of resistance.

The brushes 188, 189, 201 are rotated by the shaft 94, are insulated from the shaft 94 and each other, and respectively select voltages proportional to $+(X_0+\dot{X}TD)$ sin AF, $-(X_0+\dot{X}TD)$ cos AF and $-(X_0+\dot{X}TD)$ sin AF.

The brushes 190, 191, 202 are also rotated by the shaft 94, are insulated from the shaft 94 and each other and respectively select voltages proportional to $+(Y_0-\dot{Y}TD)$ cos AF, $+(Y_0-\dot{Y}TD)$ sin AF, and $-(Y_0-\dot{Y}TD)$ cos AF.

Normally, the dead time TD is zero, thus the terms $\dot{X}TD$ and $\dot{Y}TD$ are also zero.

Brush 189, Fig. 3, is connected by connection 192 through resistor 193, Fig. 4A, to the input circuit of amplifier 194, of the type shown in Fig. 7, having a feedback resistor 195. Brush 191 is similarly connected by connection 196, through resistor 197, to the input circuit of amplifier 194.

Brush 188, Fig. 3, is connected by connection 198 to the upper end of the winding of potentiometer 199, Fig. 4A. Brush 201, Fig. 3, is connected by connection 200 to the lower end of the winding of potentiometer 199. The mid-point of the winding of potentiometer 199 is grounded.

Brush 190, Fig. 3, is connected by connection 203 to the lower end of the winding of potentiometer 204, Fig. 4A. Brush 202, Fig. 3, is connected by connection 205 to the upper end of the winding of potentiometer 204. The mid-point of the winding of potentiometer 204 is grounded.

The windings of potentiometers 199 and 204 vary in resistance with a tangent function. For fairly slow targets, the deflection angle is usually less than 10 degrees, thus, the variation in the windings is not too great.

With zero angle at the mid-point of the winding and clockwise rotation for positive angles, the brush of potentiometer 199 will select a voltage approximately proportional to $-\tan AD\cdot X_0$ sin AF, and is connected through resistor 206 to the input circuit of amplifier 194.

The brush of potentiometer 204 selects a voltage approximately proportional to $-\tan AD\cdot Y_0$ cos AF and is connected through resistor 207 to the input circuit of amplifier 194.

The output circuit of amplifier 194 is connected to a phase controlling network 208, of the type shown in Fig. 5. A source of two-phase power 209 is connected directly to one phase winding of a two-phase motor 210 and, through the phase controlling network 208 to the other phase winding of motor 210. The shaft of motor 210 rotates the brushes of potentiometers 199 and 204.

The voltages supplied to the amplifier 194 are approximately equal to

$$-\tan AD\cdot X_0 \sin AF - \tan AD\cdot Y_0 \cos AF - X_0 \cos AF + Y_0 \sin AF$$

and, from Equation 1, the sum of these voltages should be zero. If the output current from amplifier **194** is not zero, power will be supplied by the source **209** to motor **210**, starting the motor **210** which rotates the brushes of potentiometers **199**, **204**, changing the value of tan AD till the sum of the voltages is reduced to zero, the output current from amplifier **194** ceases, and the brushes of potentiometers **199**, **204** have been rotated through the angle AD. The angle AD may be indicated on a dial **211** and is transmitted continuously or at intervals to the gun crew.

Second method

Connection **135**, Fig. 3, has a potential with respect to ground proportional to +SD, the sum of the ballistic deflection effects and is connected through resistor **213**, Fig. 4B, to the input circuit of an amplifier **214**, of the type shown in Fig. 7, having a feedback resistor **215**.

Brushes **188** and **190**, Fig. 3, are respectively connected by connections **198** and **203**, through resistors **219**, **216**, Fig. 4B, to the upper end of the winding of potentiometer **220**. Brushes **201**, **202**, Fig. 3, are respectively connected by connections **200** and **205** through resistors **217**, **218**, Fig. 4B, with the lower end of the winding of potentiometer **220**. The mid-point of the winding of potentiometer **220** is grounded, and the winding varies in resistance with a tangent function. The resistors **216**, **217**, **218**, **219** reduce interactions between the connected circuits.

Connection **74**, Fig. 3, which has a voltage with respect to ground proportional to DX, the predicted change in the X coordinate, is connected to the upper tap of potentiometer winding **221**, and through resistor **222** to the input circuit of an amplifier **223**, of the type shown in Fig. 7, having a feedback resistor **224**. The output circuit of amplifier **223** is connected to the lower diametrically opposite tap of potentiometer winding **221**, the intermediate, equidistant taps of winding **221** being grounded. Winding **221** has a sinusoidal variation of resistance.

Connection **84**, Fig. 3, which has a voltage with respect to ground proportional to +DY, the predicted change in the Y coordinate, is connected to the upper tap of potentiometer winding **225** and is also connected through resistor **226** to the input circuit of an amplifier **227**, of the type shown in Fig. 7, having a feedback resistor **228**. The output circuit of amplifier **227** is connected to the lower diametrically opposite tap of winding **225**, the intermediate, equidistant taps of winding **225** being grounded. Winding **225** has a sinusoidal variation of resistance.

Brushes **229**, **230**, **231** are rotated by shaft **94**, insulated from shaft **94** and each other, and respectively select voltages proportional to $-DX \cos AF$, $+DX \sin AF$ and $-DX \sin AF$.

Brushes **232**, **233**, **234** are rotated by shaft **94**, insulated from shaft **94** and each other, and respectively select voltages proportional to $-DY \cos AF$, $+DY \sin AF$ and $+DY \cos AF$.

Brush **229** is connected by connection **235** through resistor **241**, Fig. 4B, to the input circuit of amplifier **214**.

Brush **233**, Fig. 3, is connected by connection **239** through resistor **242**, Fig. 4B, to the input circuit of amplifier **214**.

The brush of potentiometer **220** is connected through resistor **243** to the input circuit of amplifier **214**.

The output circuit of amplifier **214** is connected to the phase controlling network **244**, of the type shown in Fig. 5. A source of two phase power **245** is connected directly to one phase winding of a two phase motor **246**, and, through the phase controlling network **244** to the other phase winding of motor **246**.

The brush of potentiometer **220** selects a voltage approximately proportional to

$$+\tan AD(X_o \sin AF + Y_o \cos AF)$$

thus the voltages supplied to the input circuit of amplifier **214** are

$$+SD - DX \cos AF + DY \sin AF + \tan AD(X_o \sin AF + Y_o \cos AF)$$

and, from Equation 2 the sum of these voltages should be zero. If the sum of these voltages is not zero, current will flow from the output circuit of amplifier **214** to the network **244** starting motor **246** to rotate the brush of potentiometer **220** until the sum is zero and the brush of potentiometer **220** has been rotated through the angle AD. The angle may be indicated on the dial **249** and is transmitted to the gun crew.

In class II firing, the target is tracked by a gun sight mounted on, or associated with, the gun, so as to turn in azimuth with the gun. The axis of the gun sight is inclined to the line of fire by the deflection angle. As the sight is aligned on the target at the instant the gun is fired, no correction for dead time is necessary, thus none is included in the values of DX and DY.

Third method

Connection **135** has a potential with respect to ground proportional to +SD and is connected through resistor **250**, Fig. 4C, to the input circuit of an amplifier **251**, of the type shown in Fig. 7, having a feedback resistor **252**.

Connection **235** has a potential with respect to ground proportional to $-DX \cos AF$ and is connected through resistor **253** to the input circuit of amplifier **251**.

Connection **239** has a potential with respect to ground proportional to $+DY \sin AF$ and is connected through resistor **254** to the input circuit of amplifier **251**.

The output of amplifier **111**, Fig. 3, has a potential with respect to ground proportional to $+R_f$ and is connected by connection **255** to the upper end of the winding of potentiometer **257**, Fig. 4C.

The output of amplifier **140**, Fig. 3, has a potential with respect to ground proportional to $-R_f$ and is connected by connection **256** to the lower end of the winding of potentiometer **257**, Fig. 4C.

The mid-point of the winding of potentiometer **257** is grounded and the resistance of the winding varies with a tangent function.

The brush of potentiometer **257** will select a voltage with respect to ground approximately proportional to $-R_f \tan AD$ and is connected through resistor **258** to the input circuit of amplifier **251**.

Brushes **230**, **234**, Fig. 3, are respectively connected by connections **236**, **240** through resistors **261**, **262**, Fig. 4C, to the lower end of the winding of potentiometer **263**. Brushes **231**, **232**, Fig. 3, are respectively connected by connections **237**, **238** through resistors **259**, **260**, Fig. 4C, to the upper end of the winding of potentiometer **263**. The mid-point of the winding of potentiometer **263** is grounded and the resistance of the winding varies with a tangent function.

The brush of potentiometer **263** will select a

SEARCH ROOM

voltage with respect to ground approximately proportional to

$$-\tan AD\ (DX \sin AF + DY \cos AF)$$

and is connected through resistor **264** to the input circuit of amplifier **251**.

The output circuit of amplifier **251** is connected to a phase controlling network **265**, of the type shown in Fig. 5. A source of two-phase power **266** is connected directly to one phase winding of a two-phase motor **267**, and, through the phase controlling network **265** to the other phase winding of motor **267**.

The voltages supplied to amplifier **251** are approximately proportional to

$$-R_f \tan AD - \tan AD(DX \sin AF + DY \cos AF) + SD - DX \cos AF + DY \sin AF$$

and from Equation 3 the sum of these voltages should be zero. If the sum is not zero, current will flow from the output circuit of amplifier **251** to the network **265**, starting motor **267** which rotates the brushes of potentiometers **257**, **263** till the sum of the voltages is zero. The position of the brushes of potentiometers **257**, **263** will indicate the angle AD, which may be shown by dial **268**, mounted on the shaft of motor **267**.

The resistors **216**, **217**, **218**, **219**, Fig. 4B and **259**, **260**, **261**, **262**, Fig. 4C reduce interactions between the associated circuits. While two tan AD potentiometers are shown in Figs. 4A and 4C, one potentiometer may be used, if the associated circuits are suitably combined. In general, it is difficult to combine a number of circuits through decoupling resistors to a single circuit and still keep the reactions between the circuits to a low value, particularly if the normal voltage of one circuit is much larger than the normal voltages of the other circuits.

The operations of the servo-motors **103**, **177**, Fig. 3, and **210**, Fig. 4A, **246**, Fig. 4B or **267**, Fig. 4C, may be stabilized by known means, such as connecting a capacitor, or a capacitor in series with a resistor across the feedback path of the control amplifier, for example, from the mid-points of the resistors **97**, **144**, Fig. 3, **195**, Fig. 4A, **215**, Fig. 4B, **252**, Fig. 4C, to ground.

What is claimed is:

1. In a system for indicating the deflection angle between the vertical plane containing the line from a gun to the present position of a target and the vertical plane containing the line of fire of the gun, a source of voltage, means connected to said source and controlled in accordance with observations of the position and movement of the target to fractionate the voltage from said source to produce a first voltage proportional to the rectangular coordinate of the target with respect to the gun along an arbitrary axis and a second voltage proportional to the rectangular coordinate of the target with respect to the gun normal to said axis, conversion means connected to said controlled means and energized by said voltages to produce a third voltage proportional to the rectangular coordinate of the target with respect to the gun along the line of fire and a fourth voltage proportional to the rectangular coordinate of the target with respect to the gun normal to the line of fire, a potentiometer having a winding varying in resistance with a tangent function connected to said conversion means and energized by said third voltage and a brush, a motor driving said brush, summing means connected from said conversion means and said brush to said motor to oppose said fourth voltage by the voltage selected by said brush, whereby in driving said brush to make the difference of said voltages zero the motor is rotated to said deflection angle, and an indicator driven by said motor.

2. In a system for indicating the deflection angle between the vertical plane containing the line from a gun to the present position of a target and the vertical plane containing the line of fire of the gun, a source of energy, means connected to said source and controlled in accordance with observations of the position and movement of said target to draw from said source a first quantity of energy proportional to the rectangular coordinate of said target with respect to said gun along an arbitrary axis and a second quantity of energy proportional to the rectangular coordinate of said target with respect to said gun normal to said axis, conversion means connected to said controlled means and energized by said quantities of energy to produce a third quantity of energy proportional to the rectangular coordinate of said target with respect to said gun along the line of fire, and a fourth quantity of energy proportional to the rectangular coordinate of said target with respect to said gun normal to the line of fire, means connected to said conversion means for controllably fractionating said third quantity of energy in accordance with a tangent function, summing means connected to said conversion means and said fractionating means to oppose said fourth quantity of energy by said fractionated quantity of energy, and a motor connected to said summing means and driving said fractionating means to make the difference of said fourth and said fractionated quantities of energy equal zero, whereby said motor is rotated proportionally to the deflection angle, and an indicator driven by said motor.

3. In a system for indicating the deflection angle between the line from a gun to the present position of a target and the line of fire of said gun, a first means controlled in accordance with observations of said target to generate a first voltage proportional to the x coordinate of the present position of said target with respect to said gun, a second means connected to said first means and controlled in accordance with said observations to produce second and third voltages respectively proportional to the components of said x coordinate perpendicular to and in the line of fire, a third means controlled in accordance with said observations to generate a fourth voltage proportional to the y coordinate of said present position, a fourth means connected to said second means and controlled in accordance with said observations to produce fifth and sixth voltages proportional to the components of said y coordinate perpendicular to and in the line of fire, adjustable means connected to said second and fourth means for attenuating said third and sixth voltages proportionally to a tangent function, thermionic means connected to said second, said fourth and said adjustable means to algebraically add said second, and said fifth voltages and said attenuated voltages, and a motor connected to said thermionic means and adjusting said adjustable means to make the sum of said voltages zero.

4. In a system for indicating the deflection angle between the line from a gun to the present position of a moving target and the line of fire of a shell directed to the predicted position of said target, a first means controlled in accordance with observations of said target to generate a first and a second voltage respectively proportional to

the x and y coordinates of the present position of said target with respect to said gun, a second means connected to said first means and controlled in accordance with said observations to produce third and fourth voltages respectively proportional to the components of said x and y coordinates in the line of fire, adjustable means connected to said second means to attenuate said third and fourth voltages in accordance with a tangent function, a third means controlled in accordance with said observations to generate a fifth voltage proportional to the lateral ballistic corrections for said shell, a fourth means controlled in accordance with said observations to generate sixth and seventh voltages respectively proportional to the components perpendicular to the line of fire of the predicted changes in said x and y coordinates, thermionic means connected to said adjustable means and said third and fourth means to subtract said fifth, sixth and seventh voltages from the sum of said attenuated voltages and a motor connected to said thermionic means and adjusting said adjustable means to make the difference of said voltages zero whereby the position of said adjustable means indicates said deflection angle.

5. In a system for indicating the deflection angle between the line from a gun to the present position of a moving target and the line of fire of a shell directed to the predicted position of said target, a first means controlled in accordance with observations of said target to generate first and second voltages respectively proportional to the predicted changes in the x and y coordinates of said target during the time of flight of said shell, a second means connected to said first means and controlled in accordance with said observations to produce third, and fourth voltages respectively proportional to the components of said changes perpendicular to the line of fire, and fifth and sixth voltages respectively proportional to the components of said changes in the line of fire, a source of a seventh voltage proportional to the firing range of said shell, a third means connected to said second means and said source to attenuate said fifth, sixth and seventh voltages in accordance with a tangent function, a second source of an eighth voltage proportional to the lateral ballistic corrections for said shell, thermionic means connected to said second and third means and said second source for subtracting said third, fourth and eighth voltages from said attenuated voltages and a motor connected to said thermionic means and adjusting said adjustable means to make the difference of said voltages zero whereby the position of said adjustable means indicates said deflection angle.

6. In a system for producing a movement proportional to the deflection angle between the vertical plane containing the line from a gun to the present position of a target and the vertical plane containing the line of fire of the gun, a shaft, a source of energy, computing means connected to said source and controlled in accordance with observations of the position and movement of the target to supply from said source a first quantity of energy proportional to the rectangular coordinate of said target with respect to said gun normal to an arbitrary axis, a second quantity of energy proportional to the rectangular coordinate of said target with respect to said gun along said axis, a third quantity of energy proportional to the rectangular coordinate of said target with respect to said gun normal to the line of fire of the gun, and to rotate said shaft proportionally to the azimuth angle between the vertical plane containing said axis and the vertical plane containing the line of fire, first means connected to said computing means and driven by said shaft to fractionate said first quantity of energy proportionally to the sine of said azimuth angle, and to fractionate said second quantity of energy proportionally to the cosine of said azimuth angle, second means connected to said first means for controllably fractionating the sum of said fractionated quantities of energy in accordance with a tangent function, summing means connected to said computing means and said second means to oppose said third quantity of energy to said fractionated energy, and a motor connected to said summing means and driving said second means to make the difference of said third and said fractionated quantities of energy equal zero, whereby said motor is moved proportionally to the deflection angle.

7. In a system for producing a movement proportional to the deflection angle between the vertical plane containing the line from a weapon to the present position of a target and the vertical plane containing the line of fire of the weapon, a shaft, a source of voltage, computing means connected to said source and controlled in accordance with observations of the position and movement of the target to supply from said source a first voltage proportional to the rectangular coordinate of said target with respect to said weapon normal to an arbitrary axis, a second voltage proportional to the rectangular coordinate of said target with respect to said weapon along said axis, a third voltage proportional to the rectangular coordinate of said target with respect to said weapon normal to the line of fire of the weapon, and to rotate said shaft proportionally to the azimuth angle between the vertical plane containing said axis and the vertical plane containing the line of fire, first means connected to said computing means and driven by said shaft to fractionate said first voltage proportionally to the sine of said azimuth angle, and to fractionate said second voltage proportionally to the cosine of said azimuth angle, second means connected to said first means for controllably fractionating the sum of said fractionated voltages in accordance with a tangent function, summing means connected to said computing means and said second means to oppose said third voltage to said fractionated voltage and a motor driving said second means to make the output of said summing means equal zero, whereby said motor is moved proportionally to said deflection angle.

8. In a system for producing a movement proportional to the deflection angle between the vertical plane containing the line from a gun to the present position of a target and the vertical plane containing the line of fire of the gun, a shaft, a source of energy, computing means connected to said source and controlled in accordance with observations of the position and movement of the target to supply from said source first and second quantities of energy respectively proportional to the predicted changes during the time of flight of the shell in the rectangular coordinates of the position of the target with respect to said gun normal to and along an arbitrary axis, a third quantity of energy proportional to the correction for the differential ballistic effects normal to the line of fire, and a fourth quantity of energy proportional to the rectangular coor-

SEARCH ROOM

dinate of said target with respect to the gun normal to the line of fire of the gun, and to rotate said shaft proportionally to the azimuth angle between the vertical plane containing said axis and the vertical plane containing the line of fire, first means connected to said computing means and driven by said shaft to respectively fractionate said first and second quantities of energy proportionally to the cosine and the sine of the azimuth angle, second means connected to said computing means for controllably fractionating said fourth quantity of energy in accordance with a tangent function, summing means connected to said computing means and said first and second means to oppose the sum of said third quantity of energy and said fractionated first and second quantities of energy to said fractionated fourth quantity of energy, and a motor connected to said summing means and driving said second means to make the output of said summing means zero, whereby said motor is moved proportionally to the deflection angle.

9. In a system for producing a motion proportional to the deflection angle between the vertical plane containing the line from a weapon to the present position of a target and the vertical plane containing the line of fire of the weapon, a shaft, a source of voltage, computing means connected to said source and controlled in accordance with observations of the position and movement of the target to supply from said source first and second voltages respectively proportional to the predicted changes during the time of flight of the shell in the rectangular coordinates of the position of the target with respect to the weapon normal to and along an arbitrary axis, a third voltage proportional to the correction for the differential ballistic effects normal to the line of fire, a fourth voltage proportional to the rectangular coordinate of said target with respect to the weapon normal to the line of fire, and to rotate said shaft proportionally to the azimuth angle between the vertical plane containing said axis and the vertical plane containing the line of fire, first means connected to said computing means and driven by said shaft to respectively fractionate said first and second voltages proportionally to the cosine and the sine of said azimuth angle, second means connected to said computing means for controllably fractionating said fourth voltage in accordance with a tangent function, summing means connected to said computing means and said first and second means to oppose the sum of said fractionated first and second voltages and said third voltages to said fractionated fourth voltage, and a motor connected to said summing means and driving said second means to make the output of said summing means zero, whereby said motor is moved proportionally to said deflection angle.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,408,081	Lovell et al.	Sept. 24, 1946
2,426,658	Wooldridge	Sept. 2, 1947
2,432,504	Boghosian et al.	Dec. 16, 1947

FOREIGN PATENTS

Number	Country	Date
164,765	Great Britain	June 23, 1921