Oct. 29, 1946. R. E. CROOKE 2,410,016

METHOD OF AND APPARATUS FOR GUNFIRE CONTROL

Original Filed June 10, 1932 2 Sheets-Sheet 1

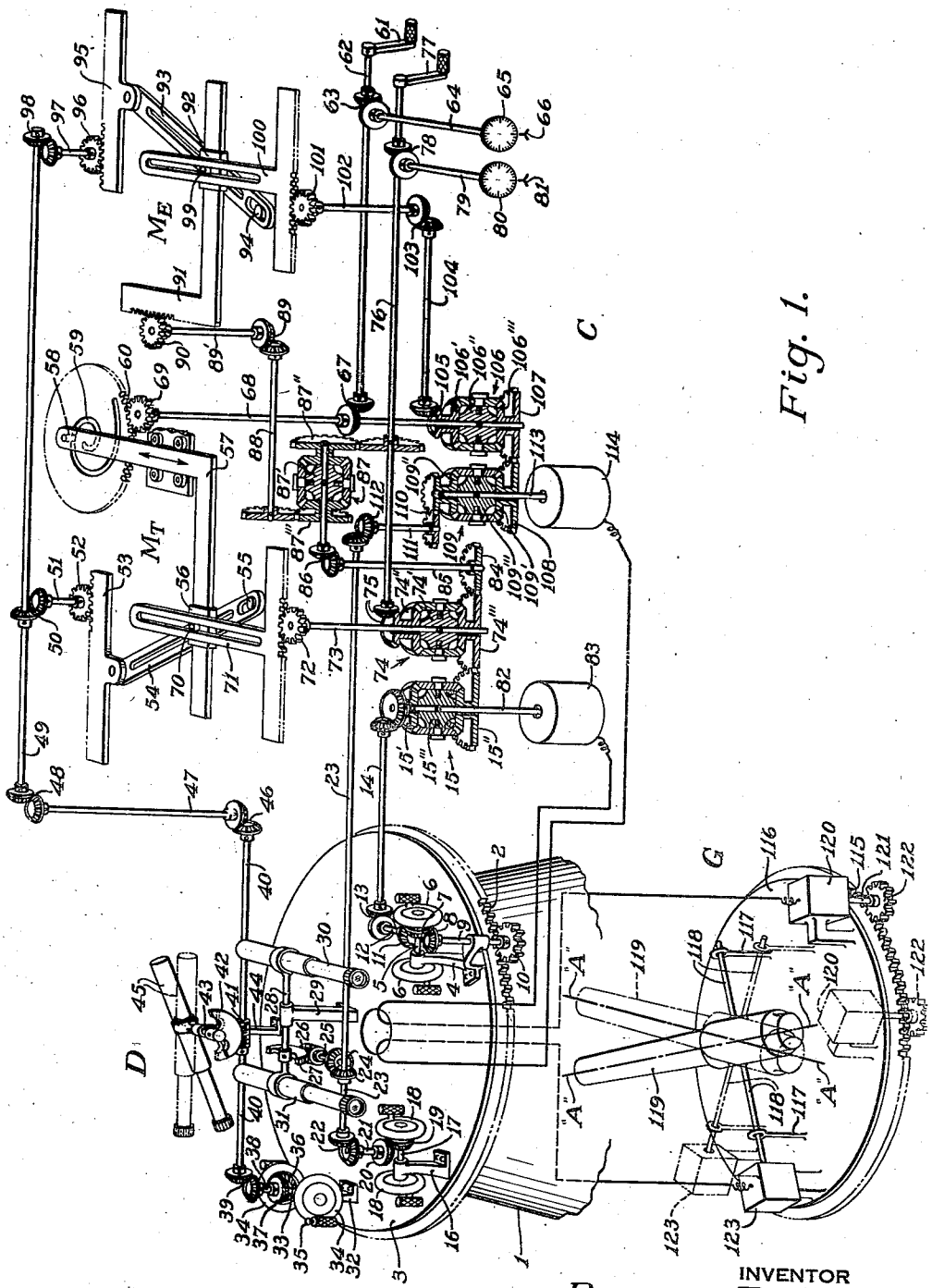


Fig. 1.

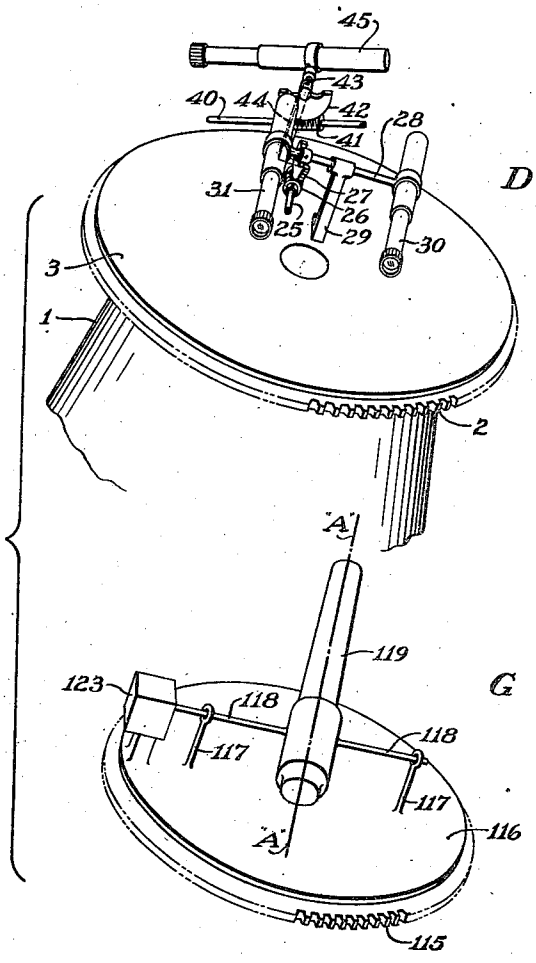
INVENTOR
RAYMOND E. CROOKE
BY
Walter J. Gill
ATTORNEY

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Fig. 2.



INVENTOR
RAYMOND E. CROOKE
BY
Walter J. Gill,
ATTORNEY

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METHOD OF AND APPARATUS FOR GUNFIRE CONTROL

Raymond E. Crooke, New York, N. Y., assignor to Ford Instrument Company, Inc., Long Island City, N. Y., a corporation of New York

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This invention relates to a method of and apparatus for compensating for errors in the aiming of ordnance mounted on angularly movable platforms, such as ships.

The angular motions of a ship referred to herein are those relative to a horizontal plane. They may be divided into two components hereinafter referred to as level and cross-level. Level, designated L, is the inclination of the deck to the horizontal in the vertical plane of the line of sight. Cross-level, designated Z, is the inclination of the deck to the horizontal in a vertical plane 90° to the plane of the line of sight.

As far as compensation for changes in the level angle is concerned, it merely requires changes in elevation of the gun relative to the deck of the ship to maintain it at its proper elevation with respect to the horizontal, corresponding to the range of the target, if the gun is to be kept constantly in position to be fired at appropriate times, in other words, if the method of firing known as continuous aim is to be employed.

As far as compensation for changes in cross-level angle is concerned, a more serious problem arises for such movement causes a proportional tilt of the trunnions of the gun relative to the horizontal. This tilt, in connection with the elevation of the gun, causes a displacement of the bore axis of the gun from the position it should occupy when the gun is properly aimed. This displacement has a component in train and another one in elevation, the former being relatively large compared to the latter. Since the component in train depends upon the tangent of the angle of gun elevation, the error in train increases rapidly as the elevation of the gun is increased for long ranges.

In systems heretofore employed for applying cross-levelling corrections to guns, the required corrections in train and elevation are continuously determined and applied to the gun, with the result that the gun must be constantly shifted in train and elevation in accordance with the changes in the cross-level angle of the ship. In the case of large caliber guns which are normally fired at relatively high elevation angles, the introduction of the necessary correctional component in train of the guns to compensate for trunnion tilt errors involves considerable difficulty on account of the magnitude of such component; for, as explained above, this component depends upon the tangent of the angle of elevation of the gun. The difficulty of rapidly moving so massive a body through large amplitudes is obvious.

It is an object of this invention to provide a

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method of compensating for the errors caused by the trunnion tilt of a gun, which avoids the above mentioned difficulties. An important advantage of the invention is the fact that it dispenses with the adjustment of the gun in train through the large amplitudes inherent in the requirements of the long range guns.

In brief, the method consists in firing only on a selected point in the cross-level and disregarding trunnion tilt errors for all other cross-level conditions, thereby avoiding the continuous adjustment of the train angle of the gun which would be necessitated if the gun were to be kept continuously in the proper vertical plane. This is accomplished by determining the corrections for the selected value of the cross-level of the gun, setting the gun with respect to the ship in accordance with the determined corrections and firing the gun when the movement of the ship in cross-level brings the bore axis of the gun into a vertical plane bearing a predetermined relation to the target at which the gun is aimed, this predetermined relation taking care of the other correctional factors such as time of flight and drift of the projectile, the effect of wind and the like.

It will be understood that in order for the gun to be properly aimed when it is brought into the specified vertical plane, its elevation with respect to the deck of the ship must be continuously changed in accordance with changes in the level angle. In general, the problem of accurately and rapidly changing the elevation of a gun is a less serious one than moving it in train, and hence the fact that this invention requires that the elevation of the gun be continuously changed to compensate for changes in level angle is relatively of little consequence.

The invention also comprehends a suitable apparatus for carrying out the method as above explained, and one form of such apparatus is herein illustrated and will be hereinafter described. The particular nature of the invention, as well as other objects and advantages thereof, will appear most clearly from the description of the particular apparatus illustrated in the drawings in which

Fig. 1 is a simplified diagram of one form of the appratus in which the invention may be embodied;

Fig. 2 is a corresponding diagram of certain elements of Fig. 1 in the positions they occupy at a subsequent stage of operation.

In Fig. 1, D indicates in general a director having associated therewith a computer C for deter-

mining the correctional factors to be applied to a gun G controlled by the director.

Preliminary to describing the apparatus in detail, it will be explained that the computer is intended to solve the following equations, which in practice give sufficiently accurate results for the purpose for which the invention is intended to be used:

$$(1) \quad D_Z = K_1 Z_S \tan U_S$$

$$(2) \quad D_D = D_Z + D_S$$

$$(3) \quad U_D = K_2 Z_S (2D_S + D_Z)$$

In these equations

Z_S represents the selected value of cross-level angle Z at which the gun is to be fired;

D_Z represents the correction in train due to the selected cross-level;

D_S represents the horizontal angle between the vertical plane of the line of sight and the vertical plane in which the gun is to be fired, which angle is due to relative motion between the ship and the target during the time of flight of the projectile, drift, wind ballistics and the like;

U_S represents the elevation of the gun in a vertical plane from a horizontal plane as a plane of reference;

U_D represents the correction in elevation due to the selected cross level at which the gun is to be fired;

K_1 and K_2 are constants due to trigonometric approximations used in the equations.

Referring now to Fig. 1, the director D includes a pedestal 1 fixed to the ship and provided with an annular rack 2 within which a table 3 is rotatably mounted upon the pedestal. The table is provided with a standard 4 carrying a shaft 5 provided with handwheels 6 to be used by the trainer of the director. Attached to the shaft 5 is a bevel gear 7 engaging a bevel gear 8 on the end of a shaft 9 supported in the standard 4 and carrying at its lower end a pinion 10 engaging with the rack 2. A bevel gear 11 likewise engages the bevel gear 7 and is attached to a shaft 12 which, by means of a pair of bevel gears 13, drives a shaft 14 which is connected to the side 15' of a differential 15, the other elements of which will be hereinafter described.

Another standard 16 is also attached to the table 3 and carries a shaft 17 provided with a pair of handwheels 18 to be used by the pointer. The shaft 17 carries a bevel gear 19 meshing with a bevel gear 20 on the lower end of a shaft 21. The upper end of the shaft is connected by a pair of bevel gears 22 to a shaft 23 which, by means of a pair of bevel gears 24, is connected to a shaft 25 provided with a worm 26 engaging a gear sector 27 on a shaft 28 mounted in a standard 29 attached to the table 3. The shaft 28 carries at one end a trainer's telescope 30 and at the other end a pointer's telescope 31.

A standard 32 is attached to the table 3 and carries a shaft 33 to which is attached a pair of handwheels 34 for use by the operator commonly known as the cross-leveller. One of the handwheels is provided with a firing key 35 to be used by this operator. The shaft 33 also carries a bevel gear 36 engaging a bevel gear 37 on the end of a shaft 38 which is connected by a pair of bevel gears 39 to a shaft 40. This shaft is provided with a worm 41 engaging a gear sector 42 on a shaft 43 mounted at the upper end of a standard 44 attached to the table 3. The other end of shaft 43 carries a cross-leveller's telescope 45 disposed at right angles to the director's and pointer's telescopes 30 and 31 respectively.

This telescope is intended to be set by the cross-leveller in accordance with the selected value of cross-level Z_S, at which the gun is to be fired. It is shown in dot and dash lines in a horizontal position and in full lines in the position it occupies when set for the selected value of cross-level.

The shaft 40 extends beyond the worm 41 into the computer of the instrument. Bevel gears 46 connect this shaft to a shaft 47 connected by a pair of bevel gears 48 to a shaft 49. By means of a pair of bevel gears 50, shaft 51 and a pinion 52, movement in accordance with the quantity $K_1 Z_S$ is imparted to the slide 53 of a multiplying device, designated M_T, for computing the cross-level correction in train under various conditions of operation. The constant K_1 is introduced by a suitable gear ratio. A link 54 provided with a pair of slots is pivoted to the slide 53. The shorter slot receives a fixed pin 55 and the longer slot receives a pin (not shown) on the lower side of a carriage 56 slidably mounted on one arm of a rectangular slide 57. The other arm of this slide carries a pin 58 entering a spiral groove 59 on a gear 60 adapted to be rotated in accordance with the factor U_S as will now be described.

The groove is arranged to cause radial movements of the pin 58 in accordance with the factor $\tan U_S$. A crank 61 on the end of a shaft 62 is adapted to be set in accordance with the values of U_S received from any suitable source. By means of a pair of bevel gears 63 the movement of shaft 62 is imparted to a shaft 64 carrying a dial 65 reading against an index 66 for showing the values of U_S applied to the computer. The shaft 62 is connected by a pair of bevel gears 67 to a shaft 68 carrying at one end a pinion 69 meshing with the gear 60.

Carriage 56 of the multiplying device M_T carries a pin 70 passing through a slot in the end of a slide 71 which, therefore, receives a movement proportional to $K_1 Z_S \tan U_S$. The slide 71 is provided with a rack which engages a pinion 72 on a shaft 73 connected to the center 74' of a differential 74, the center thus receiving a movement proportional to $K_1 Z_S \tan U_S$ or D_Z.

One side 74'' of the differential is connected by means of a pair of bevel gears 75 to a shaft 76 provided with a crank 77 by which deflection, D_S, may be applied to the computer. By means of a pair of bevel gears 78 and shaft 79, the deflection thus applied is indicated by a dial 80 reading against an index 81.

Since, as above explained, the center 74' of differential 74, receives a movement proportional to $K_1 Z_S \tan U_S$ or D_Z and the side 74'' receives a movement proportional to D_S the side 74''' will receive a movement proportional to the sum of these factors, i. e. $D_Z + D_S$, or D_D.

The side 74''' of the differential is connected to the side 15'' of differential 15. Since the side 15' of this differential is connected to shaft 14 which is movable in accordance with director train, the center 15''' is movable in accordance with the sum of the director train and D_D. A shaft 82 is attached to the center 15''' and actuates the rotatable element of a gun train transmitter 83 in accordance with the movement of the center of the differential.

Side 74''' of differential 74 engages a gear 84 on the end of a shaft 85 which, through a pair of bevel gears 86, is connected to the center 87' of a differential 87. The side 87'' of the dif-

ferential is driven through gears from the shaft 76 which represents the D_S input. The other side 87''' of the differential is connected by gears to a shaft 88 which through a pair of bevel gears 89 drives a shaft 89' having a pinion 90 engaging a rectangular slide 91 of a multiplying device M_E for computing the required cross-levelling correction in elevation, i. e. U_D.

Since the center 87' of differential 87 receives a movement from the side 74''' of differential 74 proportional to D_S+D_Z and the side 87'' receives a movement proportional to D_S from the shaft 76 the other side 87''' will receive a movement proportional to $2D_S+D_Z$ of Equation 3, which will be imparted to slide 91.

The other arm of slide 91 carries a slidable carriage 92 provided with a pin (not shown) extending into one slot of a link 93, the other slot of this link being connected to a fixed pin 94. The other end of link 93 is pivotally connected to a slide 95 provided with a rack engaging a pinion 96 on the end of a shaft 97 connected by a pair of bevel gears 98 to the end of shaft 49. The slide 95, therefore, receives a movement proportional to K_2Z_S, the constant being introduced by a suitable gear ratio.

The carriage 92 carries a second pin 99 entering a slotted arm of a slide 100, the other arm of which is provided with a rack engaging a pinion 101 which receives a movement proportional to K_2Z_S $(2D_S+D_Z)$ which, according to Equation 3, is the required cross-levelling correction in elevation due to the selected value of cross-level Z_S.

The pinion 101 is attached to one end of a shaft 102 which, through a pair of bevel gears 103, shaft 104 and bevel gears 105, drives the side 106' of a differential 106, the center 106'' of which is connected to the other end of shaft 68, which, as previously explained, is actuated in accordance with the quantity U_S which is the elevation of the gun for the particular range of the target. The other side 106''' is, therefore, movable in accordance with the sum of the quantities U_S and U_D. It carries a gear 107, which engages with a gear 108, connected to one side 109' of a differential 109. The other side 109'' of the differential is connected through a pair of gears 110, shaft 111 and a pair of bevel gears 112 to the shaft 23 which is rotated in accordance with changes in the level angle L when the pointer's telescope 31 is maintained on the target in elevation as it is in the operation of the system. This means that the side 109'' of differential 109 receives a movement proportional to the level angle L and since the side 109' receives a movement proportional to U_S+U_D the center 109''' is moved in accordance with the sum of these quantities. The shaft 113 connected to the center 109''' of the differential actuates the rotatable element of a gun elevation transmitter 114.

The gun indicated generally by G is shown in simplified form. It consists of a fixed rack 115 forming part of the gun mount and within which is a rotatable turn table 116 provided with standards 117 bearing the trunnions 118 of the gun itself 119.

The gun train transmitter 83 is electrically connected to one element of a gun train receiver 120 of any suitable construction and which is not shown in detail since it forms no part of the present invention. As is customary in devices of this character, the other element of the receiver is connected by a shaft 121 and pinion 122 to the rack 115, the arrangement being such that when the gun is properly trained in accordance with the value transmitted by gun train transmitter 83, a suitable indication to that effect will be given by the receiver in a well known manner.

A similar type of gun elevation receiver 123 is employed, one element being electrically connected to the gun elevation transmitter 114 and the other element to a trunnion of the gun so that when the gun is properly elevated in accordance with the value transmitted from the gun elevation transmitter this fact will be indicated by the receiver.

In Fig. 1 the gun is shown in dot and dash lines in the position it occupies when the platform is horizontal and the gun is aimed at the target, assuming no deflection for the purpose of simplicity. This position corresponds to the dot and dash line position of telescope 45. The gun train and gun elevation receivers are shown in their corresponding positions. Under these circumstances the bore axis of the gun, indicated by the line A—A, lies substantially in the vertical plane of the line of sight, neglecting any corrections for parallax due to differences in the positions on the ship of the director and the gun.

In Fig. 1 the full line positions of the gun and its train and elevation receivers, represent the conditions of these elements when the correctional factors corresponding to those required for the particular value of cross-level at which it is desired to fire the gun, have been computed and applied to the gun in the following manner:

In the operation of the apparatus the trainer by manipulation of his handwheel 6 connected to the pinion 10, keeps his telescope 30 on the target and thereby transmits director train through shaft 14 to the side 15' of differential 15.

As explained above, the system is operated in accordance with continuous aim, which means that the pointer likewise keeps his telescope 31 on the target, in spite of changes in level angle, L, by manipulation of his handwheels 18, and the connections therefrom to the shaft 28 which carries the telescope. This movement is also imparted by shaft 23 to the side 109'' of the differential 109.

As far as the cross-leveller is concerned, he sets his telescope 45 at the selected value Z_S of the cross-level at which it is desired to fire the gun. The position of the telescope under this condition is shown in full line. This operation through the connections leading from shaft 49, positions the slides 53 and 95 of the multipliers M_T and M_E respectively, in accordance with the selected cross-level to introduce this factor for computing the required cross-levelling corrections in train and elevation.

A fourth operator sets in, by means of crank 61, the values of gun elevation, U_S, thereby adjusting the gear 60 with its tangent cam groove. This action correspondingly adjusts the center 106'' of the differential 106.

Under the assumed conditions of no deflection, the crank 77 remains at its normal position so that the side 74'' of the differential 74 may be regarded as fixed. As previously described, the multiplying device M_T generates the value of D_Z for the selected value of cross-level at which the gun is to be fired. This factor is combined with deflection, when the latter is present, in the differential 74. The center 74' of the differential is actuated in accordance with D_Z. The side 74''' transmits this quantity to the side 15'' of dif-

ferential 15, where it is combined with director train as imparted to the side 15' of the differential by the shaft 14. The center of this differential, therefore, actuates the gun train transmitter with the result that when the gun is correspondingly trained it assumes the position shown in full lines.

As previously described, the multiplying device M_E computes the cross-levelling correction in elevation, U_D, corresponding to the selected value of the cross-level. The result of this computation is transmitted from the pinion 101 to the side 106' of differential 106 where it is combined with the gun elevation represented by U_S, so that the side 106''' of the differential transmits the sum of these quantities to the side 109' of differential 109. Side 109'' receives, as previously explained, a movement equal to the level angle L, so that the required gun elevation is transmitted to the gun to correspondingly position it in elevation as likewise shown by its full line position.

It will be apparent, from the above description and assuming that the ship is on even keel so far as cross-level is concerned, that the gun will be displaced both in train and elevation to a position where it will not be aimed at the target, in spite of the fact that the pointer and the trainer are sighting on the target. As angular movement of the ship in cross-level takes place, the cross-leveller notes the passage of the cross wires of his telescope 45 across the horizon, which means that at this instant the angular position of the ship corresponds to the selected value of cross-level at which the gun is to be fired. This angular movement of the ship will turn the gun mount through a corresponding angle, so that, as shown most clearly in Fig. 2, the bore axis A—A of the gun is now in the vertical plane of the line of sight and in proper position to be fired by the cross-leveller actuating his firing key.

While a preferred embodiment of the invention has been shown and described, it will be understood that the invention may be embodied in other forms and various changes may be made in structural details without departing from its principle as defined in the appended claims.

I claim:

1. The method of correcting for the effect of trunnion tilt of a gun mounted on an angularly movable platform which consists in determining the correction for the gun for a selected value of cross-level other than zero, setting the gun with respect to the platform in accordance with the determined correction and firing the gun when the movement of the platform brings the gun into a vertical plane bearing a predetermined relation to the target at which the gun is aimed.

2. The method of correcting for the effect of trunnion tilt of a gun mounted on an angularly movable platform which consists in determining the correction for the gun for a selected value of cross-level other than zero, setting the gun with respect to the platform in accordance with the determined correction and firing the gun when the platform partakes of a cross-level equal to that for which the correction was determined.

3. The method of correcting for the effect of trunnion tilt of a gun mounted on an angularly movable platform which consists in determining the correction in train for the gun for a selected value of cross-level other than zero, setting the gun in train with respect to the platform in accordance with the determined correction and

firing the gun when the movement of the platform brings the gun into a vertical plane bearing a predetermined relation to the target at which the gun is aimed.

4. The method of correcting for the effect of trunnion tilt of a gun mounted on an angularly movable platform which consists in determining the correction in train for the gun for a selected value of cross-level other than zero, setting the gun in train with respect to the platform in accordance with the determined correction and firing the gun when the platform partakes of a cross-level equal to that for which the correction was determined.

5. The method of aiming and firing a gun mounted on an angularly movable platform which consists in maintaining a line of sight from the platform to a target, maintaining the gun in a predetermined relation to said line of sight throughout relative movement between the target and the platform in a vertical plane containing the line of sight, establishing a second line of sight bearing a predetermined vertical angular relation to a horizontal plane and lying in a vertical plane bearing a predetermined angular relation to the first named vertical plane, generating the corrections necessary to compensate for errors in the aim of the gun due to the tilt of the trunnions of the gun resulting from angular movement of the platform measured in the second mentioned vertical plane equal to said predetermined vertical angular relation of the second line of sight, positioning the gun relatively to the platform in accordance with said generated corrections and firing the gun when the second line of sight is brought horizontal by said angular movement of the platform.

6. The method of aiming and firing a gun mounted on an angularly movable platform which consists in establishing a line of sight from the platform to the target in a vertical plane through the target, establishing a second line of sight bearing a predetermined vertical angular relation to a horizontal plane and lying in a vertical plane bearing a predetermined angular relation to the first named vertical plane, generating the corrections for the tilt of the trunnions of the gun which corrections correspond to those required for angular movement of the platform measured in the second named vertical plane equal to said predetermined vertical angular relation of the second line of sight, positioning the gun relatively to the platform in accordance with said generated corrections and firing the gun when the second line of sight is brought horizontal by said angular movement of the platform.

7. The method of aiming and firing a gun mounted on an angularly movable platform, which consists in compensating for the effect upon the gun of angular movement of the platform in the vertical plane of the line of sight to the target, determining the corrections in the aim of the gun resulting from trunnion tilt of the gun caused by selected angular movement of the platform in a vertical plane substantially perpendicular to the first named plane, adjusting the gun with respect to the platform in accordance with the determined trunnion tilt corrections and firing the gun when the platform partakes of an angular movement in the second named vertical plane equal to that for which the correction was determined.

RAYMOND E. CROOKE.