

Oct. 22, 1946.

F. E. VALENTINE ET AL

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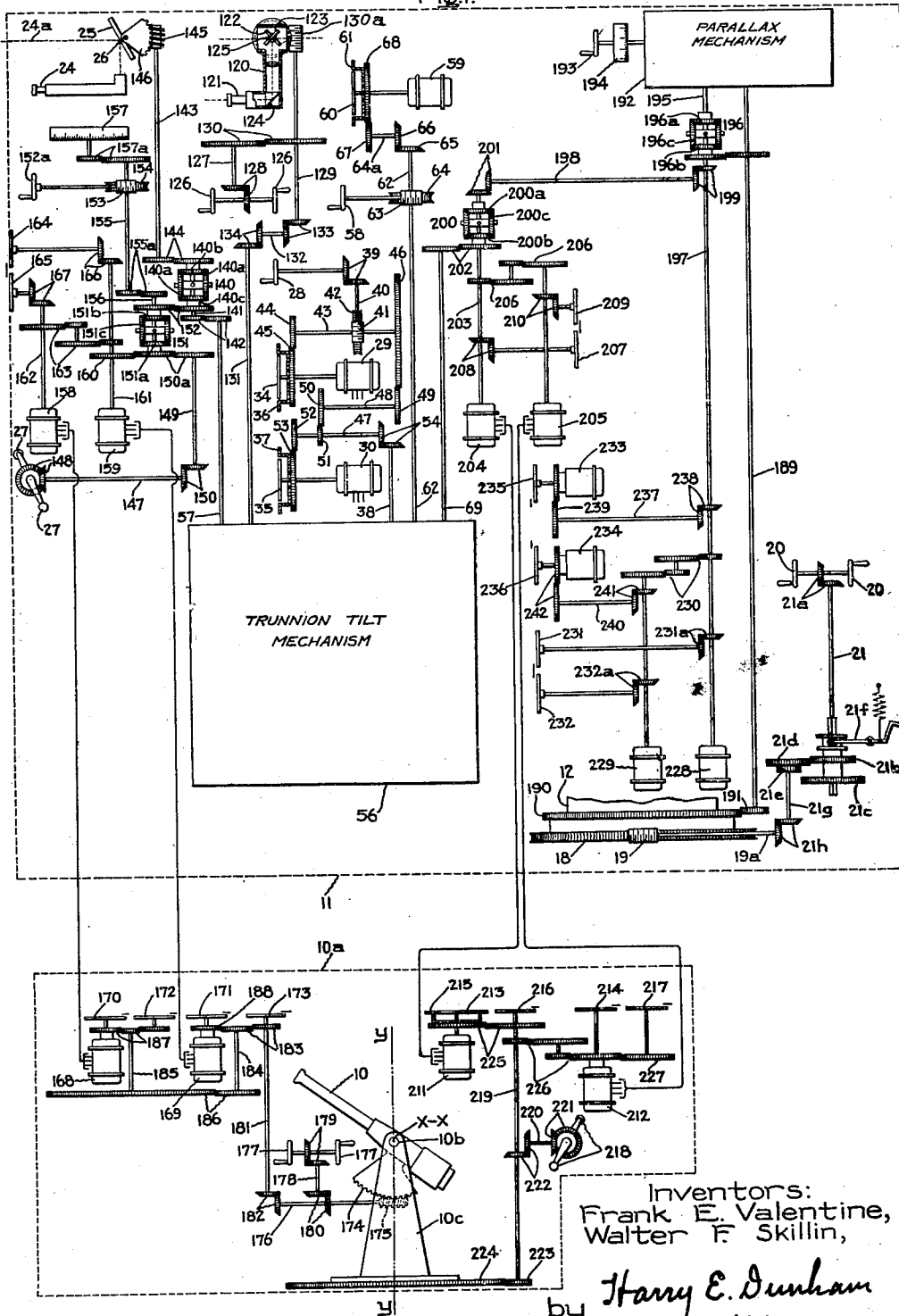
SYSTEM AND APPARATUS FOR GUNFIRE CONTROL

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Fig. 1.



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Sight operates gun movement
with gun gun

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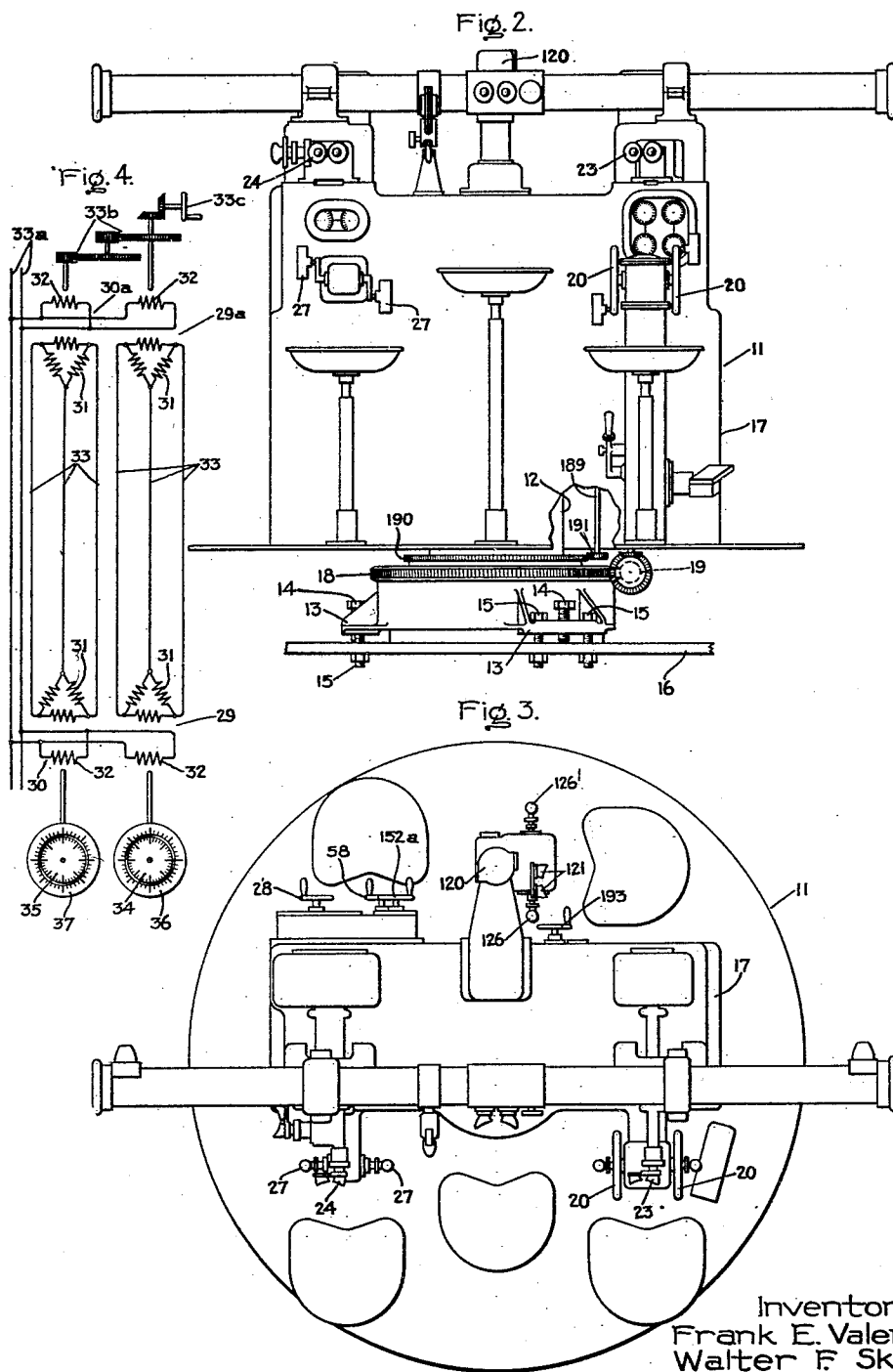
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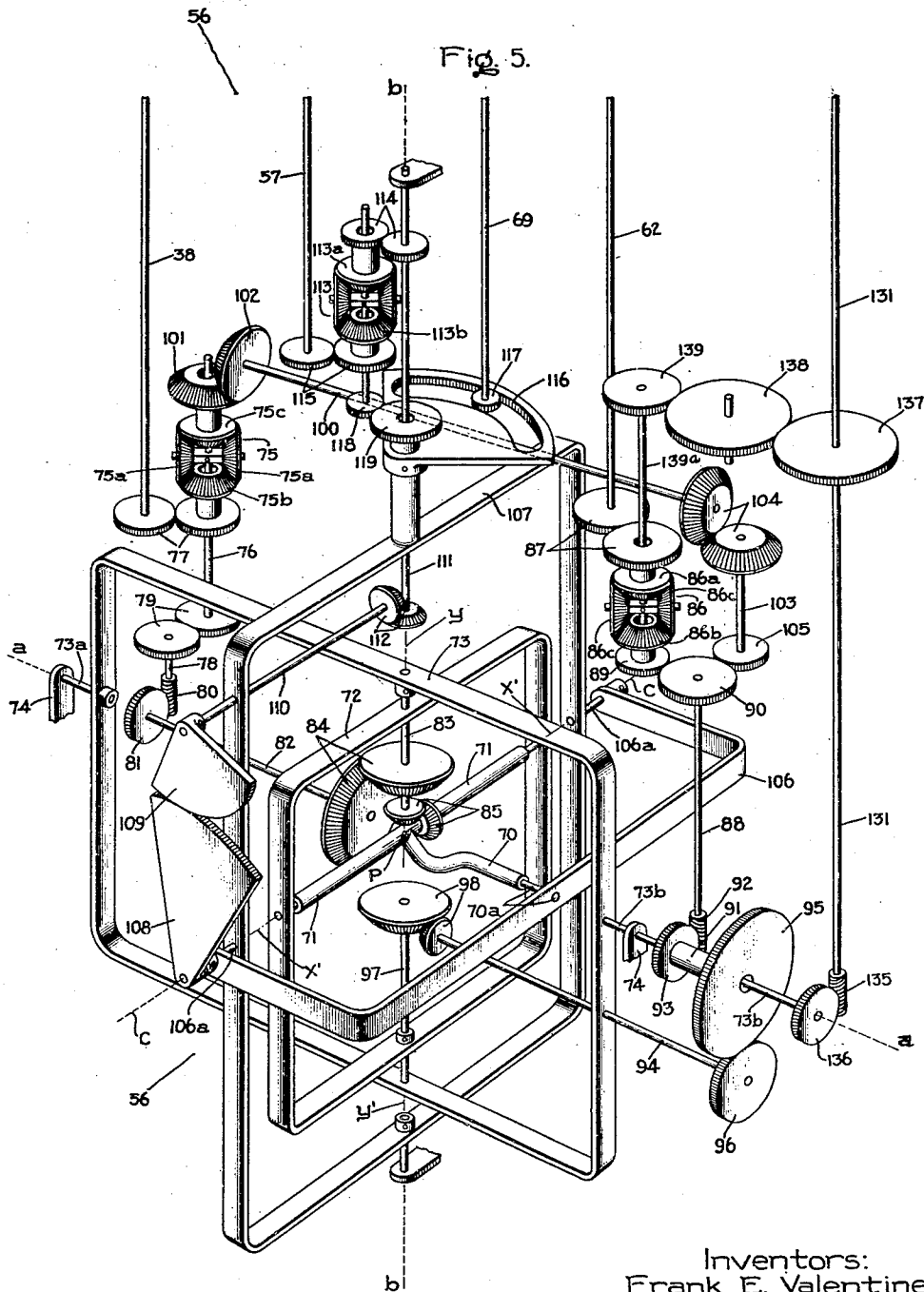
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SYSTEM AND APPARATUS FOR GUNFIRE CONTROL

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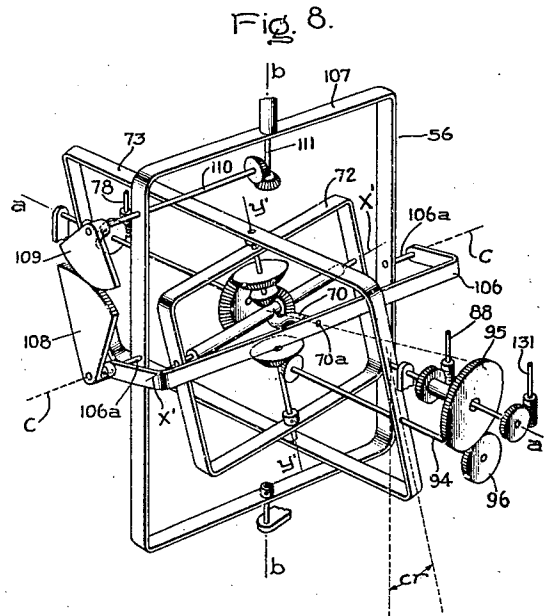
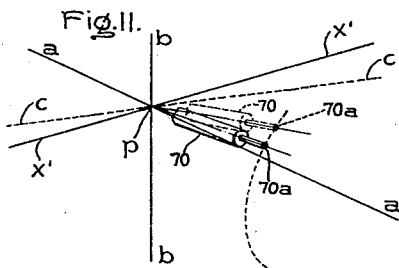
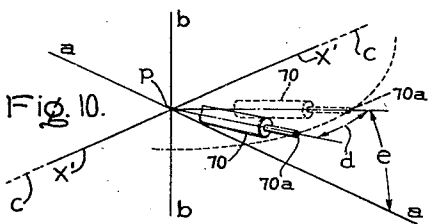
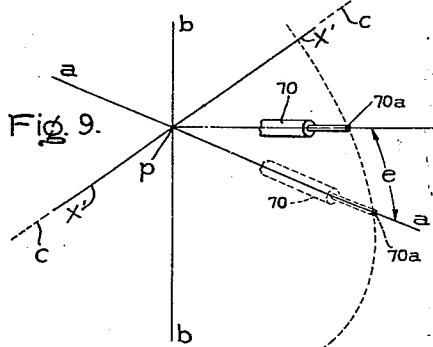
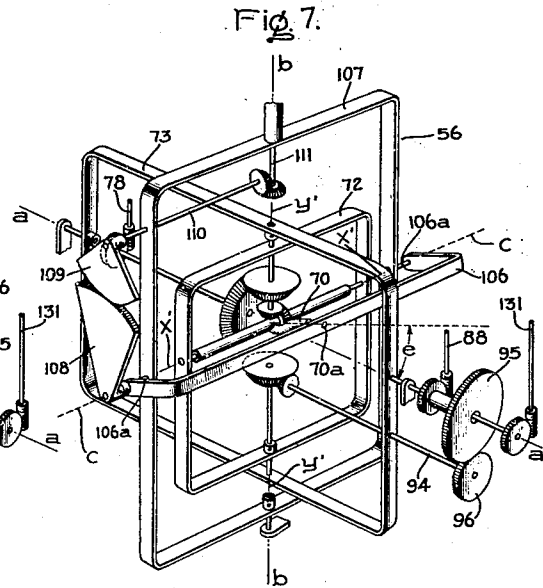
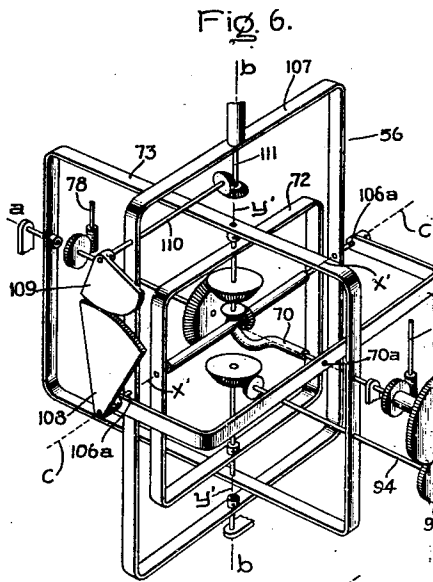
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SYSTEM AND APPARATUS FOR GUNFIRE CONTROL

Filed March 20, 1935

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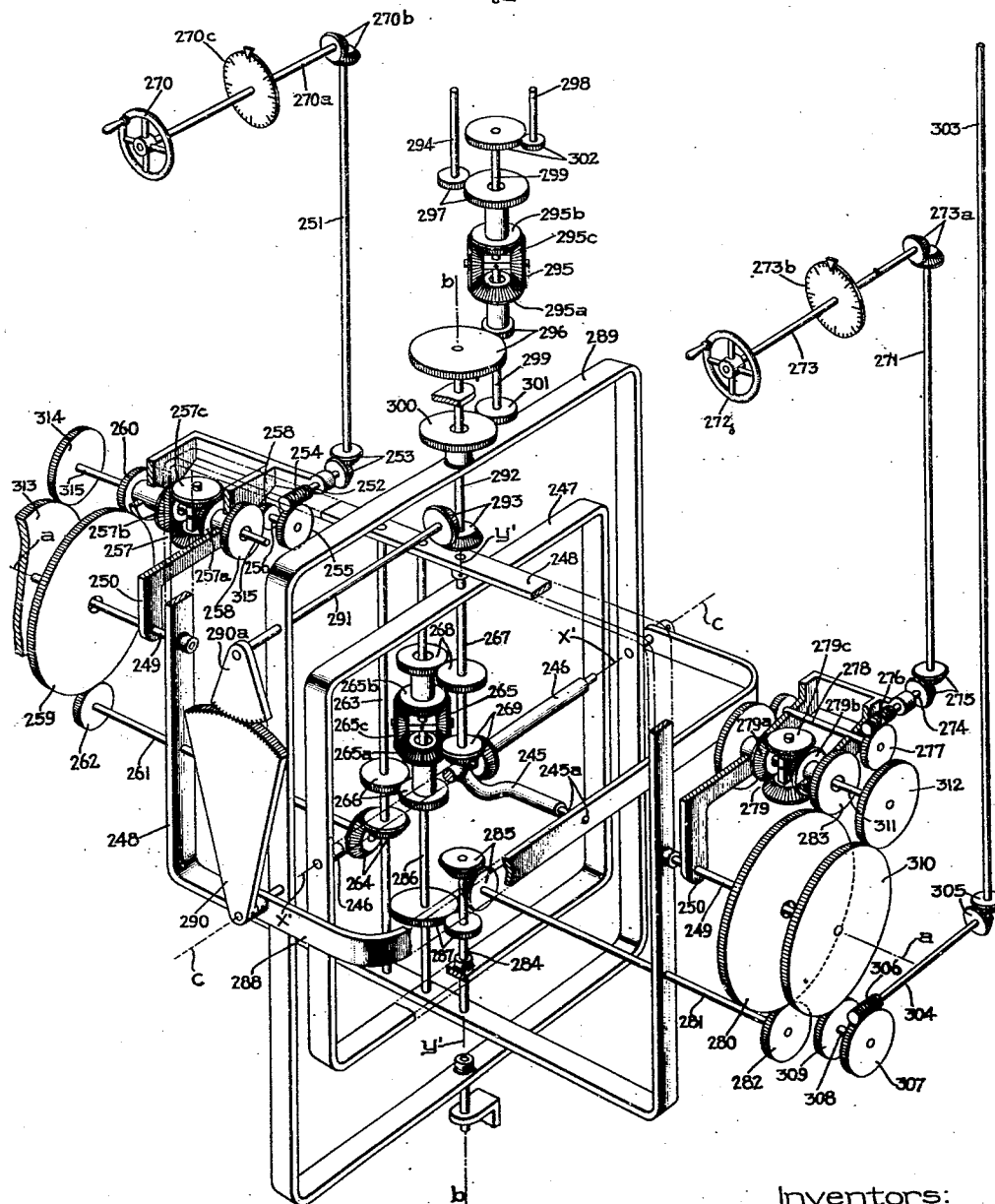
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Fig. 12.



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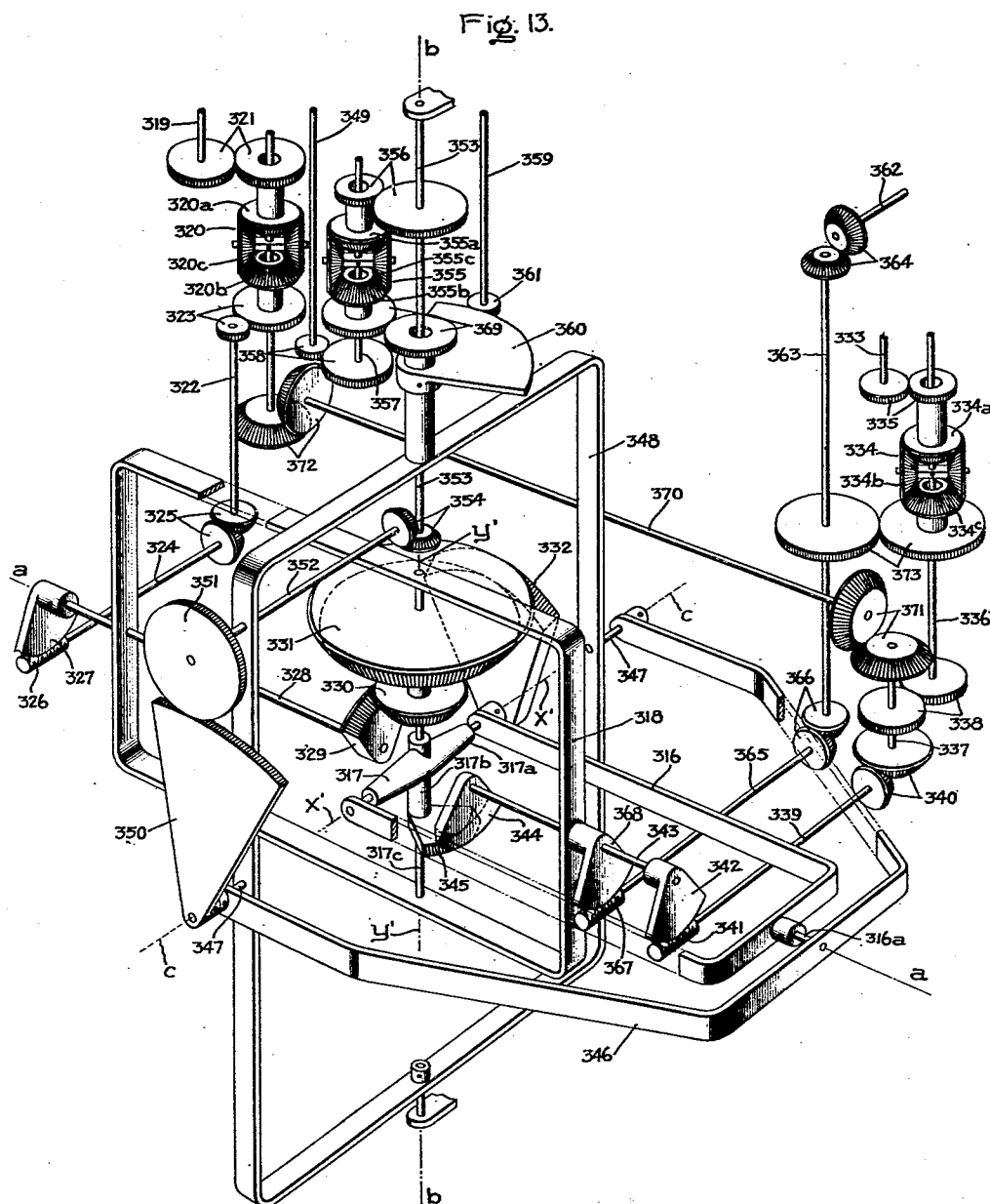
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SYSTEM AND APPARATUS FOR GUNFIRE CONTROL

Filed March 20, 1935

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Patented Oct. 22, 1946

2,409,914

UNITED STATES PATENT OFFICE

2,409,914

SYSTEM AND APPARATUS FOR GUNFIRE CONTROL

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Application March 20, 1935, Serial No. 12,006

17 Claims. (Cl. 33—49)

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This invention relates to the control of guns and the like, more particularly to the control of guns mounted on swaying foundations, such as on a rolling ship, and it has for its object the provision of an improved system and apparatus for directing guns whereby corrections are applied to the guns compensating for the inclination of the trunnions of the guns due to the roll of the ship, or other foundation on which the guns are mounted.

In the directing of guns, the calculated adjustments of range to be applied to the gun in elevation and of deflection to be applied to the gun in train are based on the assumption that the adjustments will be applied to the gun in true vertical and horizontal planes; that is, it is assumed that the trunnions of the gun about which the gun is elevated lie in a true horizontal plane, and that they are mounted so that the gun is adjusted in train on a true vertical axis. The gun, however, is mounted with its trunnions parallel with the deck of the ship on which it is carried, and thus, it is adjustable in elevation in a plane which is perpendicular to the deck and in train in a plane which is parallel to the deck. Therefore, it is only when the ship is on even keel that the gun is adjusted on train and elevation axes which are truly vertical and horizontal. Consequently, it is only when the ship is on even keel that the calculated corrections for range and deflection are properly applied to the gun.

This invention contemplates the provision of an improved system and apparatus whereby the roll or inclination of the ship or other support on which the gun is mounted about the line of sight of a target is continuously calculated and introduced as a correction so that the calculated elevation and train adjustments, based on the assumption that the gun is to be adjusted in true vertical and horizontal planes, are continuously modified in accordance with the inclination of the ship so as to direct the adjustment of the gun to cause it to assume continuously the position in space that it would occupy when adjusted with reference to the true vertical and horizontal.

In accordance with this invention, suitable gun directing apparatus is provided comprising means for generating the range and deflection corrections, calculated on the assumption that they will be applied to the gun with the ship on even keel, together with means for regenerating these values continuously in accordance with the inclination of the ship's deck when the ship rolls about the line of sight, as corrections which can be applied directly to the gun in elevation and train to cause it to assume the proper position in space with reference to the true vertical and horizontal.

More specifically, the gun directing apparatus in accordance with this invention comprises a mimic gun which is mounted in a gimbal system

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for movement about train and elevation axes corresponding to the train and elevation axes of the main gun perpendicular to and parallel with the deck of the ship. The gimbal system further provides for inclination of these axes with reference to the true vertical and horizontal in accordance with the inclination of the deck so as to cause the mimic gun to move in space with reference to the true vertical and horizontal to assume the position that the main gun would assume if permitted to move with the ship—uncompensated for its roll—to thereby generate the corrections that should be applied to the calculated values of range and deflection to be applied to the main gun to hold it in its correct position in space.

For a more complete understanding of this invention, reference should be had to the accompanying drawings, in which Fig. 1 is a diagrammatic representation of a system and apparatus for controlling guns and the like arranged in accordance with this invention; Fig. 2 is an elevation of a sighting device or director used in the system of Fig. 1 and arranged in accordance with this invention; Fig. 3 is a plan view of the director shown in Fig. 2; Fig. 4 is a diagrammatic view showing a certain means for transmitting motion used in the system of Fig. 1; Fig. 5 is an enlarged perspective view illustrating a portion of the mechanism used in the director of Figs. 3 and 4; Figs. 6, 7, 8, 9, 10, and 11 are diagrammatic views illustrating the principle of operation of the mechanism shown in Fig. 5; Fig. 12 is a perspective view illustrating a modified form of the mechanism shown in Fig. 5; and Fig. 13 is a perspective view of a further modified form of the mechanism shown in Fig. 5.

As pointed out previously, in directing guns on a target, the range correction, which will be called "sight angle" hereinafter, is a function of the range of the target, as calculated, and is an angular adjustment to be applied to the gun in a vertical plane. That is, for a given definite range, the gun must be adjusted to a definite "sight angle" in a vertical plane. The deflection correction, which will be called "sight deflection," is calculated from the velocity and direction of the wind, drift, speed, direction of ship and target, etc., as calculated, and is an angular adjustment to be applied to the gun in a horizontal plane. A gun on shipboard is mounted to be adjusted in elevation on its trunnions in a plane that is perpendicular to the deck, and in a train plane which is at right angles to the elevation plane. It is clear, therefore, that when the ship is rolling so that the gun support inclines from the horizontal, the gun is not elevated and trained in true vertical and horizontal planes respectively, but in planes at angles to these planes, the magni-

tude of the angles depending on the inclination of the ship.

It is a function of this system and apparatus to compensate for the inclination of the trunnions of the gun 10.

It is to be understood that it is assumed in this application that when the ship is on even keel its deck will be truly horizontal. In practice it may be that the deck is not in a true horizontal plane when the ship is on even keel; in such cases, a reference plane must be established. It is intended for the sake of simplicity to use the term "deck" to denote the reference plane, whether it be the actual ship's deck or the established plane. Thus, if the deck is truly horizontal when the ship is on even keel, then the term "deck" denotes the actual deck of the ship; if not, the word "deck" denotes the calculated reference plane.

Referring to the drawings, this invention has been shown as applied to the control of guns on war-ships. It is to be understood, however, that the invention is not limited to this application but has general application to those systems where guns and the like are mounted on any swaying foundation or platform.

As shown in Fig. 1, a gun 10 is mounted in a turret 10a, or other suitable mount on a ship, and is controlled by means of a sighting device or director 11, usually situated at some position remote from the gun, such as at some suitable position aloft. It will be understood that usually a plurality of guns will be controlled by the director, but for the sake of simplicity but a single gun is shown. The trunnions 10b of the gun 10 are mounted to rotate on a suitable mount 10c. The gun is arranged to be adjusted in elevation on its trunnions which rotate on an axis $x-x$ that is perpendicular to the plane of the drawing in the position of the gun shown in Fig. 1, and which is parallel to the deck of the ship. The mount 10c rotates in a train plane on an axis $y-y$ which is perpendicular to the axis $x-x$ and to the deck of the ship.

The director 11 comprises a pedestal 12 (Figs. 2 and 3) which is provided with feet 13, usually three in number, positioned 120° apart. Each foot 13 has one levelling screw 14 and two holding-down bolts 15. The pedestal is mounted on the deck 16 of a suitable director station, which deck is approximately parallel with the deck of the ship. The levelling screws provide means for levelling the director relative to the reference plane, or "deck," of the ship.

All of the controlling units or elements of the director are supported by the pedestal 12 and are arranged to rotate around it in a train plane. The elements are mounted on and supported by a frame 17, which is freely rotatable in train on suitable bearings (not shown) carried by the pedestal.

Arranged on and carried by the lower end of the pedestal 12 is a relatively large gear 18, with which a worm gear 19 meshes. The latter gear is mounted on a shaft 19a (Fig. 1) which is driven by trainer handwheels 20. The handwheels 20 drive a shaft 21 through gears 21a. Mounted on this shaft to rotate with it, but having sliding motion relative to it, are a pair of gears 21b and 21c of relatively small and large diameters respectively. The smaller gear meshes with a gear 21d, while the larger gear 21c is intended to mesh with a gear 21e, smaller than the gear 21d. The gears 21b and 21c are selectively controlled to mesh with the gears 21d and 21e respec-

tively by means of a clutch member 21f. The gears 21d and 21e are secured to a shaft 21g, which is connected with the shaft 19a by means of gears 21h. The director may be revolved rapidly in train to bring it onto a target by throwing the gear 21c into mesh with the gear 21e, and is accurately adjusted when approximately on the target by means of the gears 21b and 21d. It will be observed that when the handwheels 20 are rotated, the frame 17 and the mechanism supported thereby will be turned in a train plane. It will be understood that it is the function of the training mechanism to bring the director to bear on a target so as to measure its bearing. The director is provided with a training sight or telescope 23 (Figs. 2 and 3) to assist the "trainer" in bringing the director to bear on the target.

The director further comprises elevation sighting means. The elevation sighting means consists of an eye-piece 24 (Figs. 1, 2, and 3) through which the target is observed; the line of sight 24a is directed to the eye-piece by an adjustable mirror 25 (Fig. 1) and a suitable prism (not shown) arranged in the eye-piece 24 to direct the path of light from the mirror 25 into a path through the eye-piece and to the eye of the observer, who is known as the "pointer."

The adjustment of the director in elevation is made by adjusting the angular position of the mirror 25 about an axis at right angles to the train axis of the director 11; that is, about an axis which is perpendicular to the axis about which the director is moved in train. The mirror 25, as shown in Fig. 1, is mounted on a shaft 26, which is perpendicular to the training axis of the director. The mirror 25 is adjusted in elevation by means of handwheels 27 which are connected to drive the mirror by means of a mechanical drive which is arranged so that certain corrections may be introduced into it, as will be pointed out in greater detail hereinafter.

The mirror 25 is adjusted in elevation by the handwheels 27 so that the line of sight is adjusted to and maintained in the proper relation to the elevation of the gun 10. That is, the "pointer" adjusts the mirror 25 so as to bring the cross-hairs of the sight onto the target at the proper point in the roll of the ship that it is desired the fire of the gun shall take place. Usually, the deck of the ship will not be horizontal at the instant of fire. The angle between the ship's deck at the instant of fire and the line of sight is known as the "director correction angle" and is introduced by controlling the position of the line of sight in the proper relation to the elevation of the gun, as pointed out previously.

The director 11 is moved in train and the line of sight 24a is moved in elevation at the same speed, while certain other elements of the mechanism operate at relatively high speeds. The speed of the director in train is 1 speed and so is that of the line of sight 24a. In view of the fact that the line of sight moves through an angle twice as great as the angle through which the mirror moves, the mirror 25 is operated at one-half speed.

The angular adjustment to be applied to the gun in elevation above the deck of the ship is introduced at the director. This adjustment is known as the "gun elevation order" and is applied by turning the handwheels 27. It is transmitted directly to the gun 10. The "gun elevation order" is the total gun elevation above the deck at the instant of fire. That is, the "gun eleva-

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tion order" will be equal to "sight angle," which, as pointed out previously, is the calculated correction to be applied to the gun in elevation for a definite range of the target corrected for the "director correction angle," trunnion tilt and vertical parallax.

The "sight angle" is calculated on the assumption that the ship's deck is horizontal and is introduced into the director by means of a handwheel 28 (Fig. 1). The "sight angle" is calculated by suitable auxiliary means (not shown), such as a range keeper, located at some remote station, usually in the plotting room of the ship. The value of the calculated range of "sight angle" is transmitted by suitable means to the director where suitable reproducers of the angles 29 and 30 are located, and the adjustment is introduced by the handwheel 28. While "sight angle" may be transmitted from the range keeper to the director by any suitable motion transmitting system, preferably an alternating current system of the self-synchronous type will be used wherein the transmitting and reproducing devices are similar in construction and are each provided with a poly-circuit armature winding and a single circuit field winding. As shown diagrammatically in Fig. 4, the transmitting devices 29a and 30a, located at the range keeper, and reproducing devices 29 and 30 may each be provided with a poly-circuit armature winding 31 which is physically similar to a three-phase bi-polar, Y-connected armature winding, and which is mounted on a stator member; and each is further provided with a single circuit field winding 32. The transmitters and reproducers are connected together by sets of three conductors 33 connecting like points of their armature windings, as shown in Fig. 4. The field windings 32 of each set of connected instruments are connected to a suitable source of alternating current supply 33a. The field windings induce alternating electromotive forces in the circuits of their respective armature windings, the relative magnitude of the electromotive forces in the respective circuits of the armature windings depending upon the angular relation of the field windings therewith. When the rotors of each set of the transmitters and reproducers 29a, 30a and 29, 30 are in angular agreement, the electromotive forces induced in the various circuits of the armature windings are equal and opposite and, therefore, no current is produced. However, when the transmitter is turned and held in a new position, this voltage balance no longer exists, whereby currents are caused to flow in the armature windings, and a torque is thereby exerted upon the rotor of the reproducer, which torque turns the rotor into a position in which the voltages are again balanced; in this position, the rotors will again be in angular agreement. In this particular case, low and high speed transmitters of motion 29a and 30a and low and high speed receivers 29 and 30 are employed in order to provide greater accuracy of transmission. The rotors of the transmitters 29a and 30a, as shown, are connected together by gearing 33b which operates the rotor of the transmitter 30a at a high speed relative to the rotor of the transmitter 29a. In this particular case, the ratio of operation between the low and high speed transmitters 29a and 30a is 4 to 216. The rotor of the low speed transmitter is operated by suitable means indicated diagrammatically by a handwheel 33c.

The reproducers 29 and 30 drive indicator dials 34 and 35 respectively (Figs. 1 and 4) which co-

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operate with ring dials 36 and 37 driven by the handwheel 28. The dials 34 and 35 are provided with indices which are aligned with similarly arranged indices on the ring dials 36 and 37 when the dials 34 and 35 are in their zero positions. When the receiving devices 29 and 30 drive the dials 34 and 35 from their zero positions to indicate the "sight angle" calculated by the remote range keeper, the handwheel 28 will be turned in order to cause the dials 36 and 37 to follow the indices on the dials 34 and 35 to bring them into alignment with them. In doing so, the correction for "sight angle" is automatically introduced into the director by means of a shaft 38. The handwheel 28, as shown, is mechanically connected with the ring dials 36 and 37 and the shaft 38 by means of gears 39 connecting the handwheel 28 to a shaft 40; the shaft 40 carries a worm 41 which meshes with a worm wheel 42 carried on a shaft 43. Mounted on this shaft is a spur gear 44, which meshes with a spur gear 45 that is connected to the ring dial 36 to drive it. Also mounted on the shaft 43 is a spur gear 46 which drives a shaft 47 through a shaft 48. The gear 46 is connected with the shaft 48 by means of a gear 49 and the shaft 48 is connected with the shaft 47 by means of spur gears 50 and 51. The shaft 47 drives the ring dial 37 through spur gears 52 and 53, and the shaft 38 through bevel gears 54. The gearing between the dials 36 and 37 introduces a velocity ratio of 6:216. The shaft 38 is driven at a speed 216 times as great as the line of sight 24a.

The shaft 38 introduces the calculated value of "sight angle" into mechanism 56 which corrects the angle for tilt of the gun trunnions and issues it from the mechanism as "sight angle" corrected for trunnion tilt, which angle hereinafter will be known as "corrected sight angle." This angle is issued from the mechanism 56 by means of a shaft 57. The trunnion tilt correction mechanism 56 will be described in greater detail hereinafter.

"Sight deflection," which is utilized to generate the adjustment to be applied to the gun 10 in train, is introduced into the director mechanism by means of a handwheel 58. "Sight deflection" is calculated from the velocity and direction of the wind, drift, speed, and direction of the ship and target, etc. and is generated in the range keeper referred to above. The value of "sight deflection" thus computed in the range keeper is transmitted to the director by a motion transmission system similar to that between the range keeper and the sight angle dials 34 and 35 with the exception that in the case of "sight deflection" a single speed transmitter and reproducer only is used. As shown, a reproducer 59 of the "sight deflection" angle is provided in the director; its transmitter has not been illustrated. This reproducer drives an indicating dial 60. The handwheel 58 drives a ring dial 61 which co-operates with the dial 60 as do the ring dials 36 and 37 with their dials 34 and 35. The handwheel drives the dial through a shaft 62 to which the handwheel is connected by a worm 63 and a wormwheel 64; the shaft 62 drives a shaft 64a by means of bevel gears 65 and 66 and the shaft 64a in turn drives the dial 61 through spur gears 67 and 68. The shaft 62 also functions to introduce "deflection correction" into the trunnion tilt mechanism 56. When the dial 60 is operated from its zero position by the reproducer 59 in response to a generation of "sight deflection" in the range keeper, the handwheel 58 is turned to bring the ring dial 61 into

agreement with the dial 60 and in doing so operates the shaft 62 to introduce "sight deflection" into the trunnion tilt mechanism 56. This mechanism, as will be pointed out in greater detail hereinafter, utilizes the "sight deflection" introduced by the shaft 62, modifies it in accordance with the tilt of the gun trunnions and issues it by means of a shaft 69 as the "sight deflection" compensated for trunnion tilt. This value, which will be known hereinafter as "corrected sight deflection," is used to generate the proper adjustment of the gun in train. The shaft 62 is driven at 216 speed.

The "sight angle" correction and the "sight deflection," as pointed out previously, are computed on the assumption that the trunnion axes of the gun lie in a horizontal plane, and that the gun is elevated in a vertical plane and trained in a horizontal plane. When the deck of the ship is inclined, it is clear that it is no longer possible to adjust the gun in vertical and horizontal planes. The mechanism 56 introduces corrections continuously compensating for tilt of the gun trunnions caused by cross roll of the ship across the line of sight.

The trunnion tilt mechanism 56 is shown in detail in Fig. 5. In this figure, it is to be noted that the shafts 38, 57, 62 and 69 do not occupy the same positions relatively to each other that they do in the diagrammatic illustration shown in Fig. 1. The shafts have not been shown in the diagrammatic form of Fig. 1 in the same positions relative to each other that they occupy in the detailed disclosure of the trunnion tilt mechanism shown in Fig. 5 in the interests of simplicity of disclosure.

The trunnion tilt mechanism 56, as shown in Fig. 5, comprises a mimic gun 70 mounted in a gimbal system. The gimbal system is so arranged that the mimic gun can be adjusted in elevation and in train in planes representing the true vertical and horizontal planes respectively, whereby the calculated "sight angle" and "sight deflection" may be applied to the mimic gun. The mimic gun may be moved in these planes to a position that the gun 10 would occupy in space if adjusted when the deck of the ship is horizontal. In other words, the mimic gun 70 can be elevated and trained so as to generate "sight angle" measured in a plane representing a plane perpendicular to the deck of the ship and to introduce "sight deflection" in a plane representing a plane parallel to the deck of the ship. In addition, the gimbal system is arranged so that the trunnions of the mimic gun can be shifted with reference to the planes representing the true vertical and horizontal planes in accordance with the cross roll of the ship about the line of sight so as to cause the mimic gun to occupy the position in space with reference to the planes representing the true vertical and horizontal planes that the gun 10 would occupy in space with reference to the true vertical and horizontal when the ship's deck is inclined and the elevation and train adjustments of the gun 10 have not been compensated for the tilt of the ship. The difference of adjustments the mimic gun 70 has in elevation and train measured in the planes representing those perpendicular to and parallel to the deck of the ship, and the adjustments it has in elevation and train with reference to the planes representing the true vertical and horizontal after it has been shifted in accordance with the inclination of the ship, are measured and utilized to calculate the correct adjustments to be applied to

the gun 10 so that it can be adjusted to its correct position in space with reference to the true vertical and horizontal.

The mimic gun 70, as shown, is provided with trunnions 71, which are journaled in bearings provided for them in the opposite sides of a square ring 72 to rotate on an axis $x'-x'$. The ring 72 is mounted in a square ring 73 in bearings to rotate on an axis $y'-y'$ which is perpendicular to the axis $x'-x'$. The specific means mounting the ring 72 in ring 73 will be described below. The ring 73 is provided with trunnions 73a and 73b which are mounted in fixed bearings 74 so as to rotate on an axis $a-a$ fixed with relation to the ship. That is, the mimic gun 70 is mounted in rings 72 and 73 so as to rotate on axes $x'-x'$ and $y'-y'$ corresponding to the axes of rotation $x-x$ and $y-y$ of the main gun 10, which are respectively parallel to and perpendicular to the deck of the ship. It is contemplated that the mimic gun 70 will be moved on the $x'-x'$ and $y'-y'$ axes to generate the "sight angle" and "sight deflection," as calculated, and as generated in the shafts 38 and 62 respectively.

The shaft 38, as shown, is mechanically connected to the mimic gun 70 through a differential 75 which drives an output shaft 76 at 108 speed; the shaft 76 is mechanically connected with the planetary gears 75a of the differential, while the input gear 75b of the differential is mechanically connected to the shaft 38 through spur gears 77. The shaft 76 is connected with a worm shaft 78 through spur gears 79, the worm shaft 78 having a worm 80 which meshes with a worm wheel 81 mounted on a shaft 82. The shaft 82 is connected with a shaft 83 mounted in the axis $y'-y'$ by means of bevel gears 84 so as to drive the shaft 83 at 1 speed, and the latter shaft is geared to rotate the mimic gun trunnions 71 at 1 speed by means of bevel gears 85. In view of the foregoing arrangement, the value of "sight angle" as calculated in the range keeper and introduced into the director by the handwheel 28 is applied to the mimic gun 70 about its axis $x'-x'$. The function of the differential 75 will be described presently. The shaft 83, it will be observed, also functions to interconnect the rings 72 and 73 at the top and to pivotally support the top of the ring 72.

The calculated value of "sight deflection" is imparted to the mimic gun 70 from the shaft 62 through a differential 86. As shown, the shaft 62 is connected to the input gear 86a of the differential by spur gears 87. The output gear 86b of the differential is driven by the planetary gears 86c and is connected with a shaft 88 by spur gears 89 and 90. The gearing between the shafts 62 and 88 reduces the speed from 216 in the shaft 62 to 108 in the shaft 88. The shaft 88 drives a shaft 91 which is mounted to rotate on the fixed axis $a-a$ about the right hand trunnion 73b of the ring 73, as viewed in Fig. 5, at one speed through a worm 92 mounted on the shaft 88 and a worm wheel 93 meshing with it and mounted on the shaft 91. The shaft 94 is mounted to rotate in the ring 73, as shown. The shaft 94 is geared to a shaft 97 to operate it at one speed through bevel gears 98. The shaft 97 is mounted in the axis $y'-y'$ and is secured to the ring 72 to turn it on this axis. In view of the foregoing arrangement, it will be observed that the "sight deflection" calculated in the range keeper and introduced by the handwheel 58 is applied to the mimic gun 70 to drive it at one speed about the axis $y'-y'$. The shaft 97, as shown, is extended to be

received in the lower part of ring 73 so as to pivotally mount the lower portion of ring 72 in the ring 73.

The functions of the differentials 75 and 86 will now be explained. It will be observed that when the shaft 62 is operated to move the mimic gun 70 in train about its axis $y'-y'$ to introduce "sight deflection" as calculated, the gears 98 will impart motion to the ring 72 about its axis $y'-y'$. When the ring is thus moved, the bevel gear 85 on the trunnions 71 will be rotated on the gear 85 associated with it on the shaft 83 and, therefore, will move the mimic gun 70 in elevation from its adjusted "sight angle" position. To compensate for this, the differential 75 is operated to introduce this angle in the reverse direction and therefore hold the mimic gun in its correct adjusted position. As shown, the gear 75c of the differential is mechanically connected with the differential 86 by means of a shaft 100, which at one end is connected with the input gear 75c of differential 75 through the bevel gear 101 secured to the gear 75c and a bevel gear 102 meshing with it and mounted on the shaft 100. The other end of the shaft 100 is connected with the output gear 86b of differential 86 by means of a shaft 103; the shaft 100 is connected with shaft 103 by bevel gears 104, while the shaft 103 is connected with the output gear 86b by means of the spur gear 105 which meshes with the spur gear 90 mounted on the shaft 88. The shaft 103 is operated at 216 speed, the shaft 100 at 216 speed and the shaft 76, as before when operated by shaft 38, at 108 speed. It will be observed, therefore, that when the shaft 62 is operated to introduce "sight deflection," the mimic gun 70 is adjusted not only in train, but tends to move from its adjusted position in elevation; the elevation controlling shaft 76, however, is operated from the "sight deflection" input shaft 62 by means of the differentials 86 and 75 to introduce in a reverse direction the same angle that the gun 70 would be moved by the introduction of "sight deflection." Consequently, it is held in its correct adjusted position in elevation. The differential 86 has a further function which will be described presently.

The mimic gun 70 is mechanically connected with the "corrected sight angle" and "corrected sight deflection" shafts 57 and 69 so as to impart motion to these shafts in accordance with the adjustments of the mimic gun in elevation and train by the following mechanism: The muzzle 70a of the mimic gun 70 is pivotally secured to a semi-square ring member or bail 106 that is carried by a square ring or bail 107. The ring 107 is mounted to rotate on an axis $b-b$ fixed with relation to the ship and arranged at right angles to the fixed axis $a-a$, and further, intersecting it at the point of intersection P of the axes $x'-x'$ and $y'-y'$. The bail 106 is provided with trunnions 106a pivoted in ring 107 to rotate on an axis $c-c$, and arranged so that when the rings 72 and 107 occupy their positions shown in Fig. 5, with the axes $b-b$ and $y'-y'$ coinciding, and with the line of fire of the mimic gun lying in the axis $a-a$, the trunnions 106a and axis $c-c$ will lie in the axis $x'-x'$.

It will be observed that when the mimic gun 70 is adjusted in elevation or in train, it will carry the bail 106 with it. The motions of the bail are imparted to the output shafts 57 and 69, respectively. For this purpose, a segmental gear rack 108 is secured to one of the trunnions 106a of the bail 106 (the left-hand trunnion, as viewed in

Fig. 5) so as to move with the bail. Meshing with the rack 108 is a similar rack 109 which is secured to a shaft 110. This shaft is mounted in the adjacent upright arm of the ring 107, as shown in Fig. 5.

The shaft 110 is connected with a shaft 111 by means of bevel gears 112. The shaft 111 rotates in the fixed axis $b-b$, and is mechanically connected to drive the "corrected sight angle" output shaft 57 through a differential 113. As shown, the shaft 111 is connected with the input gear 113a of the differential by means of spur gears 114, one connected with the input gear 113a and the other with the shaft 111. The output gear 113b is connected with the output shaft 57 by means of spur gears 115. By reason of the foregoing connections between the bail 106 and the output shaft 57, the latter member is caused to generate the angle of elevation imparted to the mimic gun 70. The bail 106 and gear segment 108 move at 1 speed, the segment 109 and the shaft 111 at 4 speed, while the "corrected sight angle" shaft 57 is driven at 36 speed.

The adjustment of the mimic gun 70 in train, i. e. its "deflection correction" is transmitted to the "corrected deflection" shaft 69 directly from the ring 107. This ring, as shown, drives a segmental rack 116 with which a spur gear 117 mounted on the shaft 69 meshes. It will be observed that movement of the mimic gun 70 in train causes the bail 106, the ring 107 and the rack 116 to move with it, and hence, generate its train adjustment in the output shaft 69. The ring 107 and rack 116 operate at 1 speed and the shaft 69 at 6 speed.

The function of the differential 113 is similar to that of the differential 75. Thus, it will be observed that when the ring 107 is moved to introduce "deflection" into shaft 69, it will carry the shaft 110 with it as a body around the axis $b-b$. This motion, of course, imparts motion to the shaft 111 and would vary the "sight angle" output in the shaft 57 by an amount proportional to the deflection output in shaft 69. However, a like motion of equal magnitude is subtracted in the differential 113 so that the shaft 57 remains uninfluenced by the operation of the ring 107. This is accomplished by operating the input gear 113b of differential 113 by means of spur gears 118 and 119, the former connected to the planetary gear 113b and the latter to the ring 107. When the ring 107 in turning tends to displace the shaft 57 through a certain angle, an equal and opposite angle is subtracted in the differential, whereby the shaft 57 is uninfluenced by "deflection correction."

It will be remembered that the axes $x'-x'$ and $y'-y'$ intersecting at right angles to each other at the pivot of movement P of the mimic gun 70 represent the axes about which the main gun 10 moves, that is, the axis $x'-x'$ represents the axis $x-x$ of the main gun parallel to the plane of the deck and about which the main gun 10 moves in elevation, while the axis $y'-y'$ represents the axis $y-y$ of the main gun perpendicular to the deck and about which the gun 10 is moved in train.

The mutually perpendicular fixed axes $a-a$ and $b-b$ represent true horizontal and vertical axes in space; the axis $c-c$ represents the axis about which the calculated "sight angle" is measured; and the axis $b-b$ is the axis about which the calculated "sight deflection" is measured. If there is no cross roll, the outputs of "sight angle" and "sight deflection" shafts 57 and 69

will be equal to the calculated values of "sight angle" and "sight deflection" introduced by the shafts 38 and 62. If there is a cross roll, the mimic gun 70 continuously occupies the position in space with reference to the true vertical and horizontal that the main gun 10 would occupy, if the calculated values of "sight angle" and "deflection" were applied to it and these values were not compensated for cross roll. As a result of this, the "sight angle" and "sight deflection" in shafts 57 and 69 are continuously compensated for cross roll of the ship.

In order to compensate for cross roll of the ship about the line of sight, suitable means are provided for tilting the trunnions of the mimic gun 70 in accordance with the roll of the ship. For this purpose, the ring 73 carrying the ring 72 in which the mimic gun is mounted is tilted on its fixed bearings 74 on the axis $a-a$ by an angle equal to the angle of cross roll, and is shifted in its position to measure continuously the angle of cross roll of the ship as it varies.

The angle of cross roll is measured by a cross level sighting device 120 (Figs. 1, 2, and 3). This device comprises an eye-piece 121, and mirrors 122 and 123 (Fig. 1). The mirrors, as shown, are arranged at right angles to each other so as to bring the opposite fields of the horizon to the eyes of the observer. A prism 124 directs the lines of sight from the mirrors to the eye-piece 121. The mirrors are mounted on a shaft 125 which is driven by handwheels 126. The handwheels 126 drive a shaft 127 through bevel gears 128. The shaft 127 drives a shaft 129 through spur gears 130, which in turn drives the mirror shaft 125 through gearing 130a.

It will be understood that the observer operates the handwheels 126 to keep the horizon continuously on the horizontal cross-hair of the sighting device. In doing so, the observer automatically generates the angle of roll across the line of sight of the director, which, of course, is maintained on the target. The shaft 129 is driven at 108 speed, which speed is reduced to $\frac{1}{2}$ speed in the mirror shaft. This, of course, moves the line of sight of the device 120 at 1 speed, because the line of sight is moved at twice the speed the mirror is moved.

The shaft 129 drives a shaft 131 at 108 speed through a shaft 132 connected to the shaft 129 by bevel gears 133 and to the shaft 131 by bevel gears 134. The shaft 131 drives the ring 73 on its axis $a-a$ at 1 speed by means of a worm gear drive comprising a worm 135 (Fig. 5) mounted on shaft 131 and a worm wheel 136 meshing with it and mounted on one of the trunnions 13b of the ring 73, the right hand trunnion, as viewed in Fig. 5.

In view of the foregoing arrangement, it will be observed that when the observer at the eye-piece 121 operates the handwheels 126 to hold the sight on the horizon, he will at the same time operate the ring 73 on its fixed axis $a-a$ to continuously measure the angle of cross roll. The ring 73 when thus operated moves the mimic gun trunnions 71 through the same angle, and the resulting movement of the muzzle of the mimic gun 70 in space modifies the calculated values of "sight angle" and "sight deflection" to generate the "corrected sight angle" and the "corrected sight deflection" adjustments.

It will be observed that when the ring 73 is rotated on its axis $a-a$ by the cross level shaft 131, it will swing the shaft 94 in an arc about this axis, and hence, will impart a rotary motion

to the shaft 94 on its own axis from the gear 95. This motion of the shaft 94, unless compensated for, would rotate the gears 98 and hence, the ring 72, and thereby disturb the train adjustment of the mimic gun. The angle through which the shaft 94 would thus have moved the mimic gun in train is introduced in the differential 86 from the shaft 131 by spur gears 137, 138 and 139 and shaft 139a, which shaft is connected with planetary gears 86c of the differential 86. Thus, when the shaft 131 is rotated, the differential is operated by the shaft 131 to introduce an angle in train to the mimic gun equal and opposite to that introduced by the shaft 94 revolving on the gear 95, whereby the mimic gun holds its adjusted position in train. Moreover, when the position of the ring 73 is shifted, the adjustment of the mimic gun in elevation tends to vary because of the interaction of the gearing 84. This is compensated in the differential 75 which is driven from shaft 131 through the differential 86 so as to cause the mimic gun to hold its corrected adjustment in elevation.

The operation of the mechanism 56 may be better understood by reference to Figs. 6 to 11 inclusive. Assuming that the parts of the mechanism 56 are in their positions shown in Fig. 6, and that the shaft 38 is operated to introduce "sight angle" e , as calculated, then the mimic gun is moved through the angle e from its position shown in Fig. 6 to its position shown in Fig. 7. This operation is shown diagrammatically in Fig. 9 where the mimic gun is moved through the angle e from its dotted line position to its solid line position. When the shaft 62 is operated to adjust the mimic gun in train by the calculated "sight deflection" angle d , the mimic gun is moved from its dotted line position in Fig. 10, which corresponds to its full line position in Fig. 9, to its full line position in Fig. 10. This is the position that the mimic gun takes due to the calculated values of "sight angle" and "sight deflection" and is the position that the main gun 10 should take when the deck of the ship is horizontal. When the ring 72 is inclined through an angle of cross roll cr (Fig. 8) in response to the operation of the cross level shaft 131, it inclines the ring 72 and the gun trunnions 71 and thereby causes the mimic gun to describe a portion of a surface of a cone about the point P from the full line position of Fig. 10, which is represented in dotted lines in Fig. 11, to the full line position of Fig. 11. The muzzle 70a is the mimic gun, therefore describes a curve from its dotted line position in Fig. 11 to the full line position in this figure, which curve is a portion of the base of the cone described by the mimic gun in moving between these positions.

When the ring 73 is inclined through angle cr to cause the muzzle of the gun 70a to move from the dotted line position of Fig. 11 to the solid line position thereof, the muzzle 70a in moving pulls the bail 106 with it and causes the point of intersection of the muzzle and the bail to move through a like curve. The position of the bail 106 is thus shifted in space on its trunnions 106a, and also on the ring 107 about the fixed axis $b-b$. The first of these movements of the bail on the trunnions 106a measures the difference between the "sight angle" calculated and applied by the shaft 38 to the mimic gun 70 and the "corrected sight angle" which the mimic gun has with reference to the true vertical and horizontal axes $a-a$ and $b-b$ after it has been shifted by tilting of ring 73. In the case illustrated, the "cor-

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rected sight angle" is less than the "sight angle," as calculated, and as shown in Fig. 11, and this difference is subtracted from the calculated "sight angle," the resultant being applied to the shaft 57 through gears 108, 109, shafts 110 and 111, differential 113 and gears 115. The second movement of the bail 106 due to tilting of the ring 72, that is, its movement about the fixed axis $b-b$, rotates the ring 107 with it about this axis and measures the difference between the calculated "sight deflection" imparted to the mimic gun by the shaft 62 and the "corrected sight deflection" that the mimic gun has in space with reference to the horizontal and vertical axes $a-a$ and $b-b$ after the mimic gun has been shifted, and transmits the resultant "corrected deflection" to the shaft 69 through the rack and gear 116 and 117. In the particular example illustrated, the "corrected sight deflection" is greater than calculated "sight deflection" as shown in Fig. 11.

It will be understood that as the angle of inclination of the ship's deck varies about the line of sight, the muzzle 70a of the mimic gun 70 will be weaved back and forth through a conical path by the ring 73 as the latter is moved back and forth on its axis in accordance with the cross roll of the ship. The particular conical path through which the muzzle moves depends, of course, upon the calculated values of "sight angle" and "sight deflection" that have been imparted to it.

The "corrected sight angle" generated in the shaft 57 is combined with the "director correction" adjustment and is issued to the gun as "gun elevation order." The "corrected sight deflection" generated in the shaft 69 is combined with the "target bearing" generated by moving the director in train to bring it to bear on the target and is issued to the gun as "gun train order."

The "corrected sight angle" shaft 57 is mechanically connected to the mirror 25 through a differential 140. As shown in Fig. 1, the shaft 57 is connected with a shaft 141 through spur gears 142. The shaft 151 is mechanically connected to the planetary gears 140a of the differential 140; the output gear 140b of the differential is mechanically connected to a shaft 143 by means of spur gears 144. The shaft 143 carries a worm 145, which meshes with a worm segment 146 that is mounted on the mirror shaft so as to effect a mechanical drive between the mirror 25 and the shaft 143. In view of the foregoing arrangement, it will be observed that the "corrected sight angle" generated in the shaft 57 is applied to the mirror 25. The shaft 143 is driven at 72 speed, while the mirror 25 is driven at $\frac{1}{2}$ speed; the line of sight, therefore, is driven at 1 speed.

When the "sight angle" generated in the shaft 57 is applied to the mirror 25, the line of sight is moved from the target. The "director pointer" in returning the line of sight on to the target by operation of the handwheels 27 will automatically generate the "corrected sight angle." The handwheels 27 are mechanically connected with the mirror 25 by means of a shaft 147 which is connected with the handwheels 27 by means of bevel gears 148. The shaft 147 is connected with the shaft 149 by means of bevel gears 150, and the shaft 149 is mechanically connected with the input gear 151a of the differential 151 by means of spur gears 150a. The output gear 151b of the differential is connected with the input gear 140c of the differential 140 by means of spur gears 152. It will be observed, in view of the foregoing mechanical connections, that when the

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handwheels 27 are rotated they will impart motion to the mirror 25 through the two differentials 140 and 151.

The differential 151 is introduced in the connection between the handwheels 27 and the mirror 25 for the purpose of introducing a correction for "vertical parallax" between the director 11 and the gun. "Vertical parallax" is introduced into the differential 151 by means of a handwheel 152a, which drives a worm 153. This worm in turn drives a worm wheel 154 that is mounted upon a shaft 155. This shaft is mechanically connected to a shaft 156 which drives the planetary gears 151c of the differential 151 by means of spur gears 155a. A suitable scale 157 reading in terms of range is provided to assist in making the parallax correction. This scale, as shown, is driven from the shaft 155 through gears 157a.

It will be observed that both the introduction of the "corrected sight angle" from the shaft 57 and of "vertical parallax" correction from the handwheel 152a will turn the mirror 25 to move the line of sight 24a from the target so that when the "pointer" operates the handwheels 27 to return the line of sight to the target, he will automatically generate the correction that should be applied to the gun in elevation. In addition to these corrections, the "director correction," which is the angle between the ship's deck at the instant of fire and the line of sight selected by the "pointer" is automatically applied by the "pointer" in adjusting the line of sight to bear upon the target at the particular point in the roll of the ship that it is desired fire shall take place.

The resulting elevation order, that is, the order which is the resultant of the "corrected sight angle," "vertical parallax" correction, and "director correction," known as "gun elevation order," is transmitted to the turret 10a by means of a suitable motion transmission system which is similar to the transmission systems between the range keeper and the reproducers 29, 30, and 59, which have been previously described. As shown, the transmission system between the "pointer" and the gun 10 comprises low and high speed transmitters of angular motion 158 and 159, which are driven by the handwheels 27 to generate "gun elevation order." The handwheels 27 drive the transmitters 158 and 159 through the shaft 149, the spur gears 150a and a spur gear 160 meshing with these gears and mounted on the rotor shaft 161 of the high speed transmitter 159. The rotor shaft 162 of the low speed transmitter 158 is mechanically connected to the rotor shaft 161 through reduction gearing 163. The shaft 161 is driven at 72 speed, while the shaft 162 is driven at 4 speed. Mechanically connected with the shafts 161 and 162 respectively are indicating dials 164 and 165 which are driven at the same speed as the associated shafts. As shown, the shaft 161 is connected with the dial 164 through gears 166, while the shaft 162 is connected with the dial 165 through gears 167.

The low and high speed transmitters 158 and 159 are electrically connected to low and high speed reproducers of angular motion 168 and 169 respectively located near the gun 10. These reproducers operate dials 170 and 171 respectively so as to indicate the angle of "gun elevation order." Matched with these dials 170 and 171 are dials 172 and 173 which are operated when the gun is elevated so as to inform the "gun pointer" that the gun 10 has been elevated through the angle of "gun elevation order." The gun 10, as shown, is provided with a rack 174 secured to its

trunnions which is operated by a worm 175 mounted upon a shaft 176. The shaft 176 is operated by handwheels 177 which are mechanically connected with the shaft 176 through a shaft 178. As shown, this shaft 178 is geared to the handwheels 177 by bevel gears 179 and to the shaft 176 by bevel gears 180. The handwheels 177 are operated to elevate the gun at 1 speed and at the same time function to drive the dials 172 and 173. For this purpose, the shaft 176 is mechanically connected to the dial 173 by means of a shaft 181 to which the shaft 176 is connected by means of bevel gears 182. The shaft 181 is mechanically connected with the dial 172 by means of spur gears 183, one of which is mounted on the shaft 181 and the other on a shaft 184. This shaft in turn is connected with a shaft 185 by spur gears 186, the shaft 185 being mechanically connected with the armature member or stator of the reproducer 168 through spur gears 187. The shaft 181 is also connected with the stator or armature member of the reproducer 169 by means of a spur gear 188 meshing with the spur gear 183 mounted on the shaft 184.

Thus, when the "director pointer" operates the handwheels 27, he will operate the transmitters 158 and 159 which will operate the reproducers 168 and 169 to reproduce the angle of "gun elevation order" on the dials 170 and 171, the dials 170 and 171 being driven at 4 and 72 speeds respectively. The "gun pointer" operates the handwheels 177 to elevate the gun by the amount of "gun elevation order" by returning the dials 170 and 171 to their zero positions, and at the same time drives the dials 172 and 173 to indicate the angle that the gun has been elevated.

The "gun train order" is the value of the target's bearing, as determined by the director, compensated for "corrected sight deflection" and horizontal parallax. The target's bearing is generated when the director is turned in train by the handwheels 20 to bring the sight 23 to bear upon the target. When the director is turned upon its pedestal 12 by means of the handwheels 20, it automatically generates target's bearing in a shaft 189. Supported upon the pedestal 12 is relatively large spur gear 190 which is fixed to the pedestal, and meshing with this relatively large gear is a relatively small spur gear 191 which is carried by the shaft 189, which is mounted in the rotating part 11 of the director. Thus, when the director is rotated on the pedestal, motion will be imparted to the shaft 189. The shaft 189 is driven at 12 speed by the gear 190.

The bearing of the target generated in the shaft 189 is corrected for horizontal parallax by referring the bearing generated to a suitable reference point. The director itself may be the reference point, or if a number of directors are used in the system, the point may be located at the vertical axis of any one of the directors. It will be understood, however, that any suitable point may be chosen as the reference point. This particular director 11 is removed from the reference point and the bearing is compensated for parallax by referring it to the reference point. The train parallax may be calculated by any suitable mechanism which is designated in general by the numeral 192. Thus, for example, the train parallax mechanism described in the United States patent to W. W. Willard, No. 1,942,079, dated January 2, 1934, may be used. In this parallax mechanism, the only variable to be considered is the range of the target and this is introduced by means of a handwheel 193, a scale

194 being provided to assist in the setting of the range. The parallax mechanism 192 generates the correct angle for parallax in a shaft 195. The generated bearing of the shaft 189 is adjusted for the parallax angle in the differential 196. As shown, the shaft 195 is connected directly with the input gear 196a of the differential 196, while the bearing shaft 189 is mechanically connected with the input gear 196b of the differential. Planetary gears 196c of the differential are mechanically connected with a shaft 197 which is the output of the differential and which generates target bearing compensated for horizontal parallax. The shaft 197 is mechanically connected to a shaft 198 by means of bevel gears 199. The shaft 198, it will be observed, generates target bearing correction for horizontal parallax. This shaft is mechanically connected with the "corrected sight deflection" of output shaft 69 through a differential 200 whereby the target's bearing compensated for parallax and "corrected sight deflection" will generate "gun train order," which is the angle that the gun 10 is to be adjusted in train. In other words, the target's bearing generated in the shaft 198 is combined with the "corrected sight deflection" generated by the shaft 69 in the differential 200. As shown, the shaft 198 is mechanically connected to the input gear 200a of the differential by means of bevel gears 201 while the shaft 69 is mechanically connected to the differential input gear 200b by the spur gears 202. The planetary gears 200c of the differential are mechanically connected to the output shaft 203 of the differential which generates "gun train order." The shaft 189, as has been pointed out previously, is driven at 12 speed, the shaft 198 is driven at 36 speed, and the shaft 203 is likewise driven at 36 speed.

The shaft 203 drives a transmitter of angular motion 204, which is the high speed unit of a motion transmission system, the low speed unit being designated by the numeral 205. The low speed unit will be driven at 1 speed through reduction gearing 206. These transmitters 204 and 205 transmit the "gun train order."

A high speed indicating dial 207 is mechanically connected with the shaft 203 by means of bevel gears 208, while a low speed dial 209 is driven from this shaft through the reduction gearing 206 and bevel gears 210. It will be understood that these dials indicate "gun train order."

The high and low speed transmitters of angular motion 204 and 205 are electrically connected to high and low speed reproducers of angular motion 211 and 212 located near the gun 10. The rotor of the reproducer 211 drives a high speed dial 213, while the rotor of the reproducer 212 drives the low speed indicating dial 214. Co-operating with the high speed dial 213 is a ring indicating dial 215 and a companionate dial 216, both of which are operated by the gun when moved in train. Co-operating with the dial 214 is a dial 217 which likewise is driven when the gun is adjusted in train. The gun is adjusted in train by means of handwheels 218 which are mechanically connected with a shaft 219 through a shaft 220. As shown, the handwheels 218 are geared to the shaft 220 through bevel gears 221, and the shaft 220 is geared to the shaft 219 through bevel gears 222. The shaft 219 is geared to the gun mount 10b to rotate the gun in train by means of spur gears 223 and 224. It will be understood that the gearing is such that the gun will be moved at one speed in train. When the handwheels 218 are operated to adjust the

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gun in train, the wheels at the same time impart motion to the dials 215, 216, and 217. For this purpose, the dial 215 is mechanically connected to the shaft 219 through spur gears 225, while the dial 216 is directly connected with the shaft 219. The shaft 219 drives the dials 215 and 216 at 36 speed. The shaft 219 is also mechanically connected with the stator of the low speed reproducer 212 through reduction gearing 226 so that the stator 212 is driven at 1 speed. The dial 217 is driven at 1 speed by means of a spur gear 227 which is geared to the gearing 226.

In the operation of this portion of the mechanism, it will be understood that when the reproducers 211 and 212 are operated by the transmitters 204 and 205, they will turn the dials 213 and 214 to designate "gun train order." When the handwheels 218 are operated to adjust the gun in train, the ring dial 215 is operated to cause it to follow the angle designated by the dial 213 to bring them into agreement. At the same time, the dial 214 is operated so as to return it to its zero position, while the dials 216 and 217, the former a high speed and the latter a low speed dial, are operated to indicate the angle through which the gun is adjusted in train.

It is generally necessary to utilize the value of the target's bearing compensated for horizontal parallax generated in the shaft 197 at other points in the ship. For this purpose, the shaft 197 drives high and low speed transmitters of angular motion 228 and 229. As shown, the transmitter 228 is driven directly by the shaft 197, while the low speed reproducer 229 is driven by this shaft through reduction gearing 230. A high speed indicating dial 231 is connected to the rotor of the transmitter 228 by means of bevel gears 231a, while the low speed indicating dial 232 is connected to the rotor of the low speed reproducer through bevel gears 232a. It will be understood that the transmitters 228 and 229 also preferably will be of the self-synchronous type similar to the transmitters 29a and 30a.

Suitable target designators or reproducers of angular motion 233 and 234 are provided, the former operating on a high speed of 36 while the latter operates on the low speed of 1. The rotors of these devices operate high and low speed indicating dials 235 and 236 respectively. It will be understood that these reproducers of angular motion are operated by suitable transmitters of angular motion located at some other director station in the ship whereby the dials 235 and 236 continually reproduce in the director station 11 the target's bearing compensated for horizontal parallax, if any, between the other director station and the reference point. The stators of the reproducers 233 and 234 are continuously driven by the shaft 197, the stator of the reproducer 233 being driven by this shaft at 36 speed through an intermediate shaft 237; this shaft as shown, is mechanically connected to the shaft 197 through bevel gears 238 and with the stator of the reproducer 234 through spur gears 239. The stator of the reproducer 234 is driven at 1 speed by the shaft 197 through reduction gearing 239 and a shaft 240, which is connected with the rotor shaft of the low speed transmitter 229 by means of bevel gears 241 and connected with the stator of the reproducer 234 through spur gears 242. In view of the foregoing, it will be observed that the dials 235 and 236 will be driven from their index points to indicate the bearing of the target, as determined by the remote director, whereas the stators 233 and 234 operated by the shaft 197 re-

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turns the dial 235 and 236 to their zero positions. Any difference between the bearings generated in the two stations will, of course, at once become apparent by movement of the dials from their zero positions. By means of this arrangement, a director which is not in control of the gun 10 can be operated by the handwheels 20 so that it will generate the same bearing as the director which is in control of the gun whereby the inactive director can take over the control when necessary without undue waste of time.

In the operation of the apparatus and system, it will be understood that the director "trainer" will operate his handwheels 20 so as to bring the training telescope 23 to bear on the target and that he will maintain this telescope bearing on the target. In doing so, he will generate the target's bearing in the shaft 189, which angle is transmitted to the differential 196 where it is compensated for horizontal parallax, and thence to the shaft 198, which introduces the bearing angle corrected for horizontal parallax into the differential 200. The value of "sight deflection" which will have been calculated in the remote range keeper is introduced by the handwheel 58. As has been pointed out previously in detail, this operation causes the mimic gun 70 to generate the calculated "sight deflection" in train. The calculated value of "sight deflection" in train is continuously corrected for cross roll of the ship about the line of sight by shifting the mimic gun 70, as pointed out previously. The angle of cross roll, of course, is continuously introduced into mechanism 56 by the handwheels 126. The "corrected sight deflection" output is introduced into the differential 200 by the shaft 69. The target's bearing and "corrected sight deflection" are combined in the differential 200 and "gun train order" is generated in the output shaft 203 of the differential. This shaft operates the transmitters 204 and 205, which in turn operate the reproducers 211 and 212 in the turret, whereby the gun "trainer" is instructed to adjust the gun 10 in train by the amount of "gun train order." It will be understood, of course, that the handwheel 193 will have been operated to introduce correction for horizontal parallax in terms of range.

The "gun elevation order" will be determined by the operation of the handwheels 27 in maintaining the line of sight 24a on the target. As previously pointed out, the director "pointer" operates the handwheels 27 so as to operate the mirror 25 to bring the line of sight 24a on the target in the position of the roll of the ship where it is desired the gun 10 shall be fired. The "sight angle," which is the correction for the range to be applied to the gun 10 in elevation will be calculated in the remote range keeper and transmitter to the director where it is reproduced by the receivers 29 and 30. When the handwheel 28 is operated to generate in the shaft 38, the value of "sight angle," as indicated on the dials 34 and 35, the value is automatically introduced in the trunnion tilt mechanism 56 where the mimic gun 70 is elevated by the amount of "sight angle." This mechanism, as has been previously pointed out, shifts the mimic gun to regenerate this value as "corrected sight angle" in the shaft 57 which operates through the differential 140 to turn the mirror 25 from its adjusted position. The director "pointer" previously had operated the handwheels 27 so as to hold the line of sight in a predetermined relation with the gun which he chose arbitrarily. When the "pointer" notices

that the line of sight is not on the target at the position in the roll of the ship in which he desires it to cross the target, he again operates his handwheels 27 to restore the line of sight to the target at the desired point in the roll. In returning the line of sight to the target, the "pointer" operates the transmitters of angular motion 158 and 159 to generate "gun elevation order." This operation is repeated until the "pointer" feels that the target is brought onto his sight at the proper point in the roll of the ship for fire.

This method of control in elevation possesses the advantage that the line of sight is weaved up and down, rather than the gun 10 itself, as the trunnion tilt correction is continually changed to compensate for roll and pitch of the ship.

It will be understood, of course, that the handwheel 152a will have been operated so as to introduce the proper value for the vertical parallax, whereby the "gun train order" takes into account the elevation of the director 11 above the gun 10.

The gun "pointer" adjusts his gun in elevation in accordance with the amount and direction of displacement of the dials 170 and 171 to reproduce in the turret 10a the value of "gun train order" generated in the director station.

As previously pointed out, when the gun 10 is adjusted in elevation, the dials 172 and 173 are driven with the gun to indicate the angle of elevation, while the dials 170 and 171 are returned to their zero positions. Of course, when the dials 170 and 171 are returned to their zero positions, the angle of "gun train order" will have been imparted to the gun. Similarly, when the gun "trainer" operates the handwheels 218 to adjust the gun in train, he will operate the ring dial 215 to follow the dial 213 and the dial 217 to follow the dial 214. The dials 216 and 217 will be operated to indicate the angle of adjustment in train, while the dial 214 will be returned to its zero position.

In Fig. 12, there is illustrated a modified mechanism for compensating for tilt of the gun trunnions, which in general has the same construction as that shown in Fig. 5, and which operates on the same principle. In Fig. 12, however, there are certain differences in details of construction. For example, the differentials corresponding to the differentials 75 and 86 are located in the low speed portions of the mechanism, rather than in the high speed portions of the mechanism, as is the case of Fig. 5. As shown in Fig. 12, the mimic gun 245 is provided with trunnions 246 which are mounted in a ring 247 to rotate on the axis $x'-x'$. The ring 247 is supported on the ring 248 for rotation in train in the axis $y'-y'$. This ring 248 is provided with trunnions 249 which are mounted in fixed bearings 250 so that the ring rotates on the fixed axis $a-a$.

The mimic gun 245 is operated in elevation by means of a "sight angle" input shaft 251, which as shown drives a worm shaft 252 through bevel gears 253. The shaft 252 carries a worm 254, which meshes with a worm wheel 255 on a shaft 256. The shaft 256 operates a differential 257; as shown, the shaft 256 is connected with the input gear 257a of the differential by means of spur gears 258. The output gear 257b of the differential 257 is mechanically connected to drive the spur gear 259 by means of a spur gear 260. The spur gear 259 drives a shaft 261 through a spur gear 262. The shaft 261 is mounted on one of the upright arms of the ring 248, the left hand arm, as shown in Fig. 12, and functions to drive a

shaft 263 also mounted in the ring 248, and as shown arranged at right angles to the shaft 261; the shaft 261 is connected with the shaft 263 through bevel gears 264. The shaft 263 is connected with the mimic gun 245 to adjust it in elevation through a differential 265. As shown, the shaft 263 is connected with the input gear 265a of the differential through the spur gears 266. The output gear 265b of this differential is mechanically connected with a shaft 267 through spur gears 268. The shaft 267 is mechanically connected to the trunnions 246 of the mimic gun 245 by means of bevel gears 269.

It will be observed in view of the foregoing that when the shaft 251 is operated it will operate the mimic gun 245 in elevation through the worm shaft 254, the differential 257, the shaft 261, the shaft 263, differential 265 and the shaft 267. To adjust the mimic gun in elevation, the shaft 251 in this particular form of the invention is operated at 240 speed, the shaft 252 at 80 speed, and the shafts 261 and 263 at 1 speed, which in turn operate the shaft 267 and the mimic gun 245 at 1 speed.

The "sight angle" input shaft 251 has been shown diagrammatically as operated by a handwheel 270, but it will be understood that this shaft will be operated by a mechanism similar to the mechanism which drives the shaft 38 of the first form shown in Figs. 1 and 5. As shown, the handwheel 270 may be connected to shaft 251 by means of a shaft 270a which is connected with the shaft 251 by bevel gears 270b. A scale 270c is shown as means supplied to assist in setting "sight angle" correction.

The calculated value for "sight deflection" is introduced into the mechanism by the shaft 271, which is operated by a handwheel 272 through a shaft 273, which is connected with shaft 271 by means of bevel gears 273a. A dial 273b similar to dial 270c is provided. The shaft 271 drives a shaft 274 through bevel gears 275. The shaft 274 drives a worm 276 which in turn drives a worm wheel 277 mounted upon a shaft 278. The shaft 278 operates through a differential 279 to drive a spur gear 280, which in turn drives a shaft 281 through a spur gear 282. As shown, the shaft 278 is connected to the input gear 279a of the differential, the output gear 279b of which is connected to the gear 280 through a spur gear 283. The shaft 281 is mounted in the ring 248, as shown, and is mechanically connected to the ring 247 through a shaft 284 which is secured to the ring 247 and which is connected with the shaft 281 by means of bevel gears 285. When the handwheel 272 is operated, the motion of the wheel is transmitted to the ring 247 to adjust the mimic gun 245 in train through the shaft 271, the shaft 274, the shaft 278, the differential 279, gears 283 and 280, and the shaft 281 and 284. The shaft 271 is driven at 240 speed, while the shafts 281 and 284, the ring 247 and mimic gun are all driven at 1 speed.

It will be observed that when the ring 247 is rotated on its train axis, the bevel gear 269 carried upon the trunnions 246 of the mimic gun 245 will revolve on the gear 269 carried by the shaft 267 so that the position of the mimic gun in elevation will be changed by the amount of "deflection" turned in unless this movement is suitably compensated for. It is for the purpose of making this compensation that the differential 265 has been provided. It will be observed that when the shaft 284 is rotated to adjust the ring 247 in train, it will at the same time rotate a shaft

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286 through spur gears 287. The shaft 286 is connected to the planetary gears 265c of the differential 265. The gearing is so arranged that when the ring 247 is operated in train, the differential device 265 will be operated by the shaft 286 to subtract an angle equal to that through which the mimic gun would have been moved by movement of the ring 247 in train so that the mimic gun is held in its correct adjusted position in elevation. The shaft 286 is driven at $\frac{1}{2}$ speed from the shaft 284.

The motions of the mimic gun 245 in elevation and train are transmitted to a suitable bail 288 which is pivoted to rotate on a ring 289 in an axis c—c; this ring in turn rotates on the fixed axis b—b. The muzzle 245a of the mimic gun is pivotally connected to the bail 288. Secured to rotate with the bail 288 is a gear segment 290 and meshing with this gear segment is a similar segment 290a which is carried by a shaft 291. The shaft 291 is mounted to rotate in a vertical arm of ring 289, the left-hand arm as shown in Fig. 12. The shaft 291 is connected to rotate a shaft 292 mounted in the axis of rotation of the ring 289 by means of bevel gears 293. The shaft 292 drives the "corrected sight angle" output shaft 294 through a differential 295. As shown, the shaft 292 is connected to the input gear 295a of the differential by means of spur gears 296, and the output gear 295b of this differential is connected to the shaft 294 through spur gears 297. In view of the foregoing arrangement, it will be observed that movement of the mimic gun in elevation will be transmitted to the shaft 294.

The adjustment of the mimic gun 245 in train is transmitted to the "corrected sight deflection" output shaft 298. As shown, the movement of the mimic gun in train carries the bail 288 with it and the motion of the bail is imparted to the ring 289 about its axis of rotation b—b. This motion of the ring 289 is transmitted to a shaft 299 through a gear 300 secured to the ring and which meshes with a gear 301 carried by the shaft 299. The shaft 299 is secured to the planetary gears 295c of the differential 295 and also is mechanically connected to the output shaft 298 through spur gears 302.

The mimic gun, as has been pointed out, moves at 1 speed in elevation and train. The gear segment 290 is driven at 1 speed, the shaft 291 at 3 speed, the shaft 292 at 3 speed, while the "corrected sight angle" shaft 294 is driven at 24 speed. In "sight deflection," the ring 289, of course, is driven at 1 speed with the mimic gun, the shaft 299 is driven at 2 speed, and the "corrected sight deflection" shaft 298 is driven at 6 speed.

It will be observed that when the ring 289 is adjusted in train, the gear 293 carried on the shaft 292, which controls the "corrected sight angle" output, rotates with reference to the gear 293 carried on the shaft 291 so that unless otherwise compensated for, the shaft 294 will be operated by the "sight deflection" output mechanism. It is the function of the differential 295 to make this compensation. When the shaft 299 is operated by the ring 289, it will operate the planetary gears 295c of the differential 295 to subtract an angle equal to that which is introduced into the differential by the shaft 292 in response to motion of the ring 289, whereby the position of the shaft 294 remains unchanged when the ring 289 is operated.

The angle of cross roll of the ship about the

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line of sight is imparted to the ring 248 by means of a shaft 303 which is driven by mechanism similar to that which drives the shaft 131 of the form of this invention shown in Figs. 1 to 11, inclusive. The shaft 303 drives a shaft 304 through bevel gears 305. The shaft 304 drives a worm 306 which in turn drives a worm wheel 307 mounted upon a shaft 308. The shaft 308 drives one of the trunnions 249 of the ring 248, the right hand trunnion as viewed in Fig. 12, through spur gears 309 and 310. The shaft 303 is driven at 90 speed, the shaft 304 at 90 speed, the shaft 308 at 3 speed, while the shaft 249, that is, the trunnion of the ring 248, is driven at 1 speed. When the ring 248 is inclined, it functions to correct the "sight angle" and "sight deflection" corrections in the shafts 294 and 298 respectively for tilt of the gun trunnions in precisely the same fashion as does the ring 73 of the form of corrector shown in Fig. 5.

It will be observed that when the ring 248 is inclined in response to the operation of the shaft 303, the shaft 281 mounted in the ring 248 will be revolved due to the interaction of the bevel gears 285 and that the motion of this shaft will tend to change the train adjustment of the mimic gun 245. This motion imparted to the shaft 281 is compensated for in the differential 279. As shown, the gear 310 driven by the shaft 303 also drives a shaft 311 through a spur gear 312. The shaft 311 is connected to the planetary gears 279c of the differential 279. The gearing is so arranged that when the ring 248 is inclined, and as a result the shaft 281 tends to move from its adjusted position, the differential 279 will be operated to introduce an equal angle but of opposite sign whereby the shaft 281, and hence, the mimic gun, hold their correct train adjusted positions.

In a similar manner, when the ring 248 is inclined, the shaft 261 carried by it will tend to rotate about the gear 259 and unless this tendency were compensated for, the adjustments of the mimic gun 245 in elevation would be changed. The differential 257 provides this compensation. As shown, the left-hand trunnion 249 carries a gear 313 which meshes with a gear 314 carried by a shaft 315. The shaft 315 is mechanically connected to the planetary gears 257c of the differential 257 so that when the ring 248 is inclined, the differential will be operated to subtract an angle equal to that which would be imparted to the shaft 261 by inclination of the ring, whereby the mimic gun holds its correct adjusted position in elevation. The shaft 315 is driven at 2 speed by the trunnion 249.

The operation of this form of the trunnion tilt compensator is the same as that described in Figs. 5 to 11 inclusive. It will be observed, however, that the differential devices 257, 265, and 279 of the form shown in Fig. 12 are located in relatively low speed portions of the mechanism, whereas those in the form shown in Fig. 5 are located in relatively high speed portions of the mechanism. The advantage of the form shown in Fig. 5 is that the differentials can be made considerably smaller than those shown in Fig. 12, and provide greater accuracy.

The axes $x'-x'$, $y'-y'$, $a-a$, $b-b$, and $c-c$ correspond to the similarly indicated axes of Fig. 5.

In Fig. 13, there is illustrated still another modified form of trunnion tilt correction mechanism. In this form, the mimic gun 316 has a U shape, as shown, the ends of the two legs of

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the U being pivotally mounted upon a support 317 of cross shape. The arm 317a of the member 317 supports the mimic gun to move in elevation on the axis $x'-x'$ which corresponds to the axis $x'-x'$ of Fig. 5. The arm 317b of the support is mounted in a ring 318 to rotate on an axis $y'-y'$ corresponding to axis $y'-y'$ of Fig. 5.

The mimic gun 316 is moved in elevation to generate "sight angle" by means of a "sight angle" input shaft 319, which corresponds to shaft 38 of Fig. 5. The shaft 319 is connected to the mimic gun through a differential device 320. As shown, the shaft 319 is connected to the input gear 320a of the differential device by means of spur gears 321. The output gear 320b of the differential is mechanically connected to a shaft 322 through gears 323. The shaft 322 in turn is mechanically connected to a shaft 324 through gears 325. The shaft 324 drives a worm 326 which meshes with a worm rack 327. The rack 327 is connected to drive a shaft 328 which in turn drives a gear segment 329. The gear segment 329 meshes with a gear 330 which drives a gear 331. The gear 331 in turn drives a gear segment 332, which is connected to one arm of the mimic gun 316, the right hand arm, as viewed in Fig. 13. The gears 330 and 331 are mounted to rotate freely on the shaft 317c in the axis $y'-y'$. That is, the gears 330 and 331 do not drive the shaft 317c. It will be observed in view of the foregoing arrangement that when the shaft 319 is operated, it will adjust the mimic gun 316 in elevation through the differential device 320, the shaft 322, the shaft 324, the shaft 328, and the gears 329, 330, 331, and 332. The sight angle input shaft 319 is driven at 216 speed, the shaft 322 is driven at 108 speed, the shaft 328 is driven at 1 speed, the gear 330 is driven at 1 speed, and the gears 331, 332 and the mimic gun 316 are driven at 1 speed.

The mimic gun 316 is adjusted in train to generate "sight deflection" by means of a "sight deflection" input shaft 333. The shaft 333 is connected through a differential device 334. As shown, the shaft 333 is connected to the input gear 334a of the differential by means of gears 335. The planetary gears 334b of the differential are mechanically connected to drive a shaft 336. The shaft 336 is connected to a shaft 337 through gears 338. The shaft 337 is connected to drive a shaft 339 through gears 340. The shaft 339 drives a worm 341 which in turn drives a gear segment 342. The gear segment 342 drives a shaft 343, which in turn drives a gear segment 344. This gear segment 344 meshes with a gear segment 345 which is connected directly to the arm 317b of the support 317 so that when it is operated, it adjusts the mimic gun 316 in train about the axis $y'-y'$. The shaft 333 is driven at 216 speed, the shaft 336 is driven at 216, the shafts 337 and 339 are driven at 120 speed, the shaft 343 is driven at 1 speed, and the gear segment 345 and the mimic gun are moved at 1 speed. It is to be noted that the vertical arm 317b of the support 317 is mounted to rotate freely upon the shaft 317c. That is, the motion of the mimic gun in train does not impart any motion to the shaft 317c.

The adjustments of the mimic gun 316 in elevation and train are imparted to a ring or bail 346. The bail is provided with trunnions 347 mounted in a ring 348 to rotate in an axis $c-c$ corresponding to axis $c-c$ of Fig. 5. The muzzle 316a of the mimic gun, as shown, is pivotally connected to the bail 346.

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The movement of the bail 346 in elevation by the mimic gun 316 is imparted to a "corrected sight angle" shaft 349 by means of a gear segment 350, which is secured to move with the bail 346, as shown in Fig. 13, and which meshes with a gear 351 connected to drive a shaft 352. The shaft 352 is mounted in the ring 348, as shown, and drives a shaft 353 through gears 354. The shaft 353, as well as the ring 348, are arranged to rotate in a fixed axis $b-b$, which corresponds to the fixed axis $b-b$ of Fig. 5. The shaft 353 is mechanically connected to drive the output shaft 349 through a differential 355. As shown, the shaft 353 is connected to the input gear 355a of the differential through gears 356. The planetary gears 355c of the differential device are connected to a shaft 357, which is connected to the output shaft 349 by means of gears 358. The gear segment 350 is driven at 1 speed, the gear 351 at 4 speed, the shaft 352 and the shaft 353 are driven at 4 speed, the shaft 357 is driven at 12 speed and the shaft 349 is driven at 36 speed.

The adjustment of the bail 346 in train responsively to the operation of the mimic gun 316 in train is transmitted to a "corrected sight deflection" output shaft 359 by means of the ring 348 which drives a gear segment 360 that in turn drives the shaft 359 through a gear 361 meshing with the segment. The bail 346, the ring 348 and the gear segment 360 move at 1 speed, while the shaft 359 is driven at 6 speed from the gear rack 360.

The angle of cross roll about the line of sight is introduced into the mechanism by means of a shaft 362 which drives a shaft 363 through gears 364. The shaft 363 drives a shaft 365 through gears 366. The shaft 365 drives a worm 367 which drives a gear segment 368 attached to the ring 318 so as to shift its position on the fixed axis $a-a$ in accordance with the operation of the shaft 362. The shaft 362 is driven by mechanism similar to that which drives the cross level input shaft 131 of the first form of this invention described. The shaft 363 is driven at 108 speed, the shaft 365 is driven at 120 speed, while the gear segment 368 and the ring 318 are driven at 1 speed.

The differential devices 320, 334, and 355 perform functions similar to the corresponding differential devices in the trunnion tilt corrector mechanism shown in Fig. 5. Thus, it will be observed that when the ring 348 is adjusted in train responsively to the operation of the mimic gun 316, motion will be imparted to the "sight angle" shaft 353 by reason of the fact that the gear 354 attached to it will rotate on the gear 351 attached to the shaft 352. This, of course, would introduce an error into the adjustment of the "sight angle" shaft 349. However, when the ring 348 is adjusted in train, the angle of error that would be imparted to the shaft 349 is subtracted in the differential 355. For this purpose, the ring 348 is connected to an input gear 355b of the differential device 355 through gears 369.

Moreover, when the shaft 333 is operated to adjust the mimic gun in train, it will be observed that the position of the mimic gun in elevation would be changed by the interaction of the gear segment 332 with the gear 331, unless this movement were compensated for. This is compensated for in the differential device 320. As shown, the shaft 336 which is driven by the shaft 333 through the differential 334 is mechanically con-

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connected to a shaft 370 through the shaft 337, which is connected to the shaft 370 by gears 371. The shaft 370 is mechanically connected to the planetary gears 320c of the differential 320 through gears 372. Thus, when the shaft 333 is operated to adjust the mimic gun in train, it will operate the differential device 320 at the same time to subtract in this device the angle of error that would be imparted to the mimic gun in elevation by the adjustment of the mimic gun in train.

Furthermore, when the cross level shaft 362 is operated to adjust the position of the cross level ring 318, the gear segment 345 will rotate on the gear 344 so as to introduce an error in the train adjustment of the mimic gun, and the position of the mimic gun in elevation would tend to change by the interaction of the gearing 329 and 330. The differentials 334 and 320 compensate for these errors respectively. It will be observed that the shaft 363 is connected to the input gear 334c of the differential 334 by means of gears 373 so that when the shaft 363 is operated to adjust the ring 318, the shaft 336 will at the same time be operated through the differential device 334 to operate the mimic gun to hold it in correct adjusted position in train. The shaft 336 also will operate the differential 320 through gears 371, shaft 370 and gears 372 to hold the mimic gun in its correct adjusted position in elevation.

The operation of this form of the trunnion tilt compensator is substantially the same as that described in Figs. 5 to 11 inclusive and that described in Fig. 12. In this case, as in the case of Fig. 5, the differential devices are located in the high speed portions of the mechanism which is an advantage in that the differentials can be made smaller and operate more accurately. Furthermore, in the compensator of Fig. 13, the mimic gun 316 having a U shape and being somewhat larger than the mimic guns of the other two forms will have a greater mechanical strength.

It is to be noted in particular that the axes $x'-x'$ and $y'-y'$ of the trunnion tilt compensating mechanisms are representative of the axes $x-x$ and $y-y$ about which the main gun 10 is adjusted, but that it is unnecessary that the axes $x'-x'$ and $y'-y'$ bear any definite position or relationship on the ship with reference to the axes of the main gun. In other words, it is not necessary that the axis $x'-x'$ be parallel to the deck of the ship or that the axis $y'-y'$ be perpendicular to the deck of the ship. These axes are merely representative and may take any positions relative to the ship. Likewise, while the axes $a-a$ and $c-c$, and $b-b$, are representative of the true horizontal and vertical respectively, it is unnecessary that they actually be positioned or maintained in the true horizontal or in the true vertical. They may take any position with reference to the true horizontal and the true vertical. These features are very important in that they obviate the necessity of the provision of means for maintaining a true vertical.

It is to be understood that the numerical values of the speeds of various elements given in this specification are by way of example and are not to be interpreted as limiting the invention to these particular speeds; the speeds of operation of each of these elements may vary widely from the values given by way of example in the specification. The important feature is that in the forms of the invention shown in Figs. 5 and 13, the dif-

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ferential devices be located in parts of the mechanism that operate at speeds relatively high as compared with the speeds of operation of the mimic guns 70 and 316; in the form shown in Fig. 12, the differential devices operate in relatively low speed portions of the mechanism.

While we have shown particular embodiments of our invention, it will be understood, of course, that we do not wish to be limited thereto, since many modifications may be made, and we, therefore, contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a member adjustable about a set of train and elevation axes, means for adjusting said member about said axes in accordance with the calculated adjustments to be applied to said gun in train and elevation respectively reckoned with reference to a set of planes fixed with reference to the earth, means for inclining the positions of said axes with reference to said mount in accordance with the inclination of the trunnions of said gun due to inclination of said mount so as to cause said member to assume a position with reference to mutually normal planes fixed relatively to the mount corresponding to the position said gun assumes with reference to said set of planes fixed with reference to the earth when said calculated adjustments are applied to it and said mount is inclined, and means for measuring the angular movement of said member with reference to said mutually normal planes.

2. Gun directing apparatus for a gun mounted on a moving support, comprising a mimic gun, means mounting said mimic gun for adjustment about a pair of mutually perpendicular train and elevation axes, means for adjusting said mimic gun about said axes to generate the train and elevation adjustments calculated to be applied to said gun on mutually perpendicular train and elevation axes respectively reckoned with reference to true horizontal and vertical planes, means for shifting the position of the trunnions of said mimic gun with reference to a second set of mutually perpendicular axes fixed with reference to said moving support and representing true vertical and horizontal axes in accordance with the inclination of the trunnions of said gun due to movement of said support so as to cause said mimic gun to assume a position in space with reference to said axes fixed with reference to said moving support that said gun assumes in space with reference to the true vertical and horizontal when said calculated adjustments are applied to it and its trunnions are inclined by movement of said support and means measuring the angular movement of said mimic gun in train and elevation with reference to said axes fixed with reference to said moving support.

3. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a support for said mimic gun, means mounting said mimic gun on said support for adjustment on a pair of mutually perpendicular train and elevation axes, means for adjusting said mimic gun on said axes to generate the train and elevation adjustments calculated to be applied to said gun on mutually perpendicular train and elevation axes reckoned with reference to true horizontal and vertical

planes, means for inclining said support continuously with reference to a set of mutually perpendicular planes representative of the true vertical and horizontal and fixed with reference to said mount in accordance with the cross roll of said mount about the line of sight of a target so as to tilt the trunnions of said mimic gun to cause it to assume continuously a position with reference to said mutually perpendicular planes corresponding to the position said gun assumes with reference to true vertical and horizontal planes when said calculated adjustments are applied to it and the angular position of said mount is changing, a movable member connected to said mimic gun and means operated by movement of said member for generating the adjustments to be applied to said gun in both train and elevation.

4. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a support for said member mounting it for rotation about a second axis perpendicular to said first axis and representing the axis of adjustment of said gun in train, means mounting said support for rotation about a fixed axis representing a true horizontal axis, means for inclining said support about said fixed axis in accordance with the inclination of the trunnions of said gun due to inclination of said mount, a member mounted to move about a second fixed axis perpendicular to said first fixed axis and representing a true vertical, and a connecting member between said mimic gun and said last named member so that said last named member is moved to measure the angular position in train said mimic gun has with reference to the first of said two fixed axes, said connecting member being arranged to measure the position said mimic gun has in elevation with reference to the second of said two fixed axes.

5. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a ring, means supporting said member in said ring for adjustment in train about a second axis perpendicular to said first axis, said second axis representing the axis of adjustment of said gun in train, means mounting said ring for rotation about a fixed axis representing the horizontal, said fixed axis intersecting said first and second axes at their point of intersection, a second ring mounted to rotate about a second fixed axis representing the vertical perpendicular to said first fixed axis and intersecting it at the point of intersection of said first fixed axis with said first and second axes about which said mimic gun is adjusted, a member connecting the muzzle of said mimic gun with said second ring, means connected to said mimic gun to adjust it in elevation and train about said first and second axes in accordance with the calculated adjustment in elevation and train to be applied to said gun, means for shifting said first ring about said first fixed axis in accordance with the angle of cross roll of said mount across the line of sight of said target, whereby the trunnions of said mimic gun are shifted with reference to said two fixed axes, the position of said second ring adjusted by said

mimic gun measuring the position of said mimic gun in train with reference to the first of said fixed axes and means connected to said connecting member arranged to measure the position of said mimic gun in elevation with reference to the second of said fixed axes.

6. Gun directing apparatus for a real gun supported on a mount whose angular position varies, comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a ring, means supporting said member in said ring for adjustment in train about a second axis perpendicular to said first axis, said second axis representing the axis of adjustment of said gun in train, means mounting said ring for rotation about a fixed axis representing the horizontal, said fixed axis intersecting said first and second axes at their point of intersection, a second ring mounted to rotate about a second fixed axis representing the vertical perpendicular to said first fixed axis and intersecting it at the point of intersection of said first fixed axis with said first and second axes on which said mimic gun is adjusted, a member connecting the muzzle of said mimic gun with said second ring, a pair of shafts mounted on said first ring geared to said mimic gun and member respectively to adjust said mimic gun in elevation and train about said first named axes, means for operating said shafts so as to adjust said mimic gun in elevation and train to generate the calculated adjustment to be applied to the real gun in elevation and train, means for operating said first ring about its fixed axis so as to generate the angle of cross roll of said mount across the line of sight to said target, and means connected to said pair of shafts operating them responsively to the operation of said operating means for said first ring to compensate for the changes in adjustment applied to said mimic gun in elevation and train by the interaction of the gearing between said pair of shafts and said mimic gun and member respectively as said first ring in which said shafts are mounted is adjusted to generate said angle of cross roll.

7. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a first ring, means supporting said member in said ring for adjustment in train about a second axis perpendicular to said first axis, said second axis representing the axis of adjustment of said gun in train, means mounting said ring for rotation about a fixed axis representing the horizontal, said fixed axis intersecting said first and second axes at their point of intersection, a second ring mounted to rotate about a second fixed axis representing the vertical perpendicular to said first fixed axis and intersecting it at the point of intersection of said first fixed axis with said first and second axes about which said mimic gun is adjusted, a member connecting the muzzle of said mimic gun with said second ring, a pair of shafts mounted on said first ring geared to said mimic gun and member respectively to adjust said mimic gun in elevation and train about said two first named axes, a second pair of shafts generating respectively the calculated adjustments to be applied to said gun in elevation and train connected to said first named shafts respectively, the connections including respective differential de-

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vices, a shaft generating the angle of cross roll of said mount across the line of sight of said target, a driving connection between said last named shaft and said first ring and driving connections between said last named shaft and said differential devices arranged to operate said first pair of shafts through said differential devices to compensate for the changes in adjustment applied to said mimic gun in elevation and train by the interaction of the gears between said first pair of shafts and said mimic gun and member respectively as said first ring in which said shafts are mounted is adjusted to generate said angle of cross roll.

8. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a support for said member mounting it for rotation about a second axis perpendicular to said first axis and representing the axis of adjustment of said gun in train, a shaft for driving said mimic gun in elevation, gearing between said driving shaft and the trunnions of said mimic gun, a second shaft for driving said mimic gun in train, gearing between said second driving shaft and said support for adjusting said mimic gun in train and means operated responsively to the operation of said second driving shaft controlling the adjustment of said mimic gun in elevation to compensate for the change in adjustment of said mimic gun in elevation due to the interaction of the gearing between said first driving shaft and said trunnions when said member is operated to adjust said mimic gun in train.

9. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a first member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a support for said first member mounting it for rotation about a second axis perpendicular to said first axis and representing the axis of adjustment of said gun in train, means mounting said support for rotation about an axis fixed with reference to said mount representing a true horizontal axis, means for inclining said support about said fixed axis in accordance with the inclination of the trunnions of said gun due to inclination of said mount, a second member mounted to move about a second axis fixed with reference to said mount perpendicular to said first fixed axis and representing a true vertical, a connecting member between said mimic gun and said second member so that said second member is moved to measure the angular position in train said mimic gun has with reference to the first of said fixed axes, the position of said connecting member generating the angular position of said mimic gun in elevation referred to the second of said fixed axes, a shaft mounted in said second member, gearing between said connecting member and said shaft to operate said shaft to generate the position of said connecting member, a third member, gearing between said third member and said shaft for moving said third member to generate the position of said connecting member and thereby the position of said mimic gun in elevation, and means controlling the position of said third member responsively to the operation of said second member

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to compensate for the change in adjustment of said third member due to the interaction of the gearing between said shaft and said third member as said second member is moved to measure the angular position of said mimic gun in train.

10. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a mimic gun, a member supporting the trunnions of said mimic gun for adjustment of said mimic gun in elevation about an axis corresponding to the axis of adjustment of said gun in elevation, a ring, means supporting said member in said ring for adjustment in train about a second axis perpendicular to said first axis, said second axis representing the axis of adjustment of said gun in train, means mounting said ring for rotation about an axis fixed with reference to said mount and representing the horizontal, said fixed axis intersecting said first and second axes at their point of intersection, a second ring mounted to rotate about a second axis fixed with reference to said mount representing the vertical and perpendicular to said first fixed axis and intersecting it at the point of intersection of said first fixed axis with said first and second axes on which said mimic gun is adjusted, a member connecting the muzzle of said mimic gun with said second ring, a first pair of shafts geared to said mimic gun to adjust it in elevation and train about said two first named axes respectively, a second pair of shafts, means operating said second pair of shafts at relatively high speeds to generate respectively the calculated adjustments to be applied to said gun in elevation and train, gearing including differential devices between corresponding ones of said second pair of shafts and said first pair of shafts respectively, said gearing reducing said speeds in said second pair of shafts so that said first pair of shafts operates at relatively low speeds, and said differential devices connected so that they operate at relatively high speeds, means for adjusting the position of said first ring on its fixed axis in accordance with the angle of roll of said mount across the line of sight of said target, and means for operating said differential devices responsively to the adjustment of said first ring by its adjusting means so as to operate said first pair of shafts to compensate for changes in adjustments applied to said mimic gun in elevation and train by the interaction of the gearing between said first pair of shafts and said mimic gun and member as said first ring is adjusted to generate said angle of cross roll.

11. Gun directing mechanism for a gun mounted on ship board comprising a mimic gun, trunnions for said mimic gun, a ring mounting said trunnions so that said mimic gun can be adjusted in elevation on said trunnions, a second ring mounting said first ring for movement on an axis perpendicular to the axis of said trunnions, means mounting said second ring for rotation in a fixed axis perpendicular to the axis of movement of said first ring and intersecting said axis at the point of intersection of said axis with the axis of said trunnions, a third ring, means mounting said third ring for movement on a second fixed axis perpendicular to said first fixed axis and intersecting it at the point of intersection of the axis of said trunnions with the axis of movement of said first ring, a shaft mounted to rotate in said latter axis, gearing between said shaft and said trunnions arranged to adjust the mimic gun in elevation by operation of said shaft, a second shaft mounted to rotate in said first fixed axis,

gearing between said first and second shafts, a differential device connected to said second shaft, a driving shaft connected to said differential device to drive said second shaft through said differential device, a third shaft mounted to rotate in the axis of said first ring and connected to said ring to operate it, a fourth shaft mounted on said second ring, gearing between said third and fourth shafts, a second driving shaft, a second differential device effecting a driving connection between said second driving shaft, said fourth shaft, a third driving shaft for said second ring for inclining said second ring on its fixed axis of movement, driving connections between said third driving shaft and said differential devices so as to operate said devices to compensate for the changes in adjustments of said mimic gun in elevation imparted to it by the interaction of the gearing between said first and second shafts and in train by the interaction of the gearing between said third and fourth shafts when said second ring is inclined, and a driving connection between said second driving shaft and said first differential device including said second differential device so as to compensate for changes in the adjustment of said mimic gun in elevation due to interaction of said gearing between said trunnions and said first shaft when said first ring is moved on its axis, a bail pivoted to move on said third ring and connected to the muzzle of said mimic gun whereby said bail is moved in elevation to generate the angle of elevation of said mimic gun and said third ring is moved on its axis to generate the angle of train of said mimic gun, a fifth shaft mounted in said third ring, driving gearing between said bail and said fifth shaft, a sixth shaft mounted in the fixed axis of rotation of said third ring, driving gearing between said fifth and sixth shafts, a differential device driven by said sixth shaft and connected to drive a seventh shaft, and a driving connection between said differential device and said third ring so as to compensate for changes in adjustment otherwise applied to said seventh shaft by interaction of the gearing between said fifth and sixth shafts when said third ring is moved on its axis.

12. Gun directing mechanism for a gun mounted on ship board comprising a mimic gun, trunnions for said mimic gun, a ring mounting said trunnions so that said mimic gun can be adjusted in elevation on said trunnions, a second ring mounting said first ring for movement about an axis perpendicular to the axis of said trunnions, means mounting said second ring for rotation on a fixed axis perpendicular to the axis of movement of said first ring and intersecting said axis at the point of intersection of said axis with the axis of said trunnions, a third ring, means mounting said third ring for movement about a second fixed axis perpendicular to said first fixed axis and intersecting it at the point of intersection of the axis of said trunnions with the axis of movement of said first ring, a shaft mounted to rotate in the axis of movement of said first ring, gearing between said shaft and said trunnions arranged to adjust the mimic gun in elevation by operation of said shaft, a second shaft mounted to rotate in said second ring, gearing including a differential device connecting said first and second shafts, a driving shaft for said second shaft, gearing including a second differential device connecting said driving shaft with said second shaft, a third shaft mounted to rotate in the axis of said first ring connected to said ring

to operate it, a fourth shaft mounted in said second ring, gearing between said third and fourth shafts, a second driving shaft, gearing including a third differential device effecting a driving connection between said second driving shaft and said fourth shaft, a third driving shaft for said second ring for inclining said ring on its fixed axis of movement, driving connections between said third driving shaft and said second and third differential devices so as to operate said devices to compensate for the changes in adjustments of said mimic gun in elevation and train imparted to it by the interaction of the gearing between said second and fourth shafts and said first and second driving shafts when said second ring is inclined on its axis, a driving connection between said third shaft and said first differential device so as to compensate for changes in the adjustment of said mimic gun in elevation due to the interaction of said gearing between said mimic gun trunnions and said first shaft when said first ring is moved on its axis, a bail pivoted to move on said third ring and connected to the muzzle of said mimic gun whereby said bail is moved in elevation to generate the angle of elevation of said mimic gun, and said third ring is moved on its axis to generate the angle of train of said mimic gun, a fifth shaft mounted in said third ring, driving gearing between said bail and said fifth shaft, a sixth shaft mounted in the fixed axis of rotation of said third ring, driving gearing between said fifth and sixth shafts, a fourth differential device driven by said sixth shaft and connected to drive a seventh shaft, and a driving connection between said fourth differential device and said third ring so as to compensate for changes in adjustment otherwise applied to said seventh shaft by interaction of the gearing between said fifth and sixth shafts when said third ring is moved on its axis.

13. Gun directing mechanism for a gun mounted on ship board comprising a mimic gun of U shape, a support for said mimic gun of cross shape, means pivotally connecting the legs of said mimic gun for adjustment in elevation to one arm of said cross-shaped support, a ring, a shaft mounted on said ring at right angles to the arm supporting said mimic gun, the other arm of said support mounted to rotate on said shaft, means mounting said ring for rotation on a fixed axis perpendicular to said shaft, and intersecting it at the point of intersection of said shaft and said axis of movement of said mimic gun in elevation, a second shaft mounted on said ring, gearing connecting said second shaft with said mimic gun for adjusting said mimic gun in elevation by operation of said second shaft, a driving shaft for said second shaft, gearing including a differential device connecting said driving shaft with said second shaft, a third shaft mounted in said ring, gearing between said third shaft and said support for moving said support and mimic gun in train by operation of said third shaft, a second driving shaft, gearing including a second differential device connecting said second driving shaft with said third shaft, a third driving shaft for said ring for inclining said ring on its fixed axis of movement, driving connections between said third driving shaft and said differential devices so as to operate said devices to compensate for the changes in adjustment of said mimic gun in elevation and train imparted to it by the interaction of the gearing between said mimic gun and said second and third named shafts when said ring is inclined, and between said second driving

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shaft and said first differential device so as to compensate for changes in the adjustment of said mimic gun in elevation due to interaction of the gearing between said mimic gun and said second shaft when said ring is moved on its axis, a second ring mounted to move in a second fixed axis perpendicular to said first fixed axis and intersecting it at the point of intersection of said first fixed axis with said first shaft and the axis of movement of said mimic gun in elevation, a bail pivoted to move on said second ring and connected to the muzzle of said mimic gun whereby said bail is moved in elevation to generate the angle of elevation of said mimic gun and said second ring is moved on its axis to generate the angle of train of said mimic gun, a fourth shaft mounted in said second ring, driving gearing between said bail and said fourth shaft, a fifth shaft mounted in said axis of rotation of said second ring, driving gearing between said fourth and fifth shafts, a third differential device driven by said fifth shaft and connected to drive a sixth shaft and a driving connection between said third differential device and said second ring so as to compensate for the change in adjustment applied to said sixth shaft by the interaction of the gearing between said fourth and fifth shafts when said second ring is moved on its axis.

14. Gun directing apparatus for a real gun mounted on ship board comprising a sighting device, means mounting said sighting device for adjustment on elevation and train axes angularly fixed with reference to said ship, a control member, a driving connection between said control member and said sighting device including a differential device, a mimic gun, means mounting said mimic gun for adjustment on an elevation axis, means for adjusting said mimic gun on said axis to introduce the calculated adjustment to be applied to said real gun in elevation measured with reference to the true horizontal, means continuously inclining said axis with relation to a set of planes fixed with reference to said ship in accordance with the angular movement of the trunnions of the real gun in the vertical plane through them as the angular position of said ship varies, and a driving connection between said mimic gun and said differential device arranged so that the positions assumed by said mimic gun with relation to said fixed planes when adjusted on its axis in elevation to introduce said calculated adjustment and when said axis is inclined in accordance with said angular movement of said trunnions of the real gun are applied to said sighting device through said differential device.

15. A system of gun fire control for a gun mounted on a war ship comprising a sighting device remote from the gun, means mounting said sighting device for adjustment in elevation on an axis parallel with the deck of the ship, a control member for adjusting said sighting device on its elevation axis, a driving connection including a differential device between said control member and said sighting device, a mimic gun, means mounting the trunnions of said mimic gun on an axis for adjustment in elevation, a movable member supporting said trunnions, means for moving said member to incline said trunnions of said mimic gun with reference to a set of planes fixed with relation to said ship and in accordance with the tilt of the trunnions of said gun when said deck inclines from the horizontal, and a driving connection between said

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mimic gun and said differential device arranged so that the positions assumed by said mimic gun when adjusted in elevation on its axis and when said axis is inclined with reference to said set of fixed planes are applied to said sighting device through said differential device.

16. Gun directing apparatus for a gun supported on a mount whose angular position varies comprising a sighting device, means for adjusting said sighting device in train to cause it to bear on a target and thereby generate the bearing of said target, a mimic gun, means mounting said mimic gun for movement about an axis perpendicular to its trunnions to generate a train adjustment to be applied to said gun reckoned with reference to a true horizontal plane, means for inclining said axis with reference to a set of mutually perpendicular planes representative of the true vertical and horizontal and fixed with reference to said mount in accordance with the inclination of said mount so that said mimic gun assumes a position with reference to said mutually perpendicular fixed plane corresponding to the position that said gun assumes with reference to the true vertical and horizontal when said mount inclines and when said train adjustment is applied to it, means for measuring the train position of said mimic gun with reference to said mutually perpendicular fixed plane and means operated by said last named means and by said sighting device when adjusted in train for generating the adjustment to be applied to said gun in train.

17. Gun directing apparatus for a gun mounted on a war ship comprising means mounting the trunnions of said gun for adjustment in train on an axis perpendicular to the deck of said ship, a sighting device remote from said gun adjustable in train on an axis parallel with said axis of adjustment of said gun so that said sighting device can be brought to bear on a target, a member operated by said sighting device for generating the bearing of a target, a differential device operated by said member, motion transmitting means driven by said differential device, motion receiving means adjacent said gun controlled by said transmitting means, a mimic gun, means mounting said mimic gun for adjustment in a train axis corresponding to the train axes of adjustment of said gun and sighting device, means for adjusting said mimic gun on said axis to generate a correction to be applied to said gun in train measured with reference to a true horizontal plane, means for inclining said axis of adjustment with reference to a set of mutually perpendicular planes representative of the true vertical and horizontal and fixed with reference to said ship to cause said mimic gun to assume a position with reference to said mutually perpendicular fixed planes corresponding to the position that said gun assumes with reference to the true vertical and horizontal when said deck inclines so as to regenerate said adjustment applied to it in accordance with the tilt of said gun trunnions, a second member connected to said mimic gun so as to generate said regenerated adjustment and connected to said differential device so as to combine in said device said regenerated adjustment with said bearing, said transmitting means being operated to transmit to said receiving means the resultant adjustment to be applied to said gun in train.

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