

May 6, 1924.

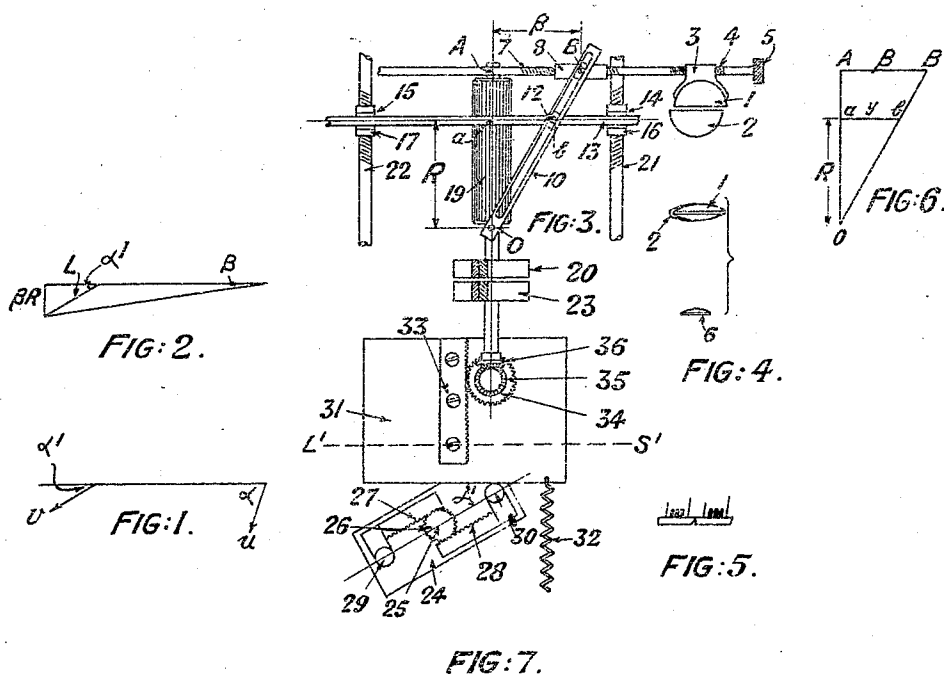
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A. BARR ET AL

FIRE CONTROL APPARATUS

Filed Aug. 26, 1921

4 Sheets-Sheet 1



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 Archibald Barr
 William Stroud,
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 Attorney

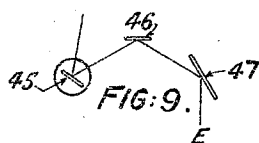
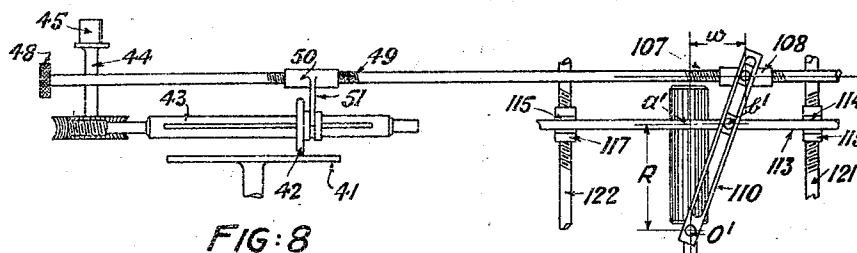
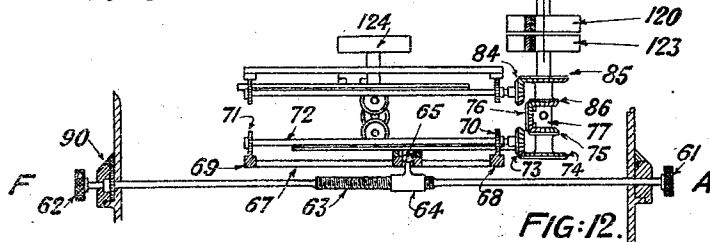
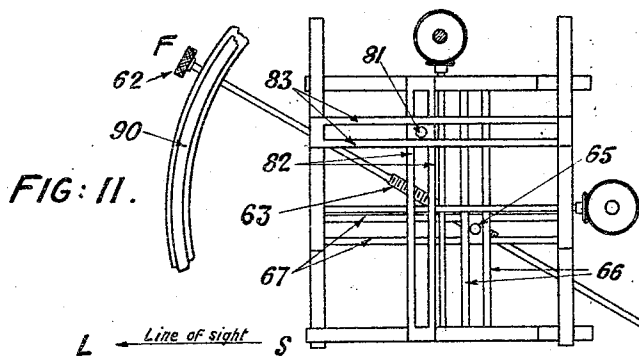
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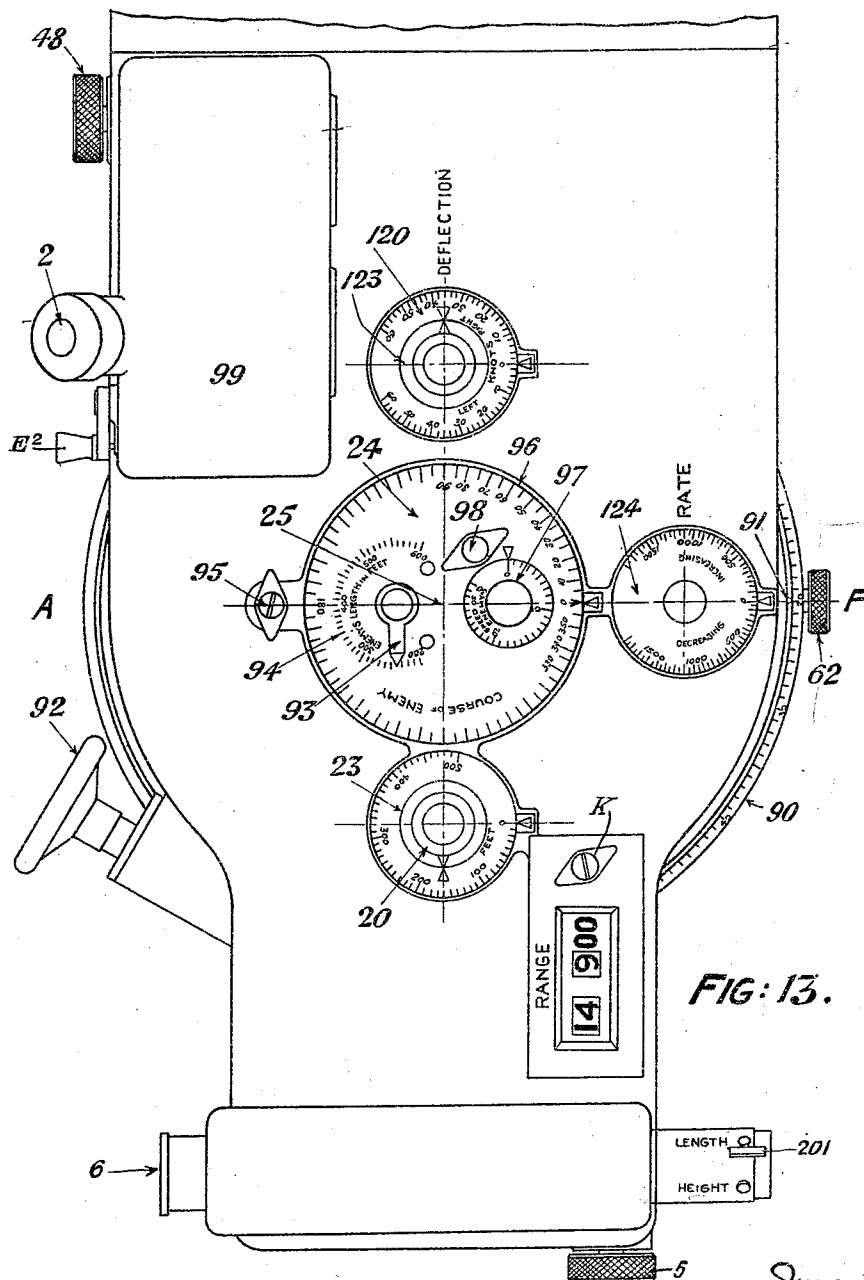
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A. BARR ET AL
FIRE CONTROL APPARATUS

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4 Sheets-Sheet 3



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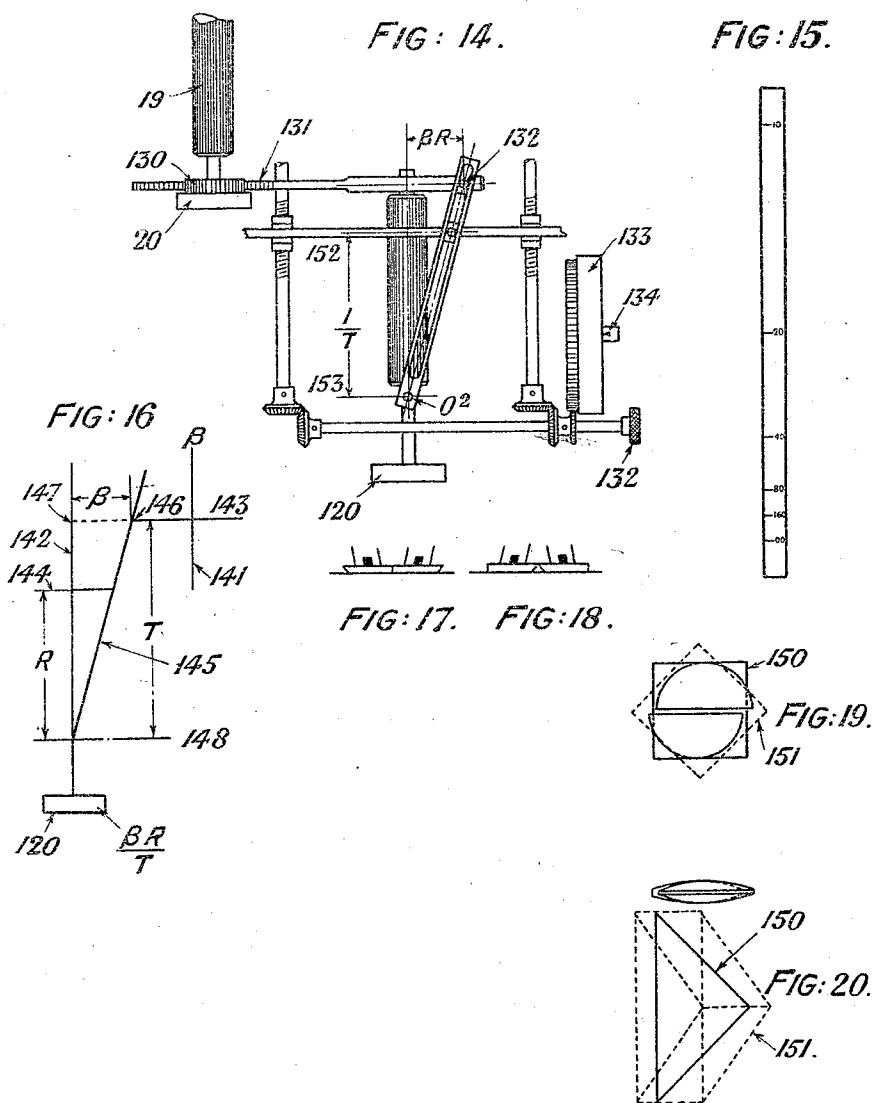
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A. BARR ET AL
FIRE CONTROL APPARATUS

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4 Sheets-Sheet 4



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Patented May 6, 1924.

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UNITED STATES PATENT OFFICE.

ARCHIBALD BARR AND WILLIAM STROUD, OF ANNIESLAND, GLASGOW, SCOTLAND,
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FIRE-CONTROL APPARATUS.

Application filed August 26, 1921. Serial No. 495,549.

(GRANTED UNDER THE PROVISIONS OF THE ACT OF MARCH 3, 1921, 41 STAT. L., 1313.)

To all whom it may concern:

Be it known that we, ARCHIBALD BARR and WILLIAM STROUD, subjects of the King of Great Britain and Ireland, and both of
 5 Caxton Street, Anniesland, Glasgow, Scot-
 land, have invented new and useful im-
 provements in fire-control apparatus—
 means for measuring the course and speed
 of a target and thereby determining the
 10 rate of change of range and deflection, for
 which we have filed application in Great
 Britain, No. 18,546, dated 11th August, 1914,
 and of which the following is a specification.

Our invention is a development of that
 15 disclosed in the specification of British
 Patent No. 1510 of 1911 (United States
 Patent No. 1,177,470 dated 28th March
 1916) for an instrument to determine the
 rate of change of range and deflection of a
 20 target from the estimated course and speed
 of the target and other data.

One of the chief features of the present
 invention consists in the provision of means
 for determining the course and speed of
 25 the target, which data can then be employed
 in determining the rate of change of range
 and the deflection of the target or for other
 purposes.

In the determination of the direction of
 30 motion of the target we shall assume in the
 first instance that we know or have deter-
 mined the length of a portion of the target,
 say the distance between two masts, or the
 35 whole length of the target, say from bow
 to stern, and have also determined the range
 of the target. A measurement of the angle
 β subtended at the observing station by the
 known length of the target will then fur-
 40 nish the means of determining the direc-
 tion of motion of the target. In the general
 case there will be four solutions, which may
 be reduced at once to two by observing
 whether the bow is directed towards the
 right or left hand side of the observer.
 45 These two solutions correspond to the two
 cases of (a) the target moving towards or
 (b) the target moving from the observer
 in a direction inclined at an angle α^1 to
 the line of sight. When the range is not
 50 very great it will usually be possible to
 distinguish easily between these cases, from
 the general appearance of the ship and of

the waterline. At great ranges when the
 target first becomes visible, it may be nec-
 55 essary in addition to ordinary observation
 to employ a rangefinder for determining
 whether the target is moving towards or
 from the observer. In such an observation
 with a rangefinder we must of course make
 allowance for the motion of our own ship
 60 to or from the target.

When the course of the target can be
 estimated with sufficient accuracy (as will
 be the case when the target presents its
 whole broadside) the measurement of the
 65 subtended angle β and of the range will en-
 able the length of the target to be deter-
 mined instead of being estimated or taken
 from a catalogue of battleship lengths.

If the length of the target, or a selected
 70 portion of the target, (assumed to be
 known) is L and the range (assumed to be
 approximately known) is R and if the
 known angle between the line of sight and
 the direction of motion of our own ship
 75 is α and the corresponding angle between
 the line of sight and the direction of mo-
 tion of the target is α^1 ; if further β is the
 measurement of the horizontal angle sub-
 tended at the observer by the length of
 80 the target then:—

$$\beta = \frac{L \sin \alpha^1}{R} \text{ and } \beta R = L \sin \alpha^1.$$

Either side of this equation represents the
 85 value of the projection of the selected part
 of the target in a direction perpendicular
 to the line of sight.

In an instrument constructed in accord-
 90 ance with our present invention we provide
 means of any suitable type for measuring
 angles in a horizontal plane, such as, e. g.
 that described in specification of British
 Patent No. 11025 of 1889, though other
 means may be employed for the purpose.
 95 Having measured β we multiply this value
 by the known value of the range R . The
 product βR may be exhibited upon a scale
 which may conveniently be in the form of a
 100 graduated disc.

We further provide a "course plate" or
 "course arm" capable of being rotated
 about a centre and provided with a pin
 whose radial distance from the centre may

be adjusted to be proportional to the value of L . This pin may be arranged to engage in a slot lying parallel to the line of sight and mounted in a guide, the direction of which is at right angles to that of the slot and therefore normal to the line of sight. As this course plate or arm is rotated the slot will be constrained to move at right angles to the line of sight and the mechanism can be so arranged that, when the position of the plate, or arm, corresponds to the angle α^1 the amount of displacement from a zero position is proportional to $L \sin \alpha^1$ and this quantity can be indicated upon a second graduated disc which may conveniently be arranged to be concentric with the first mentioned graduated disc exhibiting the value (or proportional value) of βR .

To facilitate the operation of this part of the instrument we may provide upon the course plate or arm a conspicuous line (or pointer or representation of the plan of a ship or the like) the angular position of which pointer or other indication is to be set to correspond to the angular position of the aforesaid pin and to the course of the target relatively to the line of sight.

Having set off the radial distance of the pin proportional to L , we now proceed to turn the course plate until the pointer is on the right hand side relatively to the line of sight if the target is moving to the right, or vice versa, and until the said pointer is directed more or less towards the observer if the target is approaching, or vice versa. For this purpose the general direction of motion of the target may be got by direct observation in the ordinary way.

Having thus selected the particular quadrant to which the direction of motion corresponds, we next rotate the plate until the value of $L \sin \alpha^1$ upon the second graduated disc corresponds to the value of βR exhibited upon the first disc, β having previously been obtained by measurement.

We have now determined the direction of motion of the target, and have so set the mechanism that the line from the centre of rotation of the course plate to the centre of the pin corresponds to the direction of motion of the target.

It will be clear that the direction of motion of the target can be obtained with much greater accuracy in some cases than in others. The special case in which it is most difficult, is when α^1 is approximately 90° , in which case the accurate determination of direction will not be possible, but in this position the contribution to the rate of change of range resulting from the motion of the target is inconsiderable.

We shall next consider the question of determining the enemy's speed which we may

represent by v , assuming our own speed u to be known. For this purpose we may adopt one or other of two methods:—

(1) We may measure the angular velocity ω of the target relatively to our own ship. If we multiply this angular velocity by the range we get the deflection δ , i. e. the differential velocity of the target and our own ship perpendicular to the line of sight, or

$$R\omega = \delta = v \sin \alpha^1 \pm u \sin \alpha.$$

Now u , α and R are supposed to be known, α^1 has already been determined, and therefore after measuring ω we have all the data required for getting v .

To carry out the operation easily, we shall assume that we have an apparatus (which we call a "record") constructed in accordance with the specification of British Patent No. 1510 of 1911 (United States Patent No. 1,177,470 dated 28th March, 1916), but with the modifications described later in this specification, upon which, after setting off our own speed, and the speed of the target and the course of the target relatively to the line of sight, we can read off the deflection and the rate of change of range.

We start by setting off our own speed and by setting the course of the enemy as determined by the method already explained. We next determine ω by special observation, multiply this by R , and so get the deflection, δ . This deflection being now known, we adjust the speed of the target upon the "record" until the value of the deflection is equal to that found by observation, after doing which the rate of change of range can be read off.

(2) We may measure the time of transit, T , of the target across the vertical cross-wire of the field of view of a sighting device whose direction in space is maintained invariable, say by means of a gyroscope.

In this case

$$\delta = \frac{L \sin \alpha^1}{T} = \frac{\beta R}{T}$$

so that if we divide $L \sin \alpha^1$ by T we know the deflection and can proceed as before.

In the preceding description various operations have been described with very little reference to the means of carrying them out. These operations we proceed now to describe in greater detail:—

Measurement of β .—Instead of the method described in specification of British Patent No. 11025 of 1889, to which reference has already been made, we may use two sight bars pivoted about a common centre associated with means for directing one sight bar towards one end, say the bow, of the target and the other sight bar towards the other end, say the stern, and with means for

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measuring or indicating the angle β between the bars, or we may measure this angle by means of a telescope comprising a divided objective (a heliometer) associated with a suitably placed eyepiece. By moving one half-objective horizontally in its own plane with reference to the other half, we shall produce two images of the target and we may measure the angle β by the amount of separation of the two parts of the objective required to bring the bow of one of the images into contact with the stern of the second image. These are only some of the methods that may be employed for the measurement of the angle β .

Measurement of ω .—This may be effected by means of apparatus constructed in accordance with Barr & Stroud's specification of British Patent No. 17291 of 1910 (United States Patent No. 1,031,769 dated 9th July 1912), in which a gyroscope carrying a sighting device and spinning about a horizontal axis is caused to precess at an adjustable rate so as to keep the sights upon the target.

Another of the arrangements which we may adopt is as follows:—We may attach to a non-precessing gyroscope a mirror, half of which is silvered, the line of separation between the silvered and unsilvered parts being horizontal. Upon the frame of the instrument we may place two additional prisms or mirrors so situated that a triple reflection of the target in a horizontal plane is produced, viz, (1) by the one mirror (2) by the second mirror and (3) by the mirror attached to the gyroscope. By means of this triple reflection we shall get a laterally reversed image of the target and be rotating, say mirror (1) we may bring the mast of the target (seen directly through the unsilvered portion of the mirror first referred to) into coincidence with the mast as seen after triple reflection. Any rotation of the whole instrument in azimuth will not affect this coincidence if $\omega = 0$, because the gyro-mirror remains fixed in space and the effect of the turning of mirror (1) is counteracted by the equal and opposite effect of the turning of mirror (2), as in a sextant.

We may next provide well known means for producing an adjustable angular velocity about a vertical axis in the case of one of the mirrors (1) or (2), say (1). This may be done, e. g. by using the well known device consisting of a uniformly rotating friction disc driving a roller adjustable in distance from the axis of the disc and causing the rotation of the roller to rotate the mirror (1). If then the roller is at the centre of the disc, the mirror will not turn, but if the roller is moved radially from the centre the mirror will rotate about a vertical axis forwards or backwards at a rate

depending upon the displacement of the roller from the centre of the disc.

To measure the angular velocity after setting the gyro spinning we adjust mirror (1) or mirror (2) till the two images of the object under observation (say the mast of a ship) are in coincidence, after which we adjust the friction wheel relatively to the disc till the images keep in coincidence. The displacement of the wheel from the centre of the disc is then a measure of the required angular velocity.

Measurement of the range R .—The range of the target may be determined by means of a separate rangefinder or other apparatus or we may make use of the same apparatus as is used for the measurement of the angle β subtended at the position of observation by the target.

If upon the target there is some suitable known length, lying at right angles to the line of sight, the measurement of the angle subtended by it enables the range to be directly determined. In the case of a ship, vertical heights such as the height from the water line, or a deck level, to the top or some other prominent part of the mast, are alone suitable, as their apparent heights are not dependent upon the course of the ship, as are horizontal lengths. To make the means supplied for the measurement of β angles suitable for the measurement of ranges, we may add to or combine with it a system of reflectors which turns the image of the object through 90° . Thus in the case of a ship, when this system of reflectors is inserted, the mast would appear to lie horizontally and the operation of finding the range would consist in bringing together the two ends of the known height.

To effect the rotation of the image through 90° we may insert in the path of the rays of light a system of reflectors comprising three reflecting surfaces suitably placed. The reflected image from such a system of surfaces appears rotated through a right angle. Or we may effect the desired rotation by the use of a prism having an entering refracting face, then a reflecting surface, and then an exit refracting face. When such a prism is rotated about a longitudinal axis parallel to the reflecting surface and lying in the plane normal to the two refracting faces and the reflecting face, the reflected image appears to rotate with twice the angular velocity imparted to the prism. In one position of the prism an object such as the waterline of a ship would appear in its natural horizontal position and the arrangement would be suitable for the measurement of the β angles. When the prism is rotated through 45° the object would appear rotated through 90° and the arrangement would

then be suitable for the determination of ranges as above described.

Multiplication.—To effect this operation one method of procedure is as follows:—

5 Imagine a triangle OAB, in which the angle A is (say) a right angle. Let a line *ab* parallel to AB intersect OA and OB in *a* and *b* respectively: then,

$$10 \quad \frac{OA}{AB} = \frac{Oa}{ab} \text{ or } ab = \frac{Oa \times AB}{OA}$$

or if OA is kept constant, *ab* becomes a measure of the product of *Oa* and AB. Suppose, e. g., we want to multiply β and R. As we are measuring β we may move B to or from A so that AB is proportional to β . Let us next adjust *Oa* to be proportional to the range R; then the length of *ab* is a measure of the required product. To effect this operation mechanically and to show the resulting product upon a dial or drum, we may conceive of B as being a pin attached to a nut moving upon a screw parallel to AB. OB may be a grooved bar capable of rotation about O and engaging the pin B. The part *ab* may be a rack meshing with a long pinion rod represented by OA and having a pin at *b* engaging in the groove in OB. Suitable means may be provided for moving the rack *ab* to wards or from O in proportion to the range represented by *Oa*. We may provide a disc to indicate the amount of rotation of the pinion rod OA.

35 *Division.*—Here we require the value of

$$\frac{\beta R}{T}$$

40 in which three measured quantities are involved. We have, however, already provided means for getting the product βR . We may therefore provide similar extra means for getting the value of

$$45 \quad \frac{\beta R}{T}$$

Thus e. g. if we employ the method already described with a triangle $O^1A^1B^1$ having a^1b^1 parallel to A^1B^1 and if we arrange that A^1B^1 is made proportional to the value of βR already obtained and if we further keep O^1a^1 constant and adjust the length O^1A^1 relatively to O^1a^1 so that

55 O^1A^1 is proportional to T then the rotation of the pinion rod O^1A^1 will be a measure of the deflection. Or, we may proceed to multiply βR by $\frac{1}{T}$ i. e. A^1B^1 would be

60 made proportional to βR as already described O^1A^1 would be kept constant and O^1a^1 would be adjusted proportional to $\frac{1}{T}$, say by arranging that the mechanism as-

sociated with the adjustment of the length O^1a^1 should be provided with a reciprocal scale representing the various values of T .

There remains to be briefly described the modification in the record mentioned at the beginning of this specification. In the instrument described in the specification of British Patent No. 1510 of 1911 (United States Patent No. 1,177,470 dated 28th March 1916) the enemy's course was set off relatively to the keel of our own ship. Consequently if our own ship turned its course through, say 20° the enemy's course had to be turned through 20° although that course may not have altered. Our improvement consists in the means of setting off the enemy's course with reference to the line of sight instead of with reference to the keel of our own ship. One method of carrying this improvement into effect consists in duplicating certain parts of the apparatus described in specification of British Patent No. 1510 of 1911 (United States Patent No. 1,177,470 dated 28th March 1916). In Figure 4 of specification of British Patent No. 1510 of 1911 (United States Patent No. 1,177,470 dated 28th March 1916), the pin D which engages with the slotted bars 24 and 25 is set in a position which depends upon the speed of the target and its course relatively to the centre line of our own ship, and also upon the speed of our own ship as is illustrated in Figures 1 and 3 of the British, and Figures 1 and 5 of the United States patent. The movements of the slotted bars 24 and 25 depend upon the amount of the relative change of range and of the relative deflection. In our improved apparatus we may provide two pins D and D¹ which engage with two sets of parallel bars.

One of the pins is moved about the centre of B in accordance with changes in the course of the target relatively to the line of sight and in a radial direction according to the change in the speed of the target. The other pin is set relatively to the centre B in the fore and aft direction of our own ship and at a distance corresponding to the speed of our own ship. The movements of the one set of bars give an indication of the rate of change of range and of the deflection depending upon the course of the target relatively to the line of sight and upon the actual speed of the target, while the movements of the other set of bars gives corresponding data depending up on our own actual speed. The movements of the corresponding slotted bars of the two sets are combined by means of differential gears or equivalent devices so that an indication is obtained of the rate of change of range and the deflection of the target relatively to our own ship.

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The various mechanisms above described may be combined to constitute one instrument.

Some examples of construction of apparatus according to this invention will now be described with reference to the accompanying drawings, in which:—

Figures 1 and 2 and 6 are explanatory diagrams.

Figure 3 shows part of the arrangement for measuring the angle β and multiplying the result by R.

Figure 4 is a plan of one means for measuring the angle β , while Figure 5 shows the nature of the observation to be made in the operation.

Figure 7 shows an arrangement for exhibiting the value of $L \cos \alpha^1$.

Figure 8 shows one means for measuring the angular velocity of the target and for obtaining the value of the product ωR . Figure 9 shows a detail of Figure 8 in plan, and Figure 10 shows the nature of the observation to be carried out in the process of measuring the angular velocity.

Figure 11 shows a plan of one arrangement for measuring the components of the velocities of our own ship and the target along and perpendicular to the line of sight and for finding the algebraical sums of the components in each direction, while Figure 12 shows the same arrangement in elevation. In these figures the fore and aft line is represented by FA, but for clearness the position of this fore and aft line is turned round in Figure 12 so as to be in the plane of the paper.

Figure 13 is a plan of the complete apparatus.

Figure 14 represents one method of obtaining the value of the deflection from the time of transit method.

Fig. 15 represents a detail of Figure 14.

Figure 16 represents diagrammatically an alternative method of obtaining

$$\frac{\beta R}{T}$$

from the observed values of βR and T.

Figures 17 and 18 show the appearances presented in the observation of the time of transit method.

Figures 19 and 20 show a method of utilizing that part of the instrument which measures angles in a horizontal plane to be adapted for use in a vertical plane.

In the various figures the same numbers are used to indicate the same or like parts where these occur.

In the drawings an eyepiece associated with means for measuring the angular dimensions of the target is designated 6 and an eyepiece for observing the line of sight to the target is designated 2.

In Figure 1 u represents the velocity and direction of motion of our own ship inclined at an angle α to the line of sight and v and α^1 represent the corresponding values for the target. It will be seen that the rate of change of range is $v \cos \alpha^1 - u \cos \alpha$ and the deflection is $v \sin \alpha^1 - u \sin \alpha$.

In Figure 2 the known length of the target is represented by L and $L \sin \alpha^1 = \beta R$, where β is the angle subtended by the length L at our own ship.

Figure 3 indicates at the right hand top corner one method of measuring the angle β . An objective lens is divided diametrically into two parts 1 and 2, one of which, say 1, is mounted upon a nut 3 upon a screw 4 worked by the head 5. Figure 4 is a plan of this telescopic portion. When the two halves 1 and 2 of the objective form the equivalent of a single lens, one image only of the target will be seen by an eye placed opposite the eyepiece 6, see also Figure 13, but when the head 5 is turned the image formed by the part 1 will separate from that formed by the part 2 and this separation is carried on until the two images of the target appear as shown in Figure 5. Thus the position of the nut 3 gives a measure of β . Before completing the description of the rest of Figure 3, we will consider Figure 6 which illustrates diagrammatically one method of effecting the multiplication of β and R. In the right angled triangle OAB, let ab be parallel to AB then

$$\frac{ab}{AB} = \frac{Oa}{OA} \text{ or } ab \propto Oa \times AB$$

so that if AB is made proportional to β and Oa to R, the value of ab is proportional to the product βR .

Returning then to Figure 3 (where ABOab correspond to the similar points in Figure 6), the screw 4, whose rotation furnishes a measure of β , connected to rotate with a screw of much greater pitch 7, carrying a nut 8 to which is fixed a pin B, engaging with a slot in the rod 10, which is pivoted about the pin O. Engaging in the slot is a second pin 12 fixed to a piece 13, formed on its under side, as a rack gearing at the point a with the long pinion rod 19 carrying the drum 20 at one end. This rack 13 moves in guides 14 and 15 fixed to the nuts 16 and 17 carried by the screws 21 and 22 respectively. These screws are geared together in any suitable way (not shown) so that the rack 13 is always kept perpendicular to the axis of the pinion rod 19. The distance from the pin O to the point a is made and kept proportional to the range, which means that the screws 21 and 22 are moved the same amounts for equal increments of range, whatever the range. We arrange that the distance between the centre

of the pin B and the point A shall be proportional to β and we arrange that the distance Oa shall be proportional to R so that the rotation of the drum 20 from a zero position relatively to an index (not shown) is proportional to the product βR .

In Figure 7 we indicate a device for showing the value of $L \sin \alpha^1$ upon a drum 23 in proximity to the drum 20 (of Figure 3) which shows the value of βR . The plate 24 capable of rotation about a centre 25 carries a pinion 26 mounted about this centre and gearing with the two racks 27 and 28 (suitably guided upon 24) carrying the pins 29 and 30 respectively. By rotating the pinion 26 we can therefore adjust the distance between the centres of the pins 29 and 30 (which may be taken to represent the bow and stern of the target) so as to be proportional to the length L , and this may be indicated on a suitably graduated scale (94 Figure 13) by means of a pointer 93 fixed to 26. A plate 31 (Figure 3) suitably guided so as to be capable of motion perpendicularly to a line $L^1 S^1$, and under the control of the spring 32 is kept pressing against one or other of the pins 29 or 30, so that the motion of the plate 31 may be made a measure of $L \sin \alpha^1$ and this motion may be communicated to drum 23 by the rack 33 toothed wheel 34 and bevels 35 and 36.

To find then the course of the target, we set off the distance between the pins 29 and 30 proportional to the known or assumed length of the target; in the process of measuring β the top portion of the instrument, Figure 13, has been turned in azimuth till $L^1 S^1$ is parallel to the line of sight, and we next turn the plate 24 and the "course of enemy" disc, Figure 13, attached thereto, about the centre 25 till the bow (represented by the pin 29, Figure 7, and the arrow head on the "course of enemy" disc Figure 13) is in the correct quadrant (as already explained) and then we adjust the azimuthal position of 24 carefully until the value of $L \sin \alpha^1$ upon the drum 23 is in conformity with the value of βR as indicated upon drum 20. Instead of reading off the values of $L \sin \alpha^1$ upon the one drum and that of βR upon the other, we may simply bring the two drums into conformity as shown in the figures by making coloured or other marks in corresponding positions upon the two drums.

We have next to describe how the speed of the target may be measured. For this purpose we shall first consider the method in which the angular velocity ω is measured.

Figure 8 shows on the left hand side, in elevation one method of measuring ω while on the right hand side is represented mechanism for obtaining the product $R \omega$. In Figure 8 the uniformly and slowly rotating friction disc 41 drives the friction wheel 42 feathered upon shaft 43 which rotates shaft 44 carry-

ing mirror 45, through worm gearing. In Figure 9 is shown in plan an optical device for determining the angular velocity. Three reflectors 45, 46 and 47, see Figure 9, are provided of which two 46 and 47 are stationary during the observation. Reflector 47 is silvered say on the lower half and clear upon the upper so that a direct view of the target can be obtained by an eye at E, Figure 9, corresponding to eyepiece 2, Figure 13, associated with a triply reflected (and therefore laterally reversed) view of the target as shown respectively in the upper and lower parts of Figure 10. In making the observation we select a specially prominent feature of the target say the highest mast, then make coincidence between the two views of this mast by moving one or other of the two reflectors 46 or 47 by some slow motion device (not shown) operated by a handle E^2 Figure 13 and then keep coincidence by varying the angular velocity of the slowly turning reflector 45 by moving the head 48 (Figure 8) and thereby translating the friction wheel 42 radially across the face of 41 by means of the screw 49, nut 50 and fork 51. Thus the radial distance of 42 from the centre of 41 is a measure of ω .

We next multiply ω by R after the manner described in connection with Figure 3, the parts 107, 108, etc. . . . 122, replacing the parts 7, 8, etc. . . . 22. Screws 21, 22, 121 and 122 are all geared together and driven in conformity with range so as to enable the value of R to be set off upon the two separate pieces of apparatus shown in Figure 3 and Figure 8. In this way it will be seen that if $O^1 a^1$ is made proportional to R then the drum 120 will by its rotation be a measure of the product $R \omega$.

Figures 11 and 12 show arrangements in plan and elevation respectively of our improvements upon the apparatus described in specification of British Patent No. 1510 of 1911 (United States Patent No. 1,177,470 dated 28th March 1916). In the latter we combine together our own speed and direction with the speed and direction of the target, so as to get a resultant relative speed and direction, and this resultant speed is then resolved parallel to the line of sight to give the rate of change of range and perpendicular to this line to give the deflection. In the improved modification shown in Figures 11 and 12, we resolve our own speed and the speed of the target parallel to the line of sight separately and then add the effects together by means of a differential gear to get the total rate of change of range. In the same way we resolve the speeds perpendicular to the line of sight separately and similarly add them together by a second differential gear to get the total deflection.

In Figure 11 LS represents the line of sight, FA the fore and aft line of our own

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ship. We first of all set off our own speed by turning the head 61 or 62 (Figure 12) thereby rotating the partially screwed shaft 63, and moving the nut 64 and pin 65 along the line FA. We may provide any suitable means for indicating our own speed in connection with the motion of 61. For clearness in the drawing the line FA is not shown in Figure 12 in the position corresponding to that of FA in Figure 11. The pin 65 engages in two slotted pieces 66 and 67 arranged to slide parallel and perpendicular to the line of sight respectively.

Each piece 66 and 67 carries two racks which for 67 are shown at 68 and 69, Figure 12. These racks engage in toothed wheels 70, 71 fixed to a shaft 72, whose bearings are fixed to the rotatable case of the instrument, but not shown in the figure. It will be clear from Figure 11 that as the position of the line of sight alters with reference to the fore and aft line of our own ship, carrying with it the frame in which the slotted rods 66, 67, etc., are mounted, the pin 65 remains fixed relatively to the ship, and thus the pin 65 moves the slotted piece 67 and thereby turns the shaft 72, which communicates its motion through the bevels 73, 74 and 75 to the jockey bevel 76, whose spindle is carried from the shaft 77 which carries also the drum 123, at its upper end. In a similar manner the slotted piece 66 is moved by the pin 65 and communicates its motion to one element of a differential gear to the spindle whose jockey element the drum 124 is fixed.

The pin 81 carried upon the rotatable frame of the instrument represents by its distance from the axis of rotation 25, see Figure 13 of the frame the velocity and direction of the target. The pin 81 is radially adjustable in accordance with the velocity of the target by operation of head 98, Figure 13. In gear with head 98 is a dial 97, which thus indicates the speed of the target. This pin 81 is embraced by two slotted pieces 82 and 83 whose motions are communicated respectively to the second elements of the appropriate differential gears, thus, e. g., the slotted piece 83 will drive the bevels 84, 85 and 86 and so influence the position of the jockey 76 and drum 123. The amount of rotation of the drum 123 from its zero position can thus be made to represent the algebraical sum of the displacements of the slotted pieces 67 and 83 from their central positions, i. e., the algebraical sum of the resolved components of the speeds of our own ship and the target perpendicularly to the line of sight, i. e., the position of 123 can be made to indicate the deflection.

Similarly the drum 124 can be arranged to furnish the algebraical sum of the speeds of our own ship, and the target along the

line of sight, i. e., to furnish the rate of change of range.

It will thus be seen that the position of the drum 123 depends upon our own course and speed, (i. e., upon the position of the pin 65) and upon the course and speed of the target. We have already set the course of the target so that all we have to do to determine the speed of the target is to adjust its value (see dial 97 Figure 13) until the drum 123 is brought into conformity with drum 120 upon which the observed value of the deflection $R \omega$ is exhibited. The speed of the target can now be read off upon dial 97, as explained.

Figure 13 shows a plan view of the complete instrument where LS represents the line of sight, and FA the fore and aft line of our own ship the drums 20, 23, 120, 123 and 124 being here shown for convenience as discs. We begin by setting off the range R, determined independently, by rotating head K which is geared to rotate screws 21 and 22, Figure 3, and 121 and 122, Figure 8. We then set off our own speed by rotating head 62 fixed relatively to the ship until the movable scale 90 indicates the speed opposite the pointer 91, 62 being in geared connection with 90. This motion, as already explained, shifts the pin 65 upon the nut 63 (Figures 11 and 12). Handle 92 is journaled to the top part of the instrument and carries a worm which gears with a worm wheel fixed to the ship. We then turn the hand wheel 92, thereby rotating the top part of the instrument about its centre until the line of sight (say the telescope whose eyepiece is 6) is directed upon the target, and bring the two images into end on contact as shown in Figure 5 by means of head 5, Figure 3, see also Figure 13. In this process the disc 20 (corresponding to the drum 20 of Figure 3) will have been turned. Next, knowing the length of the target, we set off the pointer 93 upon the scale 94 to correspond to this length. We next turn the plate 24 about the centre 25, say, by means of the head 95 until the arrow head at O on the circumference is in the correct quadrant. For this purpose the head 95 is provided with a pinion in gear with the toothed periphery of the plate 24. In this process the disc 23 will have been rotated and we must adjust the position of 24 until the discs 20 and 23 are in conformity when the course of the target will have been determined, and its direction relatively to the line of sight will be given upon the scale 96 engraved upon the plate 24.

The box 99 contains the reflectors 45 and 47, Figure 9, and the spinning gyroscope supporting the mirror 46. We first adjust say 47 until the two parts of the mast are in coincidence as shown in Figure 10, and then adjust the head 48 until these images

keep in coincidence. The disc 120 then shows the experimentally determined value of the deflection. We now vary the indication of the speed of the enemy by rotating the disc 97, say, by means of the head 98 (thereby moving the pin 81 (Figure 11) radially in or out) until disc 123 is in conformity with 120 when the scale of 97 will give the required speed. Meantime the disc 124 corresponding to drum 124 (Figure 11) exhibits the rate of change of ranged.

In the alternative method of obtaining the deflection, we measure with a line of sight maintained in constant azimuth gyroscopically the time of transit of the target past a cross-wire in the field of view, or we may employ the method shown in Figure 9, only instead of arranging that the reflector 45 is turned at such a rate as to keep the two images in contact we now keep the reflectors 45 and 47 fixed to the instrument and maintain the reflector 46 fixed in space by attachment to a gyroscope and then observe the time of transit from the position shown in Figure 17 to that shown in Figure 18.

In order to get the deflection from this observed time of transit T we have the relation

$$\delta = \frac{\beta R}{T}$$

and we have to provide a mechanism for indicating the value of δ from the observed values of β , R and T . Such a mechanism is shown in Figure 14. Here 19 represents the pinion rod of Figure 3, which furnishes a measure of βR by its position rotationally. Upon the shaft of its spindle is fixed a toothed wheel 130 gearing into a rack 131 carrying a pin 132 engaging in a slot in the slotted bar, capable of turning about O^2 . A brief description of the rest of this gear will suffice, since it is similar in all respects to that already described in Figure 3. Upon turning the working head 132, we adjust the value of T as given by a reciprocal scale of T (Figure 15) upon drum 133 with reference to the fixed pointer 134. During this operation the distance 152 153 will have been set out proportional to $\frac{1}{T}$. It will be clear that the rack will rotate the pinion rod proportional to

$$\beta R \times \frac{1}{T}$$

i. e. the drum 120 Figure 14 will indicate the deflection.

Figure 16 shows in diagrammatic form how the value $\frac{\beta R}{T}$ can be indicated from the separate values of βR and T in the case of each of which quantities the scales are uniform. Here 141 and 142 are pinion rods

similar to 19, Figure 3, 143 and 144 are racks similar to Figure 3, and each capable of adjustment in directions parallel to the axes of their respective pinions as already explained. 145 is a slotted bar in the upper and lower halves of which are forked the pins at the ends of racks 143 and 144 respectively. To get the value of δ for any particular values of βR and T , we set off β by rotation of the pinion rod 141, the zero position of β corresponding to the case when the pin 146 is at 147, we set off T by moving 143 to or from the line 148, the zero position of T corresponding to 148, we set off R by moving 144 to or from the line 148, the zero position of R corresponding to 148, then finally the value of $\frac{\beta R}{T}$ will be given by

the position of the drum 120 fixed to pinion rod 142 relatively to a fixed index.

Figure 19 shows in elevation and Figure 20 in plan a detail of the instrument designed to enable the arrangement for measuring the azimuthal angle β to be utilized for measuring angles in a vertical plane. A divided objective, see Figure 19, is provided having one of its halves movable laterally by means of head 5, Figure 13 and Figure 3. The right angled isosceles prism 150 is placed outside the divided objective in the position shown. When it is desired to measure vertical angles this prism is turned through 45° about an axis perpendicular to the paper in Figure 19 as shown in the dotted positions 151 by means of a lever 201, Figure 13.

In the claims β denotes the angle subtended at the observing station by the known length of the target, and α' denotes the angle between the course of the target and the line of sight.

We claim:

1. An instrument, comprising a device for measuring the angle β , means for multiplying the angle β by the range R having a first indicator for exhibiting the product βR , a device for determining the value of α' having a second indicator for exhibiting $L \sin \alpha'$, the indicators for exhibiting βR and $L \sin \alpha'$ being arranged capable of adjustment to conformity, a device for measuring ω the apparent angular velocity of the target relatively to our own ship, means for multiplying ω by the range R having a third indicator for exhibiting the product $R \omega$ (deflection), mechanism having a fourth indicator, means for adjusting the fourth indicator according to speed of enemy, the fourth indicator being mounted capable of adjustment in conformity with the third indicator, said mechanism having a fifth indicator for indicating the rate of change of range, for the purposes set forth.

2. An instrument, comprising a device for measuring the angle β , means for multiply-

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ing the angle β by the range R having a first indicator for exhibiting the product βR , a device for determining the value of α^1 comprising two contact pins mounted on a carrier rotatable about an axis the pins being adjustable apart on opposite sides of the axis in conformity with the length of the target and having a second indicator for exhibiting $L \sin \alpha^1$, the indicators for exhibiting βR and $L \sin \alpha^1$ being arranged capable of adjustment to conformity, a device for measuring ω the apparent angular velocity of the target relatively to our own ship, means for multiplying ω by the range R having a third indicator for exhibiting the product $R \omega$ (deflection), mechanism having a fourth indicator, means for adjusting the fourth indicator according to speed of enemy, the fourth indicator being mounted capable of adjustment in conformity with the third indicator, said mechanism having a fifth indicator for indicating the rate of change of range, for the purposes set forth.

3. An instrument, comprising a device for measuring the angle β , means for multiplying the angle β by the range R having a first indicator for exhibiting the product βR , a device for determining the value at α^1 having a second indicator for exhibiting $L \sin \alpha^1$, the indicators for exhibiting βR and $L \sin \alpha^1$ being arranged capable of adjustment to conformity, a device for measuring ω the apparent angular velocity of the target relatively to our own ship, comprising three reflectors and having gyro control means for stabilizing one of the reflectors, means for multiplying ω by the range R having a third indicator for exhibiting the product $R \omega$, (deflection), mechanism having a fourth indicator, means for adjusting the fourth indicator according to speed of enemy, the fourth indicator being mounted capable of adjustment in conformity with the third indicator, said mechanism having a fifth indicator for indicating the rate of change of range, for the purposes set forth.

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