July 27, 1948. E. DAWSON ET AL 2,445,765

HYDRAULIC REMOTE OPERATING SYSTEM

Filed Dec. 27, 1941

5 Sheets-Sheet 1

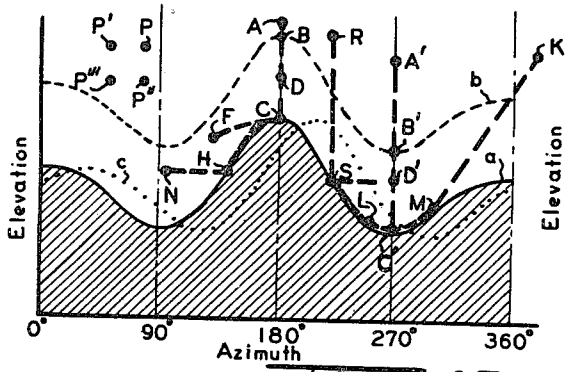


Fig. 1A.

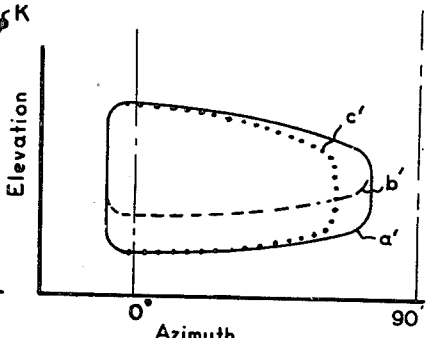


Fig. 1B.

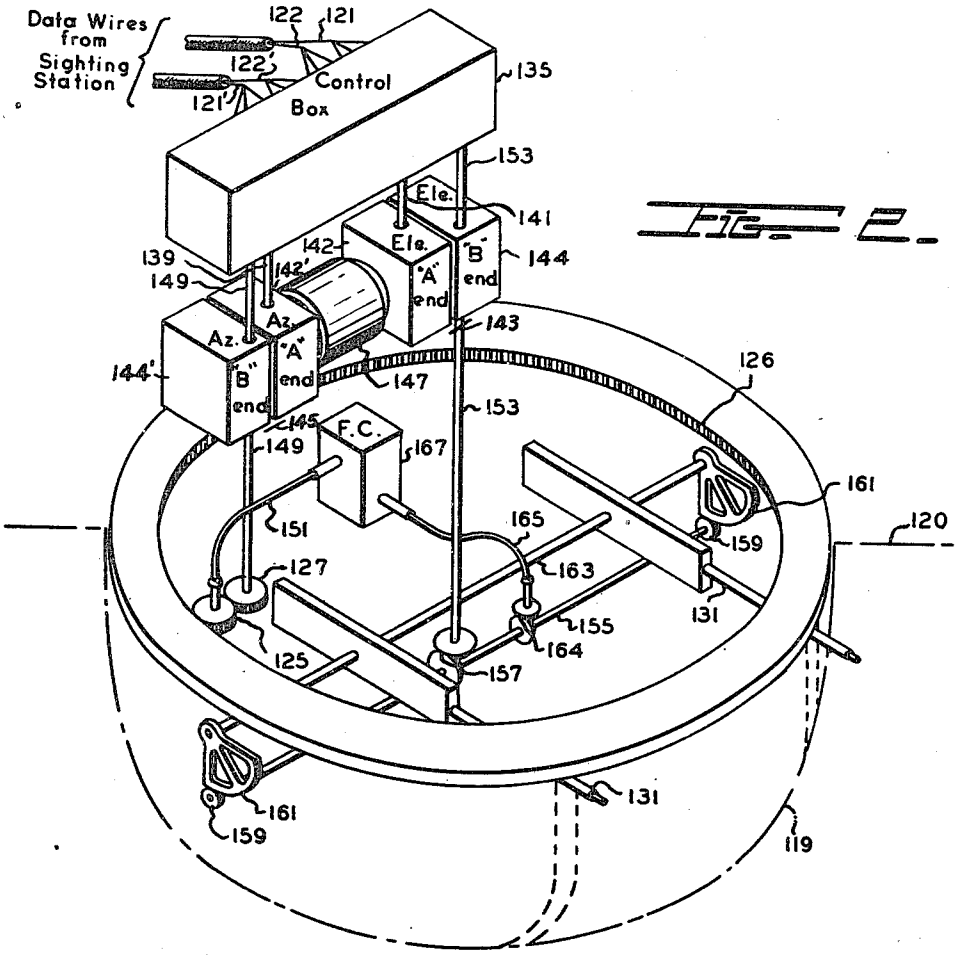


Fig. 2.

INVENTORS,
E. DAWSON, F. M. WATKINS,
& C. N. SCHUH Jr.;
BY
Herbert F. Thompson
THEIR ATTORNEY

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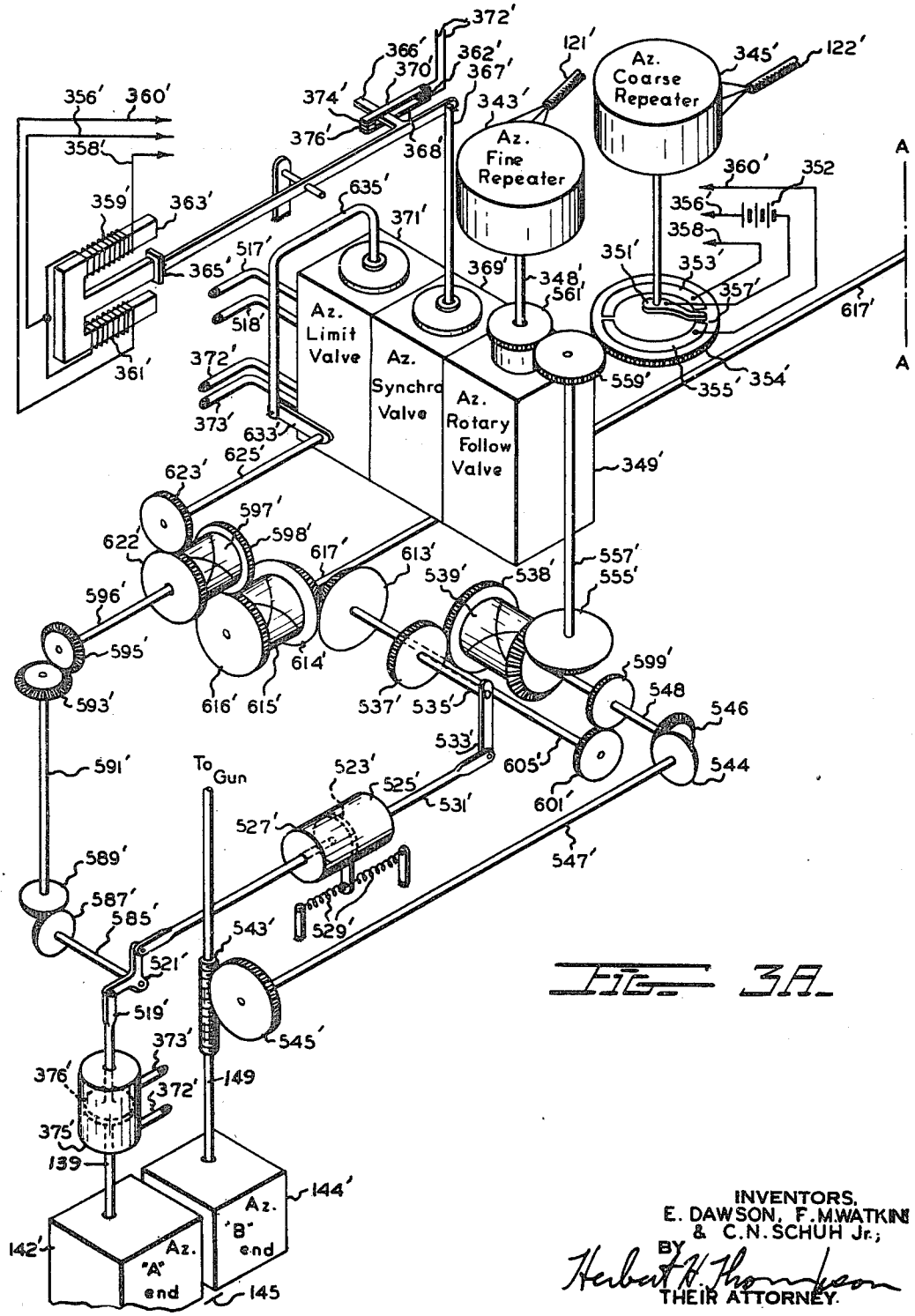


FIG. 3A.

INVENTORS,
E. DAWSON, F. M. WATKINS
& C. N. SCHUH Jr.;
BY
Herbert H. Thomson
THEIR ATTORNEY.

July 27, 1948. E. DAWSON ET AL 2,445,765

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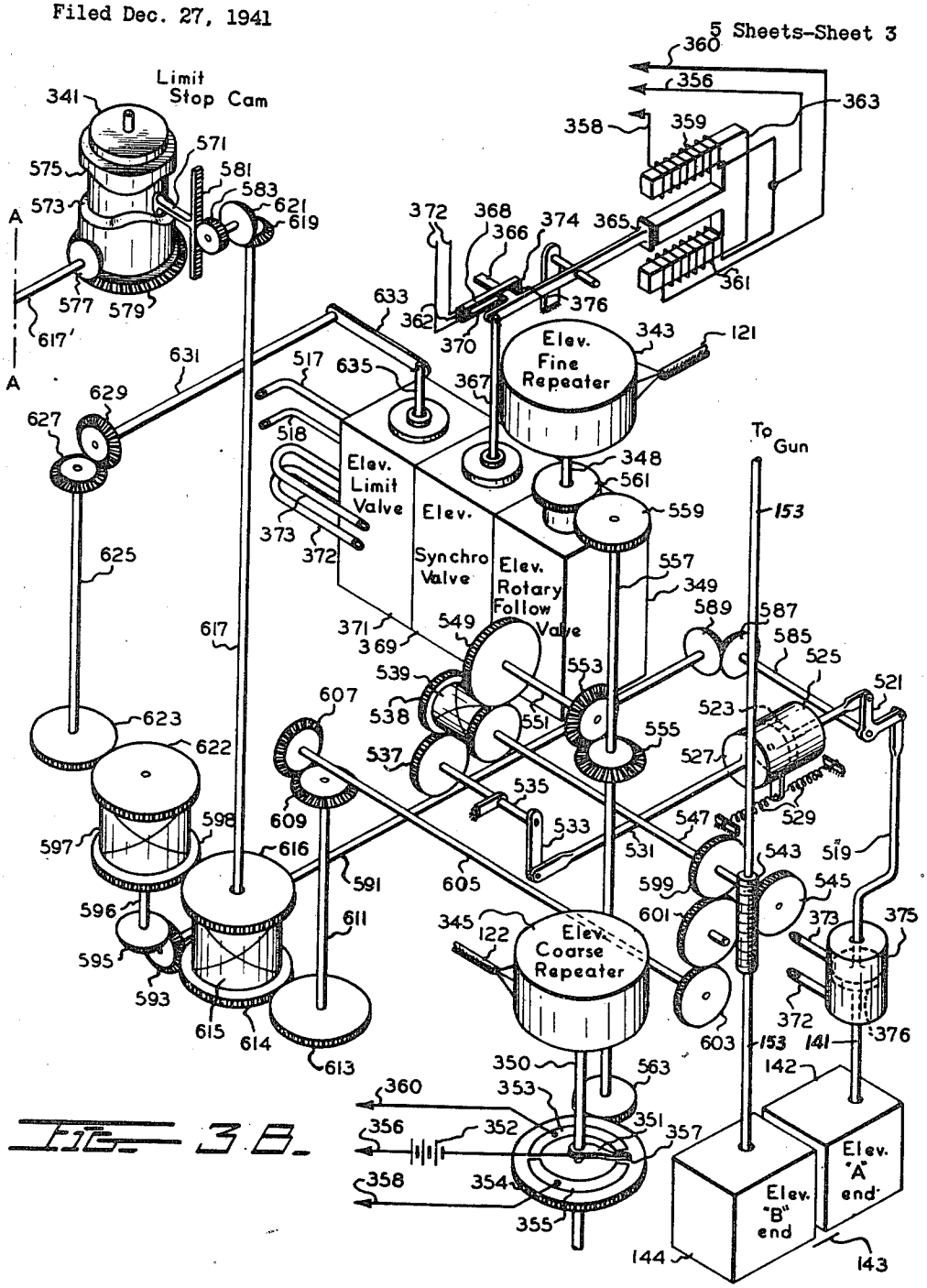


FIG. 3B.

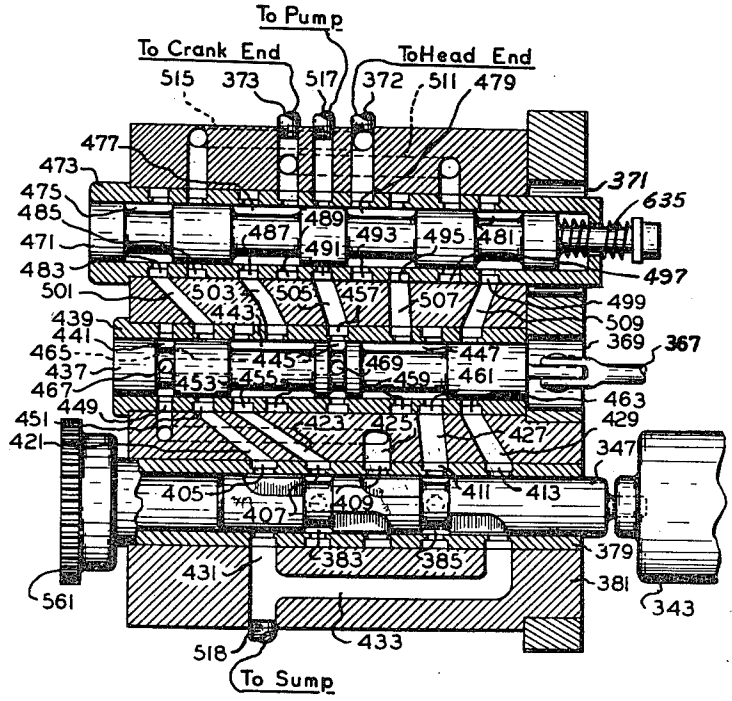
INVENTORS,
E. DAWSON, F. M. WATKINS, &
C. N. SCHUH Jr.;
BY
Herbert H. Thomson
THEIR ATTORNEY.

July 27, 1948. E. DAWSON ET AL 2,445,765

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Fig. 4



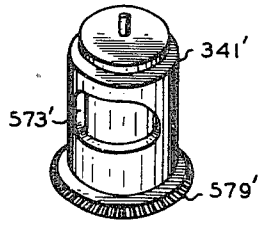


Fig. 3C

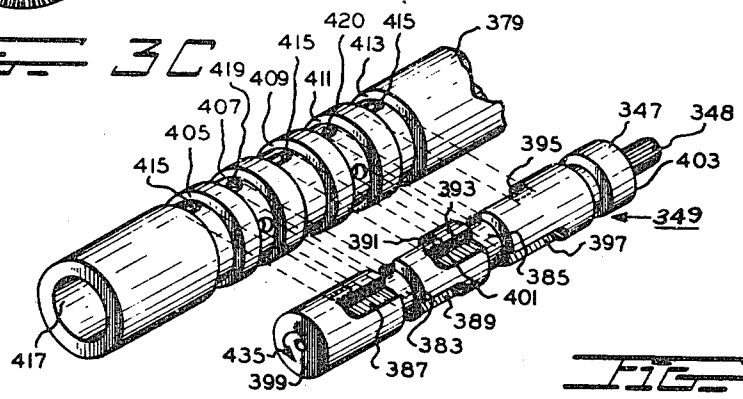


Fig. 5

INVENTORS,
E. DAWSON, F. M. WATKINS, &
C. N. SCHUH Jr.,
BY
Herbert H. Thompson
THEIR ATTORNEY

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HYDRAULIC REMOTE OPERATING SYSTEM

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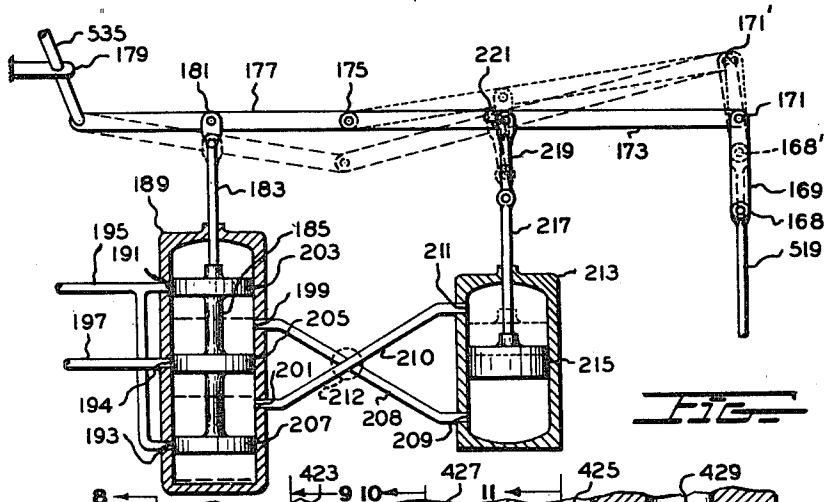


FIG. 6.

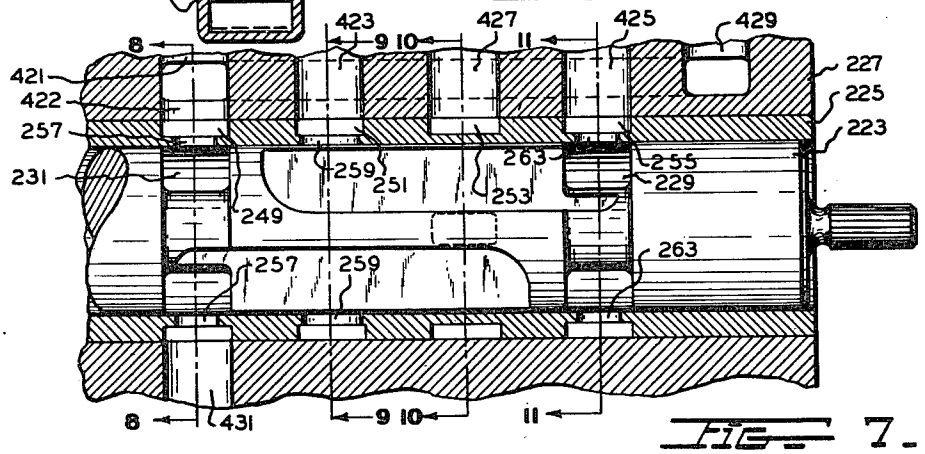


FIG. 7.

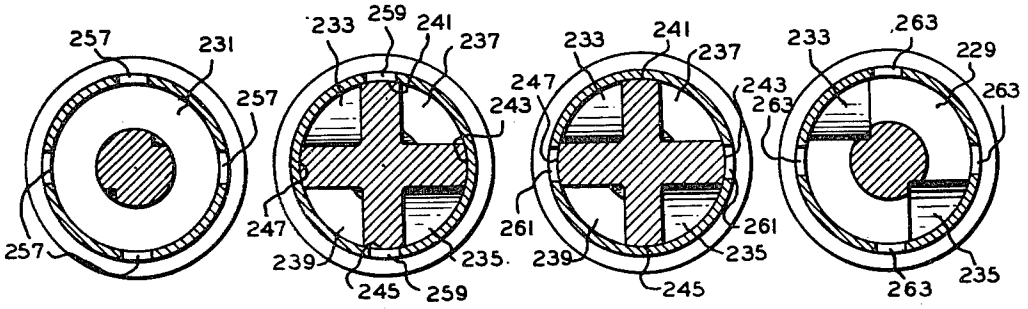


FIG. 8. FIG. 9. FIG. 10. FIG. 11.

INVENTORS,
E. DAWSON, F. M. WATKINS
& C. N. SCHUH Jr.;
BY
Herbert F. Thomson
THEIR ATTORNEY

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UNITED STATES PATENT OFFICE

2,445,765

HYDRAULIC REMOTE OPERATING SYSTEM

Edward Dawson, New York, Frederic M. Watkins, Forest Hills, and Charles N. Schuh, Jr., Bellerose, N. Y., assignors to The Sperry Corporation, a corporation of Delaware

Application December 27, 1941, Serial No. 424,612

13 Claims. (Cl. 89—37.5)

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The present invention relates to the art including remotely controlled power-operated devices, such as gun turrets for aircraft.

One type of such a device is shown in copending application Serial No. 417,580, for Remote aircraft turret control mechanism, filed November 1, 1941, in the name of W. C. Hartman, J. A. Peoples, Jr., and H. L. Hull. The present invention is concerned with improvements over the type of device shown in the aforesaid copending application, in that fine control is secured by purely hydro-mechanical means.

The present invention is adapted for use with a remote sighting station such as disclosed in copending application No. 411,186, for Inter-aircraft gun sight-computer, filed September 17, 1941, now abandoned, in the name of C. G. Holschuh and D. Fram and also in copending application Ser. No. 420,044, for Remote sighting stations, filed November 22, 1941, in the name of C. G. Holschuh and D. Fram. Such sighting stations transmit, as by remote position transmitters, electrical data for controlling the position or velocity of a remote object.

The present invention is particularly concerned with providing control means responsive to such electrical control data for controlling the velocity, and thereby the position, of a remotely controlled device, such as a gun turret for aircraft. An improved balanced hydraulic rotary follow valve is provided which is adapted to be directly driven by a fine remote position repeater energized by the electrical control data. This valve provides a differential hydraulic pressure output proportional to the relative displacement between actual and desired gun positions, and modified to provide anticipation for changes in this displacement. This differential pressure directly controls the speed of the driven object. A coarse repeater is provided also energized by the control data, which operates, upon exceeding the control range of the fine repeater, to replace the variable differential pressure by a fixed high differential pressure, and thereby provide maximum corrective effect.

In positioning gun turrets on aircraft, certain considerations are present, such as effective defense, stability requirements, weight distribution, etc., which require positioning of the guns at points of the aircraft, such as the tail, the wings, the nose or fuselage, where the gun turret is prevented from assuming all orientations in space by the obstruction of the surrounding craft on which it is mounted. Thus, a turret placed at the top of the fuselage may be permitted to assume any orientation in azimuth, but its orientation in elevation may be restricted to the range from vertically upwards to approximately the horizontal. Also, a turret placed in the tail of an aircraft might be restricted to approximately the rear semi-circle in azimuth and from vertically upwards to vertically downwards in elevation. Similarly, a turret placed in the wings of an aircraft is restricted both in azimuth and elevation to a particular solid angle of possible gun orientations.

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In each of these cases, the particular limit of rotation of the gun in one coordinate, such as in elevation, is dependent upon the position of the gun in the other coordinate, such as azimuth, or vice versa. Thus, in the case of the upper or top turret, the gun may assume lower elevations for broadside directions than for longitudinal directions with respect to the craft.

The mounting of the gun and turret in the aircraft and the fact that remote control is used, necessitate placing of definite limits upon the motion of the gun, generally both in azimuth and elevation. Also, it is desirable to decelerate the gun and turret upon approaching these limits so that by the time the limit is obtained the gun has slowed down to such a point, or has become actually stopped, so that no physical damage will result to the gun mountings. Such a limiting action must be provided independent of the control of the remotely situated sighting station; that is, it must be a local control responsive to the orientation of the gun and, as will be seen, to the speed of the gun both in azimuth and elevation, and must overcome or supersede the remote control.

It is furthermore desirable that, when the gun reaches its limit in one coordinate, say, in elevation, it still will be under control of the remote sighting station so far as the other coordinate, such as azimuth, is concerned, while being controlled by the limit device in elevation. In this way, the gun is still partially controlled from the remotely situated sighting station and in such manner that, when the orientation ordered by the sighting station comes within the range of permissible orientations of the gun, the gun control will be taken away from the limit device and restored to the remote station, so that the gun may easily and quickly respond to the remote control as soon as the gun departs from the limits.

Also, in view of the flexible nature of the control link between the remotely situated sighting station and the gun turret, it is desirable that means be provided for cutting off the firing of the gun during those periods of time when the gun and its sight are not in correspondence. The

fire cut-off just mentioned is placed under the control of the coarse position repeater, whereby, when gun and turret are out of correspondence by an amount large enough to cause the coarse repeater to become effective, gun fire will be cut off.

Accordingly, it is an object of the present invention to provide improved control apparatus for power operated devices.

It is another object of the present invention to provide improved control apparatus for remote power operated devices.

It is a further object of the present invention to provide an improved remotely operated gun turret for aircraft which may be controlled from any suitable point on the aircraft.

It is another object of the present invention to provide improved hydraulic control means for controlling the speed and/or position of a remote object.

It is still another object of the present invention to provide improved hydraulically controlled devices for operating speed- and position-controlling hydraulic mechanisms.

It is a still further object of the present invention to provide a novel hydraulic follow-up valve for hydraulically operated positioning systems, which may be directly controlled by low-power motive means, such as position repeaters.

It is still another object of the present invention to provide improved variable limit stops for power operated objects whereby such objects may be decelerated and stopped before reaching their ultimate limiting positions.

It is a still further object of the present invention to provide improved variable limit stops for power operated devices moving along two independent coordinates which will decelerate and stop either component of motion of said devices independently of the other component of motion, whereby attainment of the limit in one coordinate does not prevent full control in the other coordinate.

It is another object of the present invention to provide an improved hydraulic remote control mechanism in which control resides with fine and coarse hydraulic follow valves during control in permissible zones of operation, and in which control is taken over by a hydraulic limit valve upon approaching the limits of these zones, the limit valve control being of such nature as to restore control to the follow valves upon returning to the permissible zones.

It is still another object of the present invention to provide an improved hydraulic remote control system in which, for small relative displacements of controlled and controlling objects, control resides in a rotary follow valve and in which upon exceeding this small displacement control is taken over by a further synchro valve.

It is a further object of the present invention to provide an improved fire cut-off device for power operated gun turrets responsive to lack of correspondence between the controlling device and the turret.

Further objects and advantages of the present invention will become apparent upon examination of the following specification and drawings, wherein the invention is described, for purposes of illustration only, as used with aircraft gun turrets, although it is to be understood that it may be used generally with any type of remotely controlled device.

Referring to the drawings,

Figs. 1A and 1B are diagrams useful in explaining the theory of operation of the variable limit stops of the present invention.

Fig. 2 shows schematically the hydraulically actuated driving mechanism for the gun and turret.

Figs. 3A and 3B taken together show a schematic perspective representation of the hydraulic control mechanism for the hydraulic driving mechanism of Fig. 2.

Fig. 3C shows a modified form of limit cam, corresponding to Fig. 1B.

Fig. 4 shows a longitudinal cross sectional view of the hydraulic control valves of Figs. 3A and 3B.

Fig. 5 shows a schematic perspective exploded view of the rotary follow valve of Figs. 3A, 3B and 4.

Fig. 6 shows a modified form of turret velocity compensating device suitable for use in Figs. 3A or 3B.

Fig. 7 shows a longitudinal cross-sectional view of a modified form of rotary follow valve suitable for use in place of that shown in Figs. 4 and 5.

Figs. 8–11 are cross-sectional views of the device of Fig. 7 taken along lines 8—8, 9—9, 10—10, 11—11, respectively.

Referring firstly to Fig. 2, there is shown schematically the driving mechanism for a turret 119 carrying guns 131, illustrated in this case as being two in number. The actual construction of turret 119 may be similar to that shown in Figs. 2 and 3 or Figs. 6 and 7 of copending application Serial No. 416,290, for Power operated aircraft gun turret, filed October 24, 1941, in the name of C. G. Holschuh and L. C. Warner, now Patent 2,434,653, granted January 20, 1948.

The turret of the present invention is shown for illustrative purposes only as being a lower turret 119 mountable below the fuselage 120 of the aircraft. However, it is to be understood that the control mechanism and driving mechanism of the present invention is suitable for use with any type of turret such as a tail turret, wing turret, upper turret, nose turret, etc.

Provided within turret 119 and carried with it are two variable speed hydraulic transmission units 143 and 145 of the well known "Vickers" type, shown as being driven by a common electric motor 147 suitably energized from the power supply of the aircraft. As is well known, the speed of rotation of the servomotor or B-end of each of these units is proportional to the displacement of its corresponding pump or A-end.

The A-ends or inputs of azimuth unit 145 and of elevation unit 143 are controlled from a control box 135 whose contents are shown more in detail in Figs. 3A and 3B. This control box serves to position the respective A-ends 142, 142' of the elevation and azimuth units 143, 145 in accordance with the control data transmitted electrically over cables 121, 122, 121', 122' from a remote fire control position having gun sight computers and data transmitters such as shown in the above mentioned copending applications Ser. No. 420,044 and Ser. No. 411,186.

Considering first the turret azimuth control, the output shaft or B-end 149 of the azimuth hydraulic unit 145 has its velocity controlled by the position of A-end shaft 139 and therefore by the position of the remote computer sight in azimuth. Output shaft 149 drives the azimuth pinion 125 through a gear 127. Azimuth pinion 125 engages an internal azimuth gear 126 fixed to the craft and thereby causes the pinion 125 and turret 119 to "walk around" azimuth gear 126 and thus rotate in azimuth at a velocity depending upon the

position or orientation of the remote computer sight. Also coupled to azimuth pinion 125, as by a flexible shaft 151, is the input to a fire cut-off unit 167 which may be of the type described in Fig. 5 of the above mentioned copending application Ser. No. 416,290.

The output shaft 153 or B-end 144 of the elevation hydraulic unit 143 serves to rotate a shaft 155 through gearing 157. Connected to shaft 155 are pinions 159 which engage gear sectors 161 and thereby rotate a shaft 163 upon which guns 131 are rigidly mounted. Thus the elevation control of the gun sight computer at the remote sighting station serves to position input shaft 141 of the elevation hydraulic unit 143 and thereby controls the speed of rotation of shaft 163 and of guns 131 in elevation. Also coupled to shaft 155, as by gear 164 flexible shaft 165, is the elevation input to the fire cut-off unit 167.

It will be seen, therefore, that the gun and turret rotate together in azimuth, while the guns rotate independently of the turret in elevation, under the control of the fire control officer at the remote sighting station. It will be evident that it is not necessary that the guns rotate independently of the turret in elevation. Thus, guns 131 may be fixed to the turret and the turret itself may rotate in elevation as well as in azimuth as shown in Figs. 6–8 of copending application Ser. No. 416,290, where this type of driving mechanism is shown as being directly controlled by a locally situated gunner.

Figs. 3A and 3B, taken together, show a complete hydraulic control system suitable for use in control box 135 of Fig. 2, Fig. 3A showing the azimuth control and Fig. 3B showing the elevation control and joint elevation-azimuth limit cam.

Referring especially to Fig. 3B, the "fine" and "coarse" receivers 343 and 345 are used as remote positioning means or repeaters. "Fine" repeater 343 serves by means of shaft 348, to rotate rotatable member 347 of a rotary follow valve 349, shown more in detail in Figs. 4 and 5. "Coarse" repeater 345 by means of a shaft 350 rotates a conducting arm 351 which cooperates with other mechanism to be described, and actuates a "coarse" control or "synchro" valve 369, which is formed in the same block as rotary follow valve 349, and is also shown more in detail in Fig. 4. The differential pressure output of these two valves, as will be explained below, passes through a limit valve 371, and then proceeds through pipes 372, 373 to the head and crank ends of a control cylinder 375, and thereby displaces piston 376 and stroke rod 141 to control the tilt block of the A-end 142 of the elevation variable speed hydraulic unit 143 shown in Fig. 2 and also the "velocity" follow-back link 519.

Referring more particularly to Figs. 4 and 5, the rotary follow valve 349 is composed of a central rotary member 347 directly connected to repeater 343 and surrounded by a rotatable sleeve 379 rotating within block 381. Fig. 5 shows a perspective view of rotary member 347 and sleeve 379. It will be seen that rotary member 347 is provided with two annular grooves 383 and 385 and with a plurality, in this case shown as eight in number, of axially or longitudinally extending grooves of which 387, 389, 391, 393, 395 and 397 appear in this view. Each of these axial grooves is formed to have one radial face, forming a sharp edge with the cylindrical surface of rotary member 347.

Axial groove 387 is provided between the free

end 399 of member 347 and the first annular groove 383, and communicates with groove 383. A corresponding axial groove is located on the opposite side of rotary member 347 symmetrical in all respects to axial groove 387, with respect to the axis of rotary member 347, and therefore does not appear in Fig. 5.

Located between annular grooves 383 and 385 are four axially extending grooves of which three, being 389, 391 and 393, appear in Fig. 5. One pair of these axial grooves, namely, 391 and 389, extend from annular groove 383 partly toward annular groove 385 and are located and formed completely symmetrically with respect to the axis of rotary member 347. The second pair, namely, axial groove 393 and its opposite groove (not shown in the view taken in Fig. 5) are also located and formed symmetrically with respect to the axis of rotary member 347 and extend part way from annular groove 385 toward annular groove 383. Axial grooves 391 and 393 are angularly offset and partially co-extensive, being so formed that section 401, which separates them, is centrally located between annular grooves 383 and 385, and is provided with very sharp edges by virtue of the radial sides of axial grooves 391 and 393. A similar separating section is formed diametrically opposite to 401.

On the opposite side of annular groove 385 is the remaining pair of axially extending grooves 395 and 397 which extend from annular groove 385 part way toward the coupled end 403 of rotary member 347. Axial grooves 395 and 397 are made slightly angularly displaced from corresponding axial grooves 387 and the one opposite to 387 (not shown), by an amount exactly equal to the angular displacement of axial grooves 391 and 393 about rotary member 347, that is, by the width of section 401. It will be noted that axial groove 387 is aligned with axial groove 393, axial groove 389 with 397, and axial groove 391 with 395. The remaining pair of axial grooves not appearing in this view are also similarly aligned.

Cooperating with rotary member 347 is rotatable sleeve 379, which is formed with five outer annular grooves 405, 407, 409, 411, and 413. As shown by the projected dotted lines, groove 405 cooperates with and is positioned opposite to axial groove 387 and its opposite groove (not shown) of rotary member 347. Annular groove 407 cooperates with and is positioned opposite annular groove 383, and communicates therewith as by symmetrically located radial holes 419. Annular groove 409 cooperates with axial grooves 391, 393, 389 and the fourth axial groove not shown, being located directly opposite section 401. Annular groove 411 cooperates with annular groove 385, and communicates therewith by symmetrically located radial holes 420. Annular groove 413 cooperates with axial grooves 395 and 397.

Annular grooves 405, 409 and 413 are provided with a pair of diametrically opposed holes 415 which extend from the outside of these annular grooves through to the inner bore 417 of sleeve 379. Annular grooves 407 and 411 are provided with equally spaced holes such as 419, 420, shown as four in number, which also connect these respective grooves to the inner bore 417.

Cooperating with annular grooves 405 to 413 of sleeve 379 are corresponding openings in block 381. Thus, referring to Fig. 4, opposite groove 405 is a port and duct 421; opposite groove 407 is a port and duct 423; opposite groove 409 is a

port and duct 425; opposite groove 411 is a port and duct 427; and opposite groove 413 is a port and duct 429. Ports 421 and 429 are connected as by ducts 431 and 433 to a pipe 518 leading to a sump (not shown). Duct 425 is connected by means which will be described, to pipe 517 and thence to a source of hydraulic pressure. Duct 423 is connected, as will be shown, to one end, such as the crank end, of the control cylinder 375 of Fig. 3B. Duct 427 is connected, as will be described, to the other or head end of the control cylinder 375.

Synchro valve 369 comprises a plunger 437 which is reciprocatable within a sleeve 439 fixed in block 381. Plunger 437 is provided with a plurality of annular grooves 441, 443, 445 and 447 which cooperate with another series of annular grooves 449, 451, 453, 455, 457, 459, 461, 463 formed on the outside of sleeve 439, which latter grooves communicate with the bore of sleeve 439 by various symmetrically located holes in the same manner as shown in Fig. 5 with respect to rotary sleeve 379.

Duct 425, which communicates with annular groove 409 of sleeve 379, connects this groove 409 with annular groove 449 in sleeve 439. Duct 421 serves to connect groove 405 of rotary sleeve 379 to groove 451 of fixed sleeve 439. Duct 427 serves to connect groove 411 of sleeve 379 to groove 461 of sleeve 439. Duct 429 serves to connect groove 413 of sleeve 379 to groove 463 of sleeve 439.

Plunger 437 of the synchro valve 369 is also provided with a central bore 465 which communicates with annular grooves 441 and 445 by means of radial holes 467 and 469.

Limit valve 371 is also provided with a reciprocatable plunger 471 sliding within a sleeve 473 fixed to block 381. Plunger 471 is provided with a plurality of annular grooves 475, 477, 479 and 481 which cooperate with annular grooves 483, 485, 487, 489, 491, 493, 495, 497, 499 formed in sleeve 473 and communicating with the bore of sleeve 473 by radial holes similar to those of the synchro and the rotary follow valve sleeves.

Groove 451 of synchro valve 369 is connected to groove 483 of limit valve 371 by duct 501. Groove 455 of synchro valve 369 is connected to groove 487 of limit valve 371 by duct 503. Groove 457 of synchro valve 369 is connected to groove 491 of limit valve 371 by duct 505. Groove 459 of synchro valve 369 is connected to groove 495 of limit valve 371 by duct 507. Groove 463 of synchro valve 369 is connected to groove 499 of limit valve 371 by duct 509. Grooves 497 and 489 of limit valve 371 are connected together as by a duct 511 and to a pipe 373 leading to the crank end of control sylinder 375. Grooves 485 and 493 are connected together as by duct 515 and to pipe 372 leading to the head end of control cylinder 375. Groove 491 is connected as by pipe 517 to a pump or other source of hydraulic fluid under pressure. The pressure of pipe 517 may be made pulsating at a high frequency in order to break the static oil film friction in these valves. Also, the connections 372, 373 to the control cylinder 375 may be periodically reversed at a high rate, such as 4,000 times per minute, whereby "dither" is supplied to the A-end 142 to avoid instability.

In operation, referring now to Figs. 3B, 4 and 5, the rotary follow, synchro and limit valves are normally, when the system is in equilibrium, in the positions shown in Figs. 4 and 5. In this position fluid pressure from pipe 517 is connected through annular groove 491, duct 505, groove 457, groove 445, hole 469, duct 465, hole 467, groove

441, groove 449 and duct 425 to groove 409. Here, however, this pressure is blocked by section 401 of rotary member 347 of the rotary follow valve, which, as shown more clearly in Fig. 5, is directly opposite hole 415 communicating with groove 409 in sleeve 379.

Also, the sump pressure from line 518 connects to duct 431, groove 405, duct 421, groove 451, duct 501, groove 483 and groove 475, and to duct 433, groove 413, duct 429, groove 463, duct 509, groove 499 and groove 481, being completely blocked off from the control ducts 372, 373 by the position of rotary member 347 which blocks access from grooves 405 and 413 to grooves 383 and 385 as shown best in Fig. 5. It will be seen that, with coarse synchro valve 369 and limit valve 371 centered as shown in Fig. 4, groove 383 of rotary member 347 connects to control duct 373 by way of holes 419, groove 407, duct 423, groove 453, groove 443, groove 455, duct 503, groove 487, groove 477, and groove 489. Also, groove 385 of rotary member 347 connects with control duct 372 by way of holes 420, groove 411, duct 427, groove 461, groove 447, groove 459, duct 507, groove 495, groove 479, and groove 493.

Thus, it will be clear that, in the valve positions shown, control ducts 372 and 373 are completely isolated from both pump and sump pressures.

In operation, the fine elevation repeater 343 rotates shaft 348 in accordance with the relative displacement of the orientation of the sight computer at the remote sighting station and the gun turret mechanism, and thereby rotates rotary member 347 of the rotary follow valve 349 with respect to sleeve 379.

Rotary member 347 is adapted by its rotation with respect to sleeve 379 to control the amount and sense of the differential pressure applied to ducts 372 and 373, and thereby to control the motion of piston 376 in cylinder 375. A slight rotation of rotary member 347 in the direction shown by arrow 435 (Fig. 5) will partially uncover hole 415 in groove 409 and permit pressure port 425 to communicate through axial groove 393 with annular groove 385 of member 347 and thereby to control duct 372 as described above. At the same time, exhaust or sump pressure port 421 in casing 381 is allowed to communicate through hole 415 in annular groove 405 and axial groove 387 to annular groove 383 and thereby to control duct 373 as described above. Exhaust port 429 in casing 381 remains blocked, since hole 415 of groove 413 remains opposite a land on member 347.

In this manner, it will be seen that proportional hydraulic pressure is applied to one end of the control cylinder 375, while the other end of the control cylinder 375 is proportionally connected to the hydraulic sump or exhaust pressure. It will be clear that rotation of member 347 with respect to sleeve 379 in the opposite direction will merely serve to reverse the sump and pressure connections and will thereby produce an opposite sense of differential pressure in control ducts 372 and 373, thereby moving control piston 376 in the opposite direction within control cylinder 375.

Let it be assumed that the rotation of rotary member 347 is as shown by arrow 435. Hence, in response to motion of repeater 343, the rotary follow valve 349 acts as a torque or pressure amplifier and produces a differential pressure on the opposite faces of the poston 376 of control cylinder 375. Referring to Fig. 3B, this differential pressure serves to translate piston 376 carrying

arm 519 to actuate the stroke rod 141 of the A-end 142 of the variable speed hydraulic unit 143 shown in Fig. 2. As is well known in the Vickers A and B-type hydraulic drive, the position of the stroke rod in the A-end determines the velocity of the servomotor or B-end. Since the piston 376 will continue to translate the stroke rod 141 as long as a differential pressure is supplied by valve 349 at a rate proportional to such pressure, which in turn is proportional to the opening of said valve, it follows that the relative displacement of the valve in its sleeve determines the rate of acceleration of the B-end. A typical Vickers variable speed drive is shown in the patent to T. B. Doe et al., 2,177,098, dated October 24, 1934, for Power transmission.

The output of B-end 144 of hydraulic unit 143 is fed back, by way of shaft 153, worm 543, worm wheel 545, shaft 547, differential 539, gear 549, shaft 551, gear 553, gear 555, shaft 557 and gear 559, to rotate gear 561 fastened to rotary sleeve 379 of rotary follow valve 349, and thereby to reposition this rotary sleeve 379 with respect to rotary member 347, to provide a positional repeat-back.

In order to provide accurate and close control and avoid hunting and lag, it is desirable to also provide a component of motion to rotary sleeve 379 proportional to gun speed. This is done by controlling a second member 538 of differential 539 from the A-end 142 of hydraulic unit 143, by means of arm 519, crank 521, dashpot 525 having a piston 523 fastened to crank 521 and a casing 527 centralized by means of springs 529 and fastened to an arm 531 which is linked to crank 533 and thereby turns shaft 535, gear 537 and member 538 of differential 539.

The output of differential 539 is then the algebraic sum of the displacement of shafts 547 and 535, and corresponds to a combination of gun position and gun speed. It serves to reposition rotary sleeve 397 with respect to rotary member 347 in accordance with both the actual gun position and the rate of change of gun position, thereby controlling the differential pressure applied to control cylinder 375 and serving to maintain the orientation and speed of the gun in correspondence with the desired orientation and speed as transmitted by the remote sight computer and repeated by repeater 343.

As the gun velocity approaches a steady state, i. e., as the acceleration of the gun (whether said acceleration be positive or negative) approaches zero, it is desirable that the velocity component of control for sleeve 379 be removed in order that there shall not be a constant lag between gun orientation and sight orientation and in order to prevent overshooting as the gun is brought to rest. This is done by the action of dash-pot 525 as follows:

Upon first actuation of its piston 523 by crank 521, the casing 527 is caused by dash-pot action to move together with piston 523, thereby transmitting a velocity control component to the sleeve 379 of the rotary follow valve 349, as already described. However, after a short interval, the pressure between piston 523 and casing 527 dissipates itself, around the piston and through small orifices which may be provided in piston 523, and springs 529 serve to replace casing 527 of dash-pot 525 back to its neutral or central position, thereby removing any velocity control from the rotary follow valve, and permitting accurate tracking of the gun with the remote sight. The reverse action takes place in deceleration and the time factor of the mechanism of Fig. 6 is so designed that the gun is brought to rest substantially at the same time as the repeater motor 343 or 343' comes to rest, with a minimum of overshooting.

Should the relative displacement between sight and gun exceed the range of the fine repeater 343, the coarse repeater 345 will move its contact arm 351 off insulating segment 357 and into contact with one of contact segments 353 or 355, depending upon the sense of this relative displacement.

For purposes of illustration, let it be assumed that contact is made between arm 351 and segment 355. Thereupon battery 352 is connected by way of wires 356, 358 to coil 359, which is thereby energized and attracts armature 365, causing a downward motion of link 367. This produces a motion of plunger 437 (Fig. 4) with respect to its sleeve 439. The action is such that plunger 437 is immediately translated to its extreme position; in the illustration used, this is the left extreme position. This operation serves, as will be described, to remove the control entirely from the rotary follow valve 347 and place control entirely with the synchro valve 369, in the following manner.

Movement of plunger 437 to the left causes groove 441 to move away from correspondence with groove 449. Groove 443 causes groove 455 to communicate with grooves 451 and 453. Groove 445 moves away from groove 457. Groove 447 now is placed opposite grooves 457 and 459, grooves 461 and 463 being blocked.

The hydraulic pressure derived from pipe 517 proceeds as described before to duct 505 and groove 457. However, by the reciprocation of plunger 437, this full hydraulic pressure is now applied to groove 447, groove 459, duct 507, groove 495, groove 479, groove 493, and pipe 372 leading to the head end of the control cylinder 375. At the same time, duct 425, which normally provides hydraulic pressure to the rotary valve 347, is cut off from the pressure of pipe 517 by the reciprocation of groove 441 out of correspondence with groove 449 and of groove 457 out of correspondence with groove 445 and hole 469.

Also, upon reciprocation of plunger 367, the full sump pressure of duct 518 and groove 451 is applied to groove 443, groove 455, duct 503, groove 487, groove 477, groove 489 and to pipe 373 leading to the crank end of the control cylinder 375.

Thus, by operation of synchro valve 369, pressure from duct 517 is cut off from rotary follow valve 349, and groove 383 and duct 423 of rotary follow valve 349 are put in communication with the sump pressure in duct 421.

Movement of plunger 367 in the opposite direction acts in a similar way to reverse the differential pressure in control cylinder 375, but will still render the rotary valve 349 ineffective.

It will thus be seen that the rotary valve 349 gives a proportional type of control within its range, which corresponds to the range of control of the fine repeater 343. If this range is exceeded, the coarse repeater 345 and synchro valve 369 take over, and immediately apply fully corrective effect in the proper direction to re-orient the gun and turret at full speed until the range of control of the fine repeater 343 is again reached, at which time platform 354 carrying contacts 353 and 355 has been oriented by shaft 557 and gear 563 so that contact 351 again rests on insulating segment 357, deenergizing magnetic torque device 363 and permitting plunger 437 of the synchro valve 369 to be centralized by means of its centralizing springs (not shown).

It will be seen that the same combination of displacement and velocity components, the velocity component decreasing with time as the result of the action of dash-pot **525**, is applied as a follow-up repeat-back to both the fine repeater **343** and the coarse repeater **345** by shaft **557**. In the first case, this follow-up action is obtained by means of the hydraulic rotary follow valve mechanism; in the second case, by means of the electrical contact follow-up mechanism. In each case the repeat-back contains both displacement and velocity components.

As a result of the differential pressure control obtained from the rotary and synchro follow valves **349** and **369**, the control shaft **377** of the A-end **142** of the variable speed unit **143** and the output shaft **541** are actuated substantially without hunting or lag to control the speed of the guns or turret, in this instance in elevation, thereby yielding a sensitive and accurate remote control for the guns and turret.

The azimuth control shown in Fig. 3A is exactly similar to the elevation control just described, and similar elements are given the same reference number, but primed.

The above description applies to the control mechanism when within the desired free range of control. However, in all turrets of the present type, there is a definite limitation to the range of possible orientations because of the manner of mounting. Thus, the top turret or the bottom turret may be unrestricted in motion in azimuth but carry a variable restriction of approximately zero to 90° in elevation. Nose, tail and wing turrets on the other hand, are restricted both in elevation and azimuth and are therefore useful only in restricted solid angles of possible orientations. In order to prevent any damage to the gun or turret mounting when the gun is moved to its extreme positions, apparatus must be provided to decelerate and stop the turrets before reaching these extreme positions.

Referring to Fig. 1A there is shown by the curve *a* a plot of the extreme positions of a representative gun. Thus, each point of this plate represents a particular gun orientation, that is, a particular combination of azimuth and elevation. All points above line *a* represent permissible gun orientations. All points below, in the shaded area, represent forbidden gun orientations. The particular curve *a* shown may correspond, for example, to an upper turret where, along the fuselage (0° or 180° azimuth) the gun may be depressed less than for broadside directions (90° or 270° azimuth).

If, for illustration, a gun is oriented in elevation and azimuth corresponding to point A, and if only the elevation of the gun is changed, the locus of points corresponding to the successive gun orientations will be line AC. If the gun is being driven downward at the full elevation rate, it is desirable to start decelerating at some point B before the extreme position C is reached so that the gun may be slowed down and stopped before reaching point C, even though the remote sighting station is still "ordering" further down elevation rate. However, if the gun is being driven downward at only partial elevation rate, it is not necessary to start decelerating at point B but only at point D.

If the gun, on the other hand, started from a position of A' and traveled down in elevation, its deceleration, if at full rate, should start at point B' or if at partial rate, at D', in order to stop at C'.

In effect, if it is desired to indicate the locus of points where deceleration should start, then the requirements just illustrated may be interpreted as bodily moving curve *a* upwards proportionally to down elevation rate, into position *b* if full elevation rate is used, which curve is then the desired limit of free motion (free from limit stop action) of the guns or turret, or the locus of points where deceleration starts.

It will be clear that similar requirements are involved in motion in azimuth only, especially for turrets having restricted azimuth ranges, such as nose, tail or wing turrets. A similar curve *a'* of limit positions for such a turret may be as shown in Fig. 1B. Curve *b'* here indicates the limit of free motion in down elevation.

Curve *c* of Fig. 1A or *c'* of Fig. 1B represents the effective locus of deceleration initiation points or the limit of free movement for motion in azimuth only to the left in Fig. 1A or the right in Fig. 1B.

A further special requirement arises for conditions where the gun is already at the limit and further motion is ordered by the remote controlling sighting station. Thus, if the gun is at point M, it is clear that down elevation rate must be prevented or rendered ineffective, and right azimuth rate must be prevented or rendered ineffective, since otherwise the gun would run into the fuselage. However, down elevation rate must be permitted if accompanied by suitable left azimuth rate, and the amount of down elevation rate must be proportioned to the amount of left azimuth rate, in order that the gun shall not enter the shaded area. Similarly, right azimuth rate should be permitted if accompanied by a suitable value of up-elevation rate. It is also desirable that the gun should accurately follow the "order" from the sighting station, at least in one coordinate, even though not in the other coordinate since then the gun will be in the best position for resuming correspondence with the ordered orientation derived from the sighting station when that ordered orientation reaches the zone of permissible orientations for this particular gun. Hence, it is desirable that, for instance, with the gun at point H and right azimuth rate ordered, that the gun follow the order in azimuth. This can be safely done only by forcing the gun upward in elevation to follow the curve from H to C, even if the ordered elevation rate remains downward or less than that necessary to climb slope HC. Hence, in some way, azimuth rate must produce the desired elevation rate, or vice versa.

A further desirable feature may be illustrated by assuming the gun to be at rest at point C. The ordered elevation rate may try to drive the gun down, but the limit stop must prevent this action. If it is desired to traverse successive gun positions corresponding to points along the limit curve *a* from C to H, left azimuth rate will be ordered. Ordinarily, this will cause the gun to move in azimuth, but motion in elevation cannot take place (assuming the above desirable characteristics to be present) until the gun has moved away from the limit curve *a*. Hence, the path of the gun is along CF. To traverse CH, the elevation rate control must anticipate the azimuth motion, whereby elevation and azimuth motion may occur together along CH. This may be done by effectively shifting the limit curve horizontally to the right, to position *c'*, proportionally to azimuth rate. In this way, the down elevation rate control is released, or allowed to become effective, permitting motion from C to H.

It will be clear that the characteristics ob-

tained by interchanging elevation and azimuth in the above discussion are also desirable and should be provided.

From the above discussion of desirable characteristics, it will be clear that the limit stop mechanism must be controlled by azimuth rate and elevation rate as well as gun azimuth and gun elevation. This is done in the present invention by use of limit cam 341, azimuth limit valve 371', elevation limit valve 371, and their various connections to the control mechanism already described.

Limit cam 341 is shown as being of the cylindrical type cooperating with a reciprocable cam follower 571. Cam 341 is provided with two cam surfaces 573 and 575 corresponding to the upper and lower limits in elevation.

As will be more fully described below, cam 341 is rotated in proportion to gun azimuth, and this motion is modified proportionate to azimuth rate. Cam follower 571 is shifted proportionate to gun elevation, and its motion is modified proportionate to elevation rate. It will be clear that the connections to cam 341 and cam follower 571 may be interchanged, so that the cam follower 571 is actuated by azimuth and azimuth rate while cam 341 is actuated by elevation and elevation rate, if desired.

In the cam illustrated, no limit in azimuth is provided, since the gun and cam may rotate the full 360° under the azimuth control (as in Fig. 1A). However, if restricted azimuth is also to be provided, as in the case shown in Fig. 1B, then the cam 341 may be formed substantially as shown in Fig. 3C, with only a portion of its cylindrical surface cut out to form the cam surfaces.

Referring to Figs. 3A and 3B, the elevation rate data is derived from the motion of elevation control piston 376 by way of arm 519, crank 521, shaft 585, gears 587 and 589, shaft 591 and gears 593 and 595 actuating one member 596 of differential 597. A second member 598 of differential 597 is actuated by gun elevation data from the B-end 144 of the elevation variable speed unit 143 by means of shaft 541, worm 543, worm wheel 545, gears 599, 601 and 603, shaft 605, gears 607 and 609, shaft 611, gear 613 and one member 614 of differential 615, a second member 616 of which engages second member 598 of differential 597. A third member 617 of differential 615, whose motion, at least in the range of free gun movement corresponds to a combination of gun elevation and elevation rate, actuates gears 619 and 621, and thereby operates cam follower 571 through pinion 583 and rack 581.

Connected to the third member 622 of differential 597, as by a gear 623, shaft 625, gears 627 and 629, shaft 631, crank 633, and arm 635 is the plunger 471 of the limit valve 371, whose internal structure has been described above.

The system just described therefore comprises four interconnected variables, namely, gun elevation, elevation rate, position of cam follower 571 and position of limit valve plunger 471. The system is such that any three of these variables may act as independent variables, in which case the fourth is a fully determined dependent variable. The action of this system will be later described.

Similarly, referring to Fig. 3A, azimuth rate data is derived from the motion of azimuth control piston 376' by means of arm 519', crank 521', shaft 585', gears 587', 589', shaft 591' and gears 593', 595' actuating one member 596' of differential 597'. A second member 598' of differential 597' is actuated by gun azimuth data derived from the B-end 144' of the azimuth variable speed unit 145 by means of output shaft 541', worm 543', worm wheel 545', shaft 547', gears 544, 546, shaft 548, gears 599', 601', shaft 605' and gear 613' driving member 614' of differential 615', whose second member 616' engages member 598' of differential 597'. The third member 617' of differential 615' rotates cam 341 by way of gears 577 and 579 (Fig. 3B).

Connected to the third member 622' of differential 597', as by gear 623', shaft 625', crank 633' and arm 635' is the plunger 471' of the azimuth limit valve 371', whose structure has already been described above.

Referring now more specially to the elevation control of Fig. 3B, in normal operation, when the limits of elevation are not reached or approached, arm 635 connected to plunger 471 of elevation limit valve 371 remains fixedly centralized by means of the limit valve centralizing springs (not shown). Accordingly, gear 623 and member 622 of differential 597 remain fixed, whereby differential 597 acts as a simple gear train. Hence, shaft 617 is actuated by elevation rate data derived from shaft 591 through gears 593, 595, differential 597 (operating as a fixed gear train) and member 616 of differential 615, and by gun elevation data derived from B-end 144 by way of shaft 611 and gear 613 which drives another member 614 of differential 615. Therefore, cam follower 571 is accurately positioned proportionately to a combination of gun elevation and elevation rate.

In the same manner, azimuth limit valve 371' is normally centralized (when the gun is not near the limit and is free) by its centralizing springs, thereby immobilizing arm 635' and element 622' of differential 597', which then acts as a fixed gear train. Accordingly, shaft 617' is displaced proportionately to gun azimuth data derived from B-end 144' by way of shaft 605', gear 613' and member 614' of differential 615', whose other member 616' is then driven proportionately to azimuth rate data derived from control piston 376' by way of shaft 591', gears 593', 595' and differential 597' acting as a fixed gear train and engaging member 616' of differential 615'.

In the above manner, cam 341 is driven proportionately to gun azimuth, with an added lead component of motion proportional to azimuth rate, while cam follower 571 is driven proportionately to gun elevation, with an added lead component of motion proportional to elevation rate.

Cam 341 has its cylindrical surface cut out as at 573 or 575 in accordance with the chosen limits of operation; that is, in accordance with curve a of Fig. 1 or a' of Fig. 1A. It will be clear that the slopes of the cam surfaces may be chosen to have any desirable maximum by suitably selecting the scales of the azimuth and elevation cam motions; that is, by adjusting the gear ratios in the various gear trains. Hence, except for the lead components caused by azimuth or elevation rate, the position of cam follower 571 relative to cam 341 corresponds to the actual orientation of the gun relative to its mounting. Actually, however, if the instantaneous position of the gun corresponds to point P (Fig. 1A) and the gun is travelling to the left in azimuth only, the corresponding position of cam follower 571, relative to curve a will be P'. From another point of view, which is closer to the actual situation, P represents the gun position when taken relative to

curve *a*, and the same point P represents the cam follower position when taken relative to curve *c*, which is the same as *a* but shifted to the right proportionately to the azimuth rate in the same manner as is the cam body **341**.

In the same way, if the gun P moves only in down elevation, the cam follower **571** (relative to curve *a*) would be at P''. If the gun P moves both in elevation and azimuth, the cam follower might be at P'''.

Considering now, for the moment, motion of the gun in down elevation only, as along path AC or A'C', when the limit at which deceleration is to be started is reached, cam follower **571** will engage one of the cam surfaces, such as surface **573**, thereby fixing member **617** of differential **615**. If any further motion of the gun in elevation takes place, as evidenced by rotation of shaft **611**, then shaft **611** drives gear **613** and differential **615**, which now acts as a simple gear train, and will drive member **598** of differential **597** to thereby actuate (since member **596** is held by control piston **376**) gear **623**, shaft **625**, gears **627**, **629**, shaft **631**, crank **633**, arm **635**, and the plunger **471** of the elevation limit valve **371**.

Thus, if it be assumed (Fig. 4) that either the elevation rotary follow valve **349** or the elevation synchro valve **369** has applied pump pressure to duct **507** (and thereby to pipe **372** and the head end of control cylinder **375**) and exhaust pressure to duct **503** (and thereby to pipe **373** and the crank end of cylinder **375**) plunger **471**, assumed to move to the right, will serve to throttle, or partially cut off, access of pipe **373** to duct **503**, by displacement of groove **477** relative to grooves **487** and **489**, and will also serve to partially throtte pressure from duct **507** to pipe **372**, by displacement of groove **479** relative to grooves **493** and **495**, thereby decreasing both the exhaust pressure and the pump pressure as applied to the respective sides of the control piston **376** of control cylinder **375**. If further actuation of the plunger **471** occurs to the right, duct **503** is cut off completely from pipe **373** and if still further actuation occurs, pipe **373** is brought into communication with pressure pipe **517** supplied by small pump (not shown) usually built in the A-end of the Vickers variable speed drive as shown at **62** in the patent to Doe et al. heretofore referred to by way of grooves **489**, **477** and **491**. In the same way, duct **507** is first cut off entirely from pipe **372**, and if further actuation occurs, exhaust duct **501** is brought into communication with pipe **372** by means of grooves **483**, **475** and **485**, thereby applying exhaust pressure to pipe **372**. In this way, the actual differential pressure applied to control cylinder **375** is first cut off and then reversed, causing complete stopping and reversal of movement of the gun.

However, since reversal of motion of the gun would at once act to permit the centralizing springs to return plunger **471** back toward its neutral position (to the left in this case), it will be seen that only such reversal takes place as is necessary to stop the gun and thereafter the plunger **471** is left in a position in which the differential pressure is in equilibrium with the gun and control mechanism.

Thus, in this way, motion of this elevation limit valve plunger **471** acts to cause a decrease in the differential pressure applied to the elevation control cylinder **375**, and if motion of the gun in elevation persists, will operate to cut off or remove this differential pressure. If this motion persists further, the limit valve **371** will reverse this differential pressure so as to drive the gun back away from the limit. However, this back motion extends only far enough to permit the limit valve plunger **471** to return far enough to the left so that the differential pressure is cut off and the gun stops. The gun is thus rapidly decelerated and stopped just at the required limit, even though the sighting station is ordering further down elevation rate. The only effect of the remote sighting station under these circumstances is to actuate the rotary follow and synchro valves. But since the limit valve **371** overrides and takes control away from the rotary follow and synchro valves, by cutting off access of these valves to the control cylinder **375**, the latter valves are rendered ineffective, placing the gun completely under control of the limit valve and cam arrangement and completely independent (in elevation at least) of the remote sighting station.

Now, for the sake of further illustration, let it be assumed that the gun is stopped at its limit at point C, which also now indicates the position of cam follower **571**, since the gun is at rest. If down elevation rate is ordered by the remote sighting station, rotary follow valve **349** will attempt to set up a differential pressure in pipes **372**, **373** to drive elevation control piston **376** in the direction corresponding to down elevation rate. However, any motion of piston **376**, even before the gun begins to move, will be transmitted through arm **519**, crank **521**, shaft **585**, gears **587**, **589**, shaft **591**, and gears **593**, **595** to member **596** of differential **597**.

Member **614** of differential **615** is held stationary by the gun, which has not yet begun to move. Member **617** of differential **615** is also held stationary by action of cam surface **573** on cam follower **571**. Hence, member **616** of differential **615** is kept stationary, thus immobilizing member **598** of differential **597**, so that this differential **597** acts as a simple gear train and transmits the motion of member **596** to member **622**, and thence to gear **623**, shaft **625**, gears **627**, **629**, shaft **631**, crank **633** and arm **635** to actuate the plunger **471** of elevation limit valve **371**, which then acts to neutralize or cut off the differential pressure tending to move piston **376**, so that no motion of the gun can occur. The gun is thus fully blocked as far as down elevation rate is concerned.

If up elevation rate is ordered, the motion of piston **376** in response to the differential pressure produced by rotary follow valve **349** operates as before to actuate member **596** of differential **597**. However, now member **617** of differential **615** is not blocked, since cam follower **571** is free to move upwards. The centralizing springs of limit valve **371** are made stiff enough so that the motion of member **596** is transmitted now to member **617** of differential **615**, whose other member **614** is still immobilized by the gun (which is assumed to have not yet moved). Hence, cam follower **571** is driven away from cam surface **573**, and elevation limit valve **371** is not actuated, leaving full control in elevation (at least upwards) with the rotary follow valve **349**, and hence with the remote sighting station, as is desirable under these circumstances. Thus it is clear that the action of the limit stop mechanism is effective only when the gun is ordered against the stop, and leaves the gun perfectly free in the other direction.

Let it now be assumed that the gun is at R (Fig. 1A) and only down elevation rate is ordered. The gun will travel along RS until the cam follower **571** strikes the cam **341** as at S. If cam **341** were unable to move, the same sequence of oper-

ations would be effected as along path AC, as described above, and the gun would be stopped by operation of elevation limit valve 371.

However, motion of cam 341 is opposed, in this case, only by the centralizing springs of azimuth limit valve 371'. If the force exerted by this spring on the cam 341 is the same as that exerted by the elevation limit valve centralizing springs, the effect of engagement of cam pin 571 with cam 341 will be to stress both elevation and azimuth centralizing springs, in relative amounts corresponding to the slope of the cam surface 573. The stressing of elevation centralizing springs permits operation of the elevation limit valve 371 to decrease elevation rate, as discussed above with respect to path AC. The stressing of the azimuth centralizing spring permits motion of cam 341.

Since the gun is stationary in azimuth, B-end 144' and member 614' of differential 615' are stationary. Hence, the motion of cam 341 is transmitted to shaft 617' and through differential 615' acting as a simple gear train to member 598' of differential 597'. Since zero azimuth rate has been ordered from the sighting station, control piston 376' is stationary, as is member 596' of differential 597', which therefore acts as a simple gear train and transmits the motion to member 622' and thereby to plunger 471' of azimuth limit valve 371'. Operation of the limit valve 371' produces a differential pressure in lines 372', 373', and the gun is thereby operated in azimuth, following line SLC'. At C', cam follower 571 can no longer rotate cam 341, and the gun stops entirely in the manner explained above.

Hence, it will be clear that the gun will follow the ordered elevation faithfully until the lowermost elevation (C') is reached. During the time the limit stop is effective, however, the gun azimuth will not be true ordered azimuth.

With the gun and cam follower now assumed stationary at point C', if left azimuth rate is ordered, then, before the gun can move, azimuth rotary follow valve 349' operates to create a differential pressure in lines 372', 373' and thereby move azimuth control piston 376' to start motion of the gun to the left. However, before this gun motion occurs, piston 376' will actuate crank 521', shaft 585', gears 587', 589', shaft 591', gears 593', 595', and shaft 596' connected to one member of differential 597'. A second member 622' of this differential 597' is held by the centralizing springs of plunger 471' of azimuth limit valve 371'. Hence the motion is transmitted partially to member 622' and thence to plunger 471' of azimuth limit valve 371', and partially to member 598' and thence to member 616' of differential 615'. Since the gun is assumed to have not yet moved, member 614' of differential 615' is kept stationary, and differential 615' also acts as a simple gear train to transmit the motion of piston 376' to shaft 617', and thereby rotate cam 341.

Operation of azimuth limit valve 371' acts to decrease the effective pressure applied to azimuth control cylinder 375', and hence to decrease the effective azimuth rate.

Since cam follower 571 is in engagement with cam surface 573 at a minimum point C', the only way in which cam 341 can rotate in response to its driving forces, which are derived from motion of the piston 376' and the gun, is by moving cam follower 571 upwards. This upward motion of cam follower 571 is transmitted by way of rack 581, pinion 583, gears 621, 619 to shaft 617 connected to one member of differential 615. Since the gun is at first stationary in elevation, member 614 of differential 615 is kept stationary, so that the motion of member 617 is transmitted as by a simple gear train to member 616, and thereby to member 598 of differential 597. Member 596 of differential 597 is also kept stationary, since the differential pressure on elevation control piston 376 is zero, so that the motion of member 598 is directly transmitted to member 622 and thence, by way of gear 623, shaft 625, gears 627, 629, shaft 631, crank 633 and arm 635 to plunger 471 of elevation limit valve 371, which is thereby actuated to set up a differential pressure in lines 372, 373 which will drive the gun upwards.

Hence, as azimuth rate is introduced from the remote sighting station, the gun follows in azimuth, but lifts itself in elevation over any obstructions, (as determined by the shape of cam 341) by action of limit cam 341 and elevation limit valve 371. It will be clear that, in the present illustration, the same action occurs for right and left azimuth rate.

If azimuth rate is introduced from the remote sighting station while the gun is at point C, that is, while cam follower 571 is at a high spot of cam surface 573, and while the remote station is ordering further down elevation rate, the differential pressure thereby created in lines 372' and 373' in response to rotation of azimuth rotary follower valve 349' moves control piston 376' and thence, in the manner just described above, rotates shaft 617' and cam 341.

This action at once, even before gun motion occurs, moves cam surface 573 away (in the right or left direction, depending on which azimuth rate is ordered) from cam follower 571, and frees follower 571 for downward motion, whereby elevation limit valve plunger 471, previously held fully displaced by the ordered down elevation rate (the gun having been assumed stopped at the limit in elevation), may now be restored toward neutral by action of its centralizing springs, the motion being permitted by motion of arms 635, crank 633, shaft 631, gears 629, 627, shaft 625, gear 623, member 622 of differential 597 (whose member 596 is immobilized by the control piston 376, which is centered by zero differential pressure), to member 598 of differential 597, member 616 of differential 615 (whose member 615 is immobilized by the gun and B-end of 144 of the elevation-variable speed unit) and thereby to shaft 617 and thence to cam follower 571, which is now free to move, as already described.

In this manner the elevation limit valve 371 "backs off" to permit at least partial down elevation rate even before the gun begins to move, so that the gun may accurately follow curve CH or CS.

It will be seen that the present device of Figs. 3A and 3B has all the desirable characteristics described above. In the region away from the desired boundaries of motion, the gun is directly under the control of, and tracks accurately and rapidly with, the remote sighting station. In the proximity of these boundaries, rate of motion in elevation or azimuth or both is restricted by action of the respective variable limit stops, despite the "orders" of the remote sighting station.

This restricted motion is such that the gun is stopped if desired or ordered motion (path AC or A'C') is perpendicular to the surface of the limit boundary, which is the same as that of the cam surfaces 573 and 575 of cam 341. If the

ordered motion (KM or RS) is not perpendicular to the cam surfaces, the gun will continue in the same general direction (KML or RSL) but will follow the cam surface KML or SLC', instead of the ordered direction KM or RS, until a point (L or C') on the cam surface is reached where the ordered direction KM or RS is perpendicular to the cam surface, whereupon the gun will stop, since at point L the effect of left azimuth rate (tending to drive the gun along LC) is balanced by down elevation rate (tending to drive the gun along LC'). In effect the gun is caused to "glance off" the cam surface, to prevent its harmful engagement with the body of the craft, the cam being so designed that the gun is so prevented at all points.

The above analysis has been on the assumptions that the effects of the azimuth and elevation limit valve centralizing springs were equal, and that the cam surface **573** is an exact replica of the limit curve. However, neither of these assumptions is necessary.

In an upper turret, particularly, as described herein, it is desirable to have the turret follow the remote sight in azimuth despite any limit action in elevation. For this purpose, the azimuth limit valve centralizing springs are made stiffer than the corresponding elevation springs. Also, the elevation scale of cam **341** is made smaller than the azimuth scale. The effect of these variations is to make it easier for cam **341** to drive cam pin **571** than the reverse, so that limit action is more readily effected in elevation than in azimuth.

Thus, assume the gun positioned at point N, and only right azimuth is ordered. The gun will move freely from N to H, when the cam and cam pin engage. Since the azimuth springs are stiffer than the elevation springs, the azimuth limit valve will be only very slightly, almost negligibly, stressed, and no appreciable slowing up of the gun in azimuth is caused. However, the elevation limit valve is actuated, causing up elevation rate to be set in, and the gun follows curve HC. At C, the cam pin is freed from cam **341**, and down elevation rate is produced by action of elevation rotary follow valve, because of the lack of correspondence between the sight and gun orientations. Hence, the gun goes along curve CS, still with the same azimuth rate. From S the gun proceeds again in azimuth alone. By this procedure, the gun again picks up the target at S, having continuously tracked with the target in azimuth, the limit stop mechanism causing the gun to ride over obstruction HCS.

It will be clear that, if desired, elevation centralizing springs may be made stronger than the azimuth springs, resulting in somewhat inverse operation.

The elevation and azimuth cam scales may be selected in any desired manner to provide optimum operation. An especially desirable condition is to make the slope of the cam surface (**573** or **575**) with as small a maximum as possible, to obtain good cam action.

Because of the flexible link just described between the sighting station and the gun, there may be moments when the gun orientation is completely out of correspondence with the orientation ordered from the sighting station. Such moments occur, for instance, when the gun has engaged its variable limit stops, when the gun is first energized to place it under the control of the sighting station, or during slewing, when the

ordered rate of motion of the gun may exceed its maximum possible rate.

During such moments of non-correspondence it is desirable to cut off or prevent firing of the guns, which, in remote turrets of the present type, is usually remotely controlled by means of a solenoid mounted on the gun, whose circuit may be closed at a remote point to initiate firing. Since this non-correspondence is first evidenced by relative motion between rotor **347** and sleeve **379** of rotary follow valve **341**, it is possible to interrupt the electrical circuit of the firing solenoid upon such relative motion, and thereby prevent firing of the guns.

However, slight lack of correspondence is not objectionable, since the projectiles are likely to "spray" anyway, and may still be effective. Hence, it is more desirable to use the "coarse" repeater to control this fire cut-off. Thus, in Fig. 3B, when elevation "coarse" repeater **345** rotates contactor arm **351** into contact with either of contact sectors **353** or **355**, magnetic device **363** is energized to move arm **365** in one or the other direction.

Arm **365** carries an insulated projection **366**, which, upon motion of arm **365** in either direction, serves to separate insulated spring leaves **368**, **370** and thereby interrupt contacts **374**, **376**.

A similar arrangement is provided for azimuth control (Fig. 3A) and serves to interrupt contacts **374'**, **376'** whenever gun and ordered direction differ in azimuth by more than the width of insulating segment **357'**.

Elevation contacts **374**, **376** are connected, as by wires **372**, in series with corresponding azimuth contacts **374'**, **376'**, and also in series with the control circuit of the firing solenoid (not shown).

In this manner, whenever the gun orientation is out of correspondence with its ordered direction (either in elevation or azimuth or both) by an amount exceeding the angular width of insulating segment **357** or **357'**, gunfire is cut off.

Fig. 6 shows a preferred modification of the velocity compensating device of Figs. 3A or 3B represented by dash-pot **525**. In place of this dash-pot connection between link **519** actuated by the control piston **376** and the shaft **535** which serves to control one member of differential **539**, there may be inserted the apparatus of Fig. 6, which is shown as interposed between the same link **519** and shaft **535**.

Link **519** is pivotally coupled at **168** to a link **169**, which is pivotally connected at **171** to a link **173**, which in turn is pivotally connected at **175** to a crank **177** fixedly connected to shaft **535**, whose bearing **179** is shown as fixed to the base of the structure. Pivoted at point **181** of crank **177** is a piston rod **183** connected to a triple piston **185** of a compensating control cylinder **189**. Cylinder **189** is provided with two exhaust ports **191** and **193** connected as by a duct **195** to a source of low hydraulic pressure or exhaust pressure.

Centrally located between exhaust ports **191** and **193** is a pressure port **194** connected as by duct **197** to a source of high hydraulic pressure, which may be the same source of pressure as applied to the various control valves shown in Figs. 3A or 3B. Cylinder **189** is also provided with two outlet ports **199** and **201**. Piston **185** is formed in three sections **203**, **205** and **207**, which, in the normal position indicated by the solid lines in the drawing, respectively cover exhaust and pressure ports **191**, **194** and **193**. Outlet ports **199** and **201** are connected respectively to the head-end

port 209 and crank-end port 211 of an operating cylinder 213 whose piston 215 is connected as by piston rod 217 and link 219 to a pivot 221 intermediate the pivot points 171 and 175 of link 173.

In operation, when the A-end 142 of Fig. 3B is at the zero velocity position, link 519 and shaft 535 are so positioned that the elements of Fig. 6 are in the positions indicated by the solid lines, and piston 185 is centrally located over exhaust and pressure ports 191, 193 and 194, cutting these ports off completely from the head-end 209 and crank-end 211 of the operating cylinder 213.

Now, if elevation rate is ordered by motion of control piston 376 within control cylinder 375, for instance, in such direction as to move arm 519 upward to the position shown by the long dash lines, piston 215 of operating cylinder 213 remains stationary at first, causing link 173 to pivot about pivot 221, thereby causing crank 177 to rotate to the dashed line position, and thus actuating shaft 535, which transmits its motion, corresponding to turret velocity, through differential 539 in the manner described above with respect to Fig. 3B.

At the same time, since crank 177 is moved downward, pivot point 181 moves downward causing piston 185 to assume the dashed line position. In this position, hydraulic pressure is applied to outlet port 199 and exhaust pressure is applied to outlet port 201 of cylinder 189. Hence, pressure is applied to the head-end of operating cylinder 213 and exhaust is applied to the crank-end, thereby causing piston 215 to rise, as shown, to the dotted position. At this time, however, pivot point 168 remains fixed in its new position 168', since link 519 has not moved, so that the motion of piston 215 now causes link 173 to pivot about pivot points 171' and 168', and thereby piston 215 will continue to rise and rotate link 173 about pivot point 171' until by this means crank 177 has been rotated backward until piston 185 is again centrally located.

When this takes place the differential pressure applied to piston 215 is removed by the action of piston 185 in cutting off the exhaust and pressure ports 191, 193 and 194, and hence the system has again reached a rest position shown by the dotted lines of Fig. 6.

In this way, it will be clear that initially the motion of shaft 519 is transmitted directly to shaft 535 to introduce a turret velocity component of control in the follow-up system applied to follow-up sleeve 348 and follow-up platform 354, as described above with respect to Fig. 3B. This velocity component is caused to be removed by the action of compensating cylinder 189 and operating cylinder 213.

The amount of delay in removing this velocity component of control depends upon the response of the hydraulic system comprising cylinders 189 and 213. This response may be made slow enough to give appreciable delay in the removal of the turret velocity control component either by making ducts 208 and 210 small enough, as by a throttling section, so that hydraulic fluid can flow only slowly into operating cylinder 213; or by providing other means, indicated at 212, such as a continuously rotating valve which will connect ports 199 and 201 to ports 209 and 211, respectively, only during a fractional part of each revolution, thereby serving to restrict flow of oil from compensating cylinder 189 to operating cylinder 213 in much the same manner as would be done in a narrow orifice in these lines 208 and 210, without the accompanying disadvantages and likelihood of clogging which exists with the use of small orifices.

It will be clear that a similar device to that of Fig. 6 may be used in place of dash-pot arrangement 525' of Fig. 3A.

Fig. 7 shows an alternative construction for rotary follow valve 349 or 349'. Here, a rotary member 223 rotates within a rotatable sleeve 225 which in turn rotates within a fixed member or block 227. As before, rotary member 223 may be driven directly by the fine repeater 343, and the rotary sleeve 225 is driven by the follow-up gear 561, as shown in Figs. 3A or 3B. Rotary member 223 is provided with two annular grooves 229 and 231 and with four axial grooves 233, 235, 237 and 239, of which grooves 233 and 235 extend from groove 229 toward groove 331 and are symmetrically placed with respect to the axis of rotation of rotor member 223. In a similar manner axial grooves 237 and 239 extend from annular groove 231 toward annular groove 229 and are symmetrically disposed about the axis of rotor member 223.

As shown in the cross sections of Figs. 8 to 11, these grooves 233, 235, 237 and 239 are symmetrically disposed about the axis of rotary member 223, and leave a land or high portion 241, 243, 245 and 247 between each adjacent pair of grooves.

Rotary sleeve 225 is formed with four annular grooves 249, 251, 253 and 255, groove 249 being located opposite annular groove 231 of rotary member 223 and groove 255 being located opposite annular groove 229 of rotary member 223. Grooves 251 and 253 are symmetrically located between grooves 249 and 255. Each of these grooves communicates with the central bore of sleeve 225 as by holes 257, 259, 261 and 263, respectively.

It is noted that each set of these holes corresponding to any particular groove is located symmetrically with respect to the axis of rotation of rotary sleeve 225 or rotary member 223. Grooves 249 and 255 may be provided with any desired number of holes shown in this instance as four in number. Grooves 251 and 253 are each provided with two holes 259, 261, these holes being disposed in each instance on a diameter of sleeve 225, and holes 261 being displaced 90° away from holes 259. Each of these holes is formed to be of substantially the same size as the width of the lands or high portions of rotary member 223.

Groove 249 is adapted to be connected to ducts 421 and 429 shown in Fig. 4 and thereby communicate with the sump or exhaust pressure by means of duct 518 connecting to groove 249 as by duct 431. Groove 251 connects with duct 423 shown in Fig. 4 and thereby communicates with the crank-end of control cylinder 375. Groove 253 communicates with duct 427 and thereby connects, as described above, to the head-end of control cylinder 375. Groove 255 connects to duct 425 and thereby is connected to the source of fluid pressure as described above.

Thus, it will be clear that with the limit and synchro valves 349 and 369 in their central or neutral positions, fluid pressure will be applied through duct 425, groove 255, holes 263 and annular groove 229 to one pair of axial grooves 233 and 235. In a similar manner, sump or exhaust pressure will be connected by way of duct 431, groove 249, holes 257 and groove 231 to the other pair 237 and 239 of axial grooves.

In the positions shown in Figs. 7 to 11, the outlet ports 259 and 261 are completely cut off from exhaust or pump pressure, since these holes 259

and 261 are blocked by the lands or high portions 241, 243, 245 and 247 as shown in Figs. 9 and 10. However, upon rotation of rotary member 223 with respect to rotary sleeve 225, these lands or high portions 241, 243, 245 and 247 will uncover ports 259 and 261, and will permit pump pressure to be applied to one set of ports and exhaust pressure to the other set of ports, depending upon the direction of relative motion between rotary member 223 and sleeve 225.

It will be clear therefore that rotary motion of rotary member 223 with respect to sleeve 225 will produce a differential pressure in ducts 423 and 427 whose magnitude is proportional to the amount of relative displacement, at least up to the point where lands 241, 243, 245 and 247 uncover completely ports 259 and 261, and that this differential pressure will have a sense corresponding to the sense of relative motion between rotary member 223 and sleeve 225.

It will therefore be evident that this valve shown in Figs. 7 to 11 is the full equivalent, in operation at least, to the rotary follow valve 349 shown more in detail in Figs. 4 and 5. The limit and synchro valves 349, 369 shown in Fig. 4 may be used unchanged with the rotary follow valve of Fig. 7, the connections being made as already indicated.

It will be clear that the principles of variable limit stop described with respect to Figs. 1A and 1B are not restricted to hydraulic devices, as here illustrated, but may be used with electrical, mechanical, etc., systems.

Also, although the present device has been illustrated as a remote control, it will be clear that it may be applied to any type of power-operated device.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Having described our invention, what we claim and desire to secure by Letters Patent is:

1. In a positioning mechanism for a remotely directed gun having a control device, fine control means for moving said gun at a speed corresponding to relative displacement between the control device and said gun, coarse control means for moving said gun at a predetermined speed, means for bringing said last-named means into action upon such displacement exceeding the control range of said fine control means, and means responsive to operation of said course control means for interrupting firing of said gun, whereby gunfire is cut off during periods when the gun position differs from desired position by a predetermined amount corresponding to the control range of said fine control means.

2. In a positional control system having a controlling object and a driven object, a hydraulic transmission including a variable stroke pump and servo motor for driving said driven object, a stroke rod for the pump for governing the direction and velocity of said motor, a control valve for governing the movements of said stroke rod and having two relatively movable parts, means for moving one of said parts from the movements of said controlling object, means for moving the other of said parts from the movements of said driven object, the relative displacement of the parts of said valve producing proportional pressure, and means controlled by said pressure for moving said stroke rod.

3. A remote control mechanism comprising a driven object, a source of fine control data and a source of course control data, each of said data corresponding to a desired position of said object, a hydraulic transmission including a variable stroke pump and servo motor for driving said object, a stroke rod for the pump governing the speed and direction of movement of said motor, a control valve for governing the position of said stroke rod having two relatively movable members, means for moving one of said members in accordance with said fine control data, means for moving the other of said members in accordance with the actual position of said object, means responsive to relative displacement of said members for producing a differential pressure normally controlling the position of said stroke rod, and means responsive to predetermined lack of correspondence between said coarse data and said object for transferring such control to an independent source of pressure.

4. A remote control mechanism comprising a driven object, a hydraulic transmission for driving said object, a source of fine control data and a source of coarse control data, each of said data corresponding to a desired position of said object, said transmission including a servo motor and a pump of the variable-stroke type for driving said object, a stroke rod for the pump governing the speed and direction of movement of said motor, a control valve for governing the position of said stroke rod having two relatively movable members, means for moving one of said members in accordance with said fine control data, means for moving the other of said members in accordance with the position and speed of said object, means responsive to relative displacement of said members for producing a differential pressure normally controlling the position of said stroke rod, and means responsive to a predetermined lack of correspondence between said coarse data and a combination of the position and speed of said object for transferring such control to an independent source of pressure.

5. In a positional control system having a controlling object and a driven object, a hydraulic transmission including a variable stroke pump and servo motor for driving said driven object, a stroke rod for governing the direction and velocity of said motor, a control valve for governing the movements of said stroke rod and having two relatively movable parts, means for moving one of said parts from the movements of said controlling object, means for moving the other of said parts in accordance with both the actual displacement and velocity of said driven object, means responsive to relative displacement of said parts for producing differential pressure, and power means controlled thereby for positioning said stroke rod.

6. A positional control system comprising a controlling object, a driven object, a hydraulic transmission including a variable stroke pump and servo motor for driving said object, a stroke rod for governing the direction and velocity of said motor, a control valve for governing the movements of said stroke rod and having two relatively movable parts, means for relatively moving said parts from the movements of said controlling object, means for relatively oppositely moving said parts in accordance with the actual position of said driven object, a third

means for temporarily modifying said last-mentioned motion in accordance with the speed of said object, and means responsive to relative displacement of said parts for moving said stroke rod to control the speed of the driven object.

7. A remote control mechanism as in claim 6, in which said temporary motion-modifying means comprises a dash-pot mechanism having one part connected to said control valve and a second part connected to said stroke rod.

8. A remote control mechanism as in claim 6, wherein said temporary motion-modifying means comprises a mechanical differential mechanism for moving said control valve from said stroke rod and spring centralized dash-pot means for delayably restoring said mechanism to its neutrol position.

9. In a positional control system having a controlling object and a controlled object, a variable speed drive for actuating the controlled object, a controller for said drive having its output governing the speed of said variable speed drive and having a composite input responsive in part to the difference of position between the controlling and controlled objects, and a degenerative velocity feedback connection from the variable speed drive to said input, including means for causing the feedback to gradually decay whereby such velocity term disappears as a steady speed of said drive is reached.

10. A control mechanism for a gun comprising a source of control signal corresponding to a desired orientation of said gun, control means responsive to said desired orientation signal for driving said gun into correspondence with said desired orientation signal, means for producing a signal having components corresponding respectively to the actual orientation and actual velocity of said gun, and means responsive to a predetermined amount of non-correspondence between said two signals for preventing firing of said gun.

11. In a gun positioning mechanism having a control device and a gun, a fine transmitter and receiver at said device and gun respectively, means controlled by said receiver for positioning said gun upon small relative displacement between said device and gun up to but not exceeding a predetermined relative displacement, a coarse transmitter and receiver also at said device and gun, means controlled by said coarse receiver for fixedly positioning said gun upon relative displacement between said device and gun exceeding said predetermined displacement, and means for preventing firing of said gun so long as and only so long as such relative displacement exceeds said predetermined value.

12. In a positional control system having a controlling object, a controlled object, and motive means for driving said controlled object, a controller governing the speed and acceleration of said motive means and actuated in accordance with the positional disagreement of said two objects, of displaceable means for securing close following of the controlling object by the controlled object also affecting the position of said controller, means for displacing said displaceable means in accordance with the velocity of said motive means, and automatic means for wiping out the displacement caused by said velocity responsive means as acceleration ceases to avoid lag in following.

13. In a positional control system, a source of positional orienting data, a controlled object, motive means for accelerating the turning of said object to maintain said object oriented in the position indicated by said source, a dually governed controller for said motive means, a first governing means for said controller responsive to the amount and direction of departure of the position of said object from the position indicated by said source, a second governing means displacing said controller in a direction and proportional in amount to the direction and velocity of said motive means and opposing the first governing means, and means for causing a gradual decay in the displacement caused by said second governing means as acceleration of said motive means ceases.

EDWARD DAWSON.
FREDERIC M. WATKINS.
CHARLES N. SCHUH, JR.

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Certificate of Correction

Patent No. 2,445,765. July 27, 1948.

EDWARD DAWSON ET AL.

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 7, line 57, for "sylinder" read *cylinder*; column 8, line 73, for "poston" read *piston*; column 11, line 45, for "plate" read *plot*; column 18, line 45, for "arms" read *arm*; column 22, line 17, for the reference numeral "331" read *231*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 11th day of January, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

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