Jan. 2, 1962 W. LEATHERS ET AL 3,015,254

STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

Filed Dec. 29, 1945 5 Sheets-Sheet 1

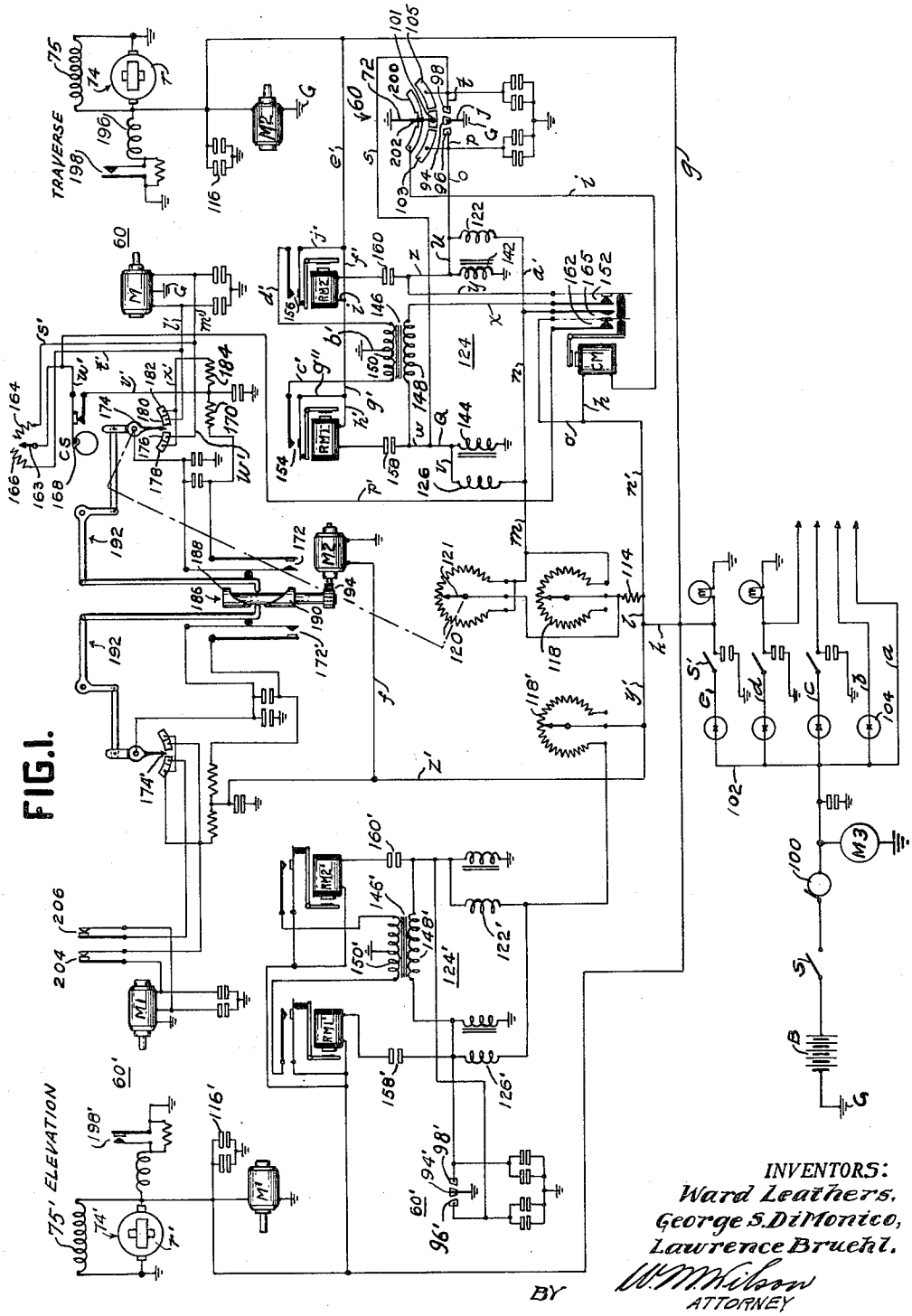


FIG. 1.

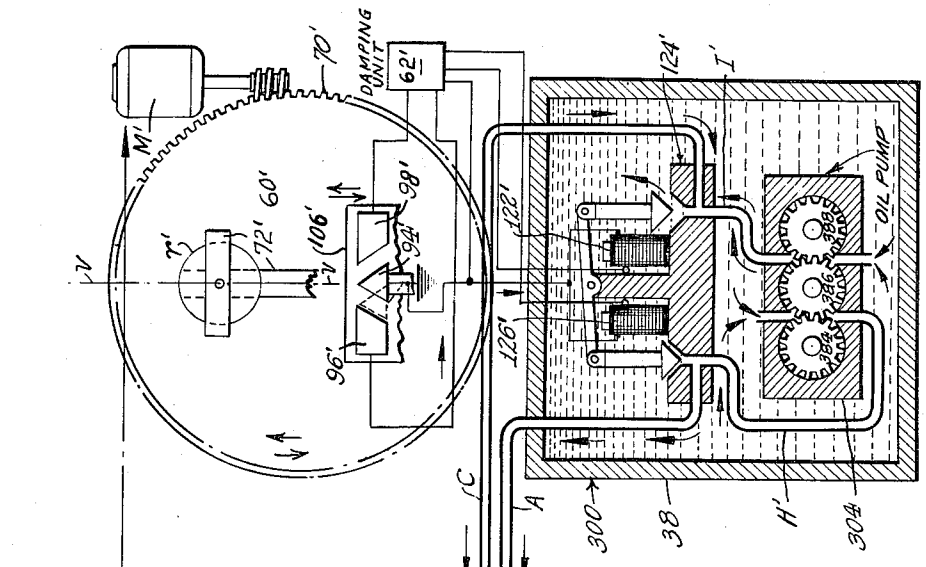
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STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

Filed Dec. 29, 1945 5 Sheets-Sheet 2



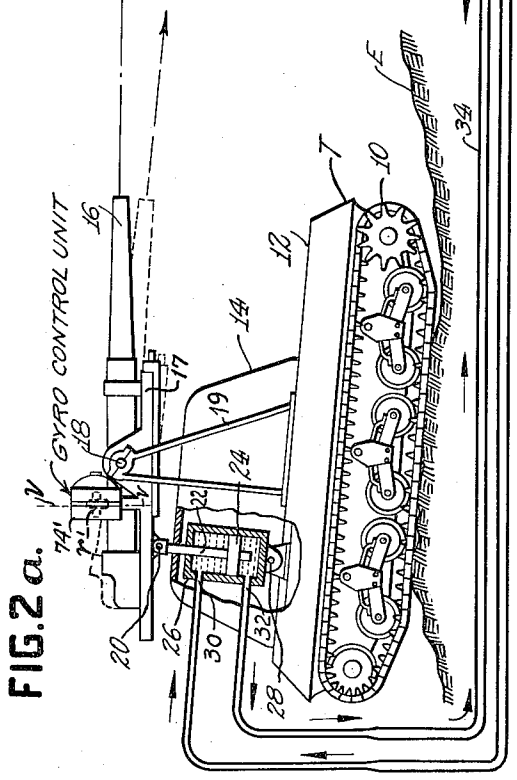


FIG. 2a.

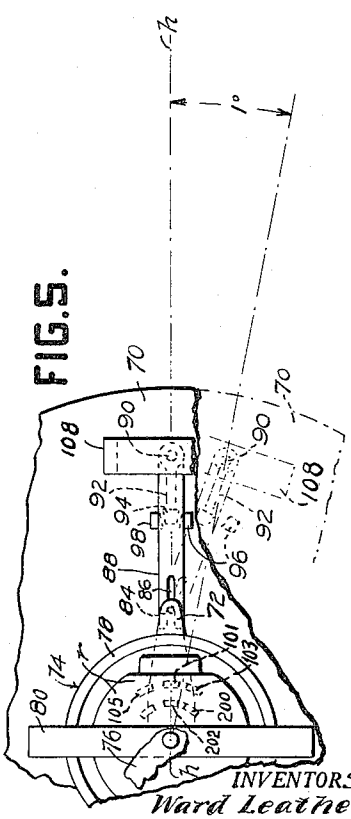


FIG. 5.

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STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

Filed Dec. 29, 1945 5 Sheets-Sheet 3

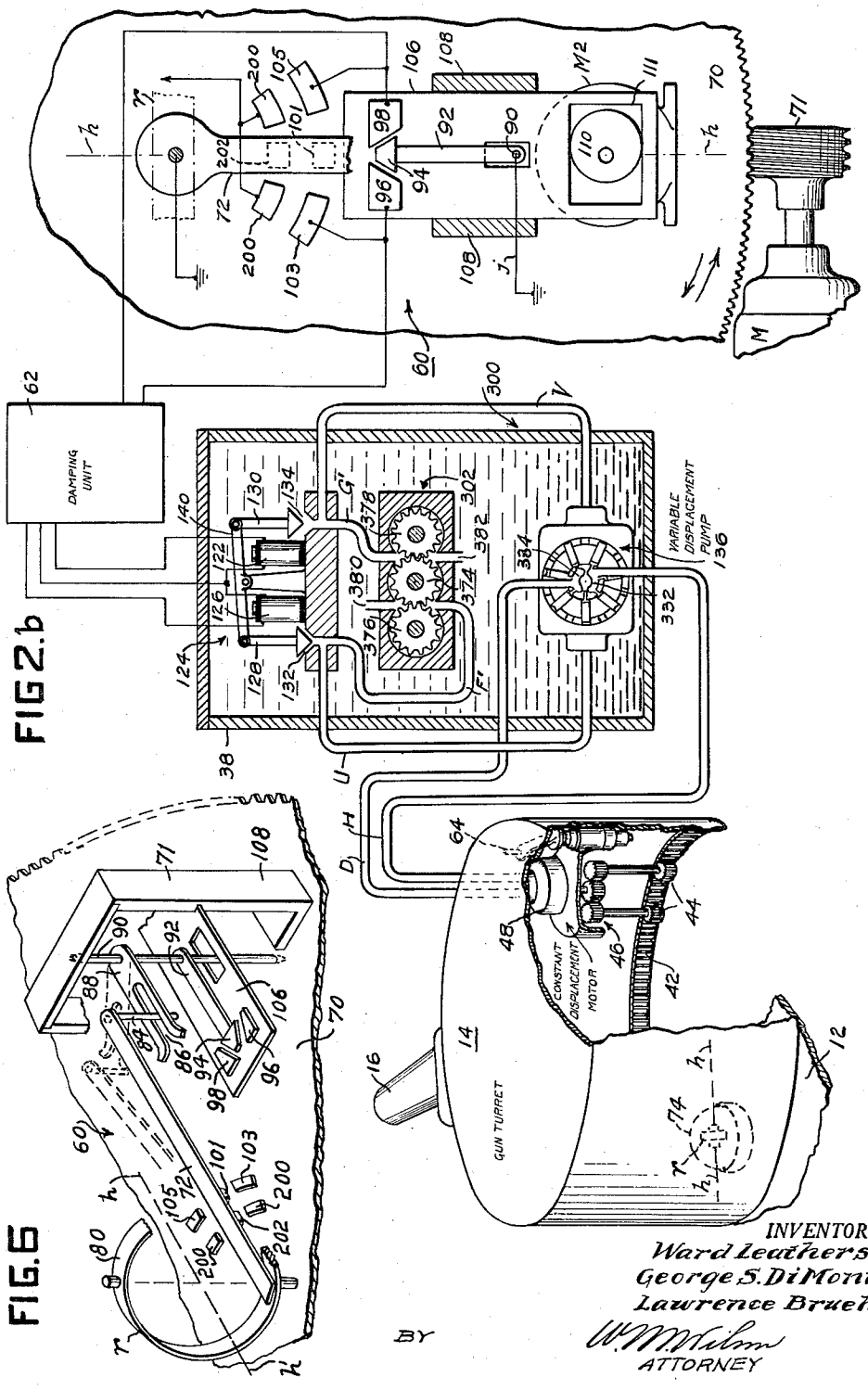


FIG. 2b

FIG. 5

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STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

Filed Dec. 29, 1945 5 Sheets-Sheet 4

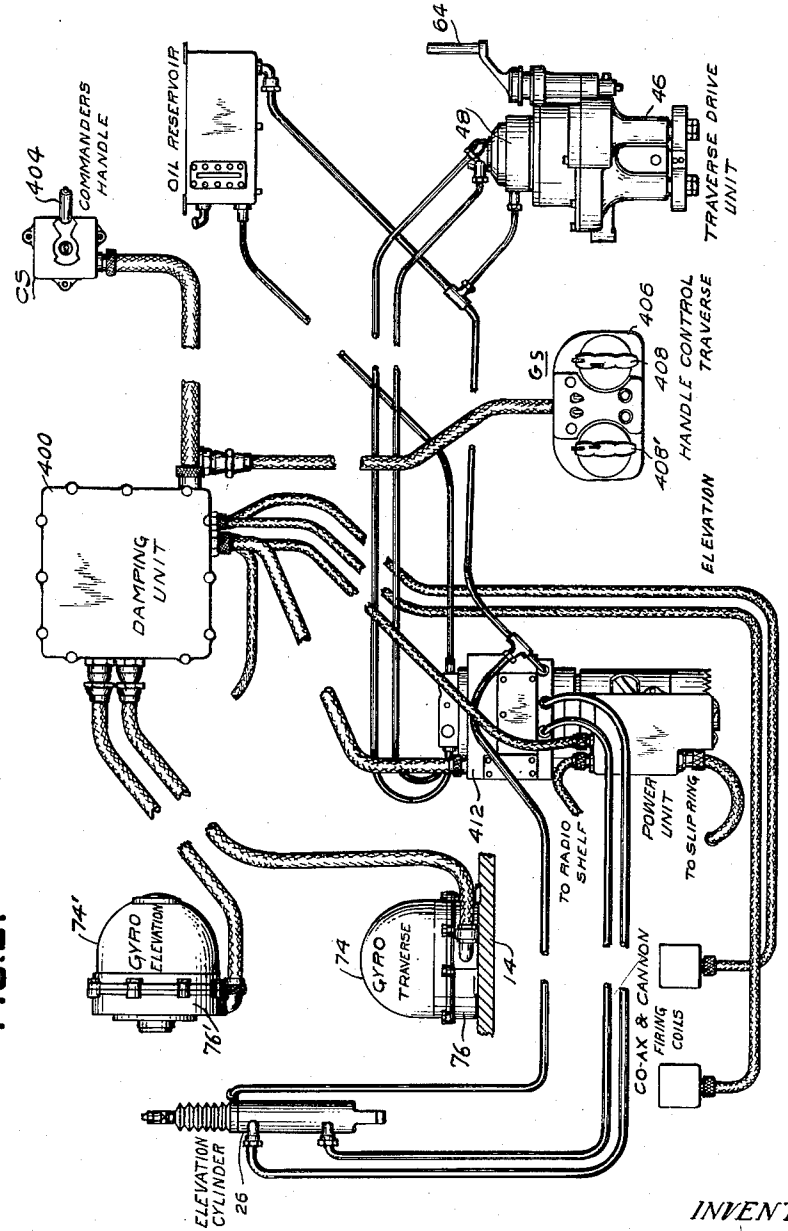


FIG. 3.

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STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

Filed Dec. 29, 1945 5 Sheets-Sheet 5

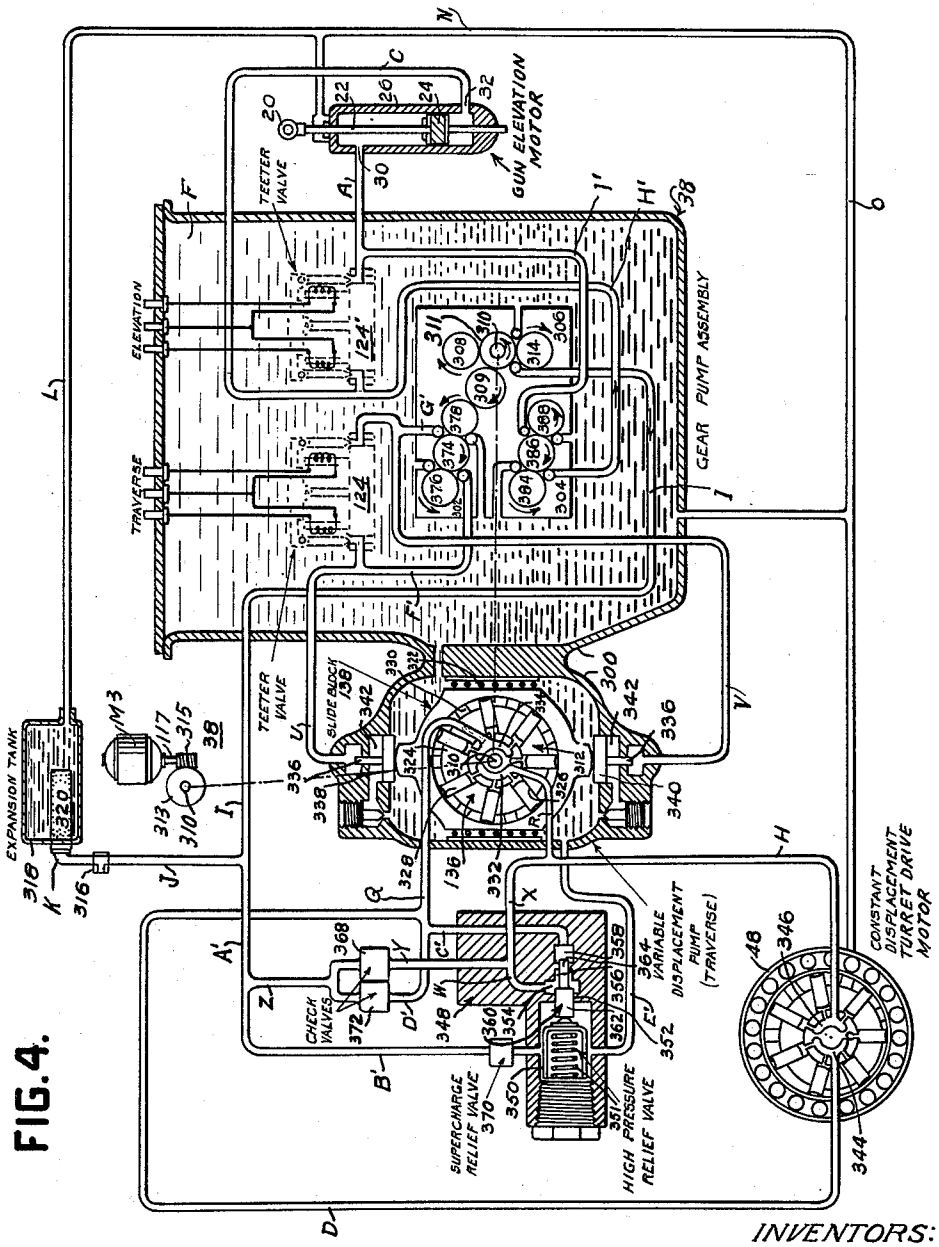


FIG. 4.

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United States Patent Office 3,015,254 Patented Jan. 2, 1962

3,015,254

STABILIZED CONTROL MECHANISM FOR A GUN MOUNTED ON A TURRET

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Filed Dec. 29, 1945, Ser. No. 638,394
3 Claims. (Cl. 89—41)

The improved stabilized gun control mechanism comprising the present invention is primarily adapted for installation in, and use in connection with, tank turrets where stabilization problems are highly specialized. The invention, however, is capable of other uses and the same may, with but slight modification, be adapted for use in connection with all manner of turret-mounted guns whether on sea-going vessels, aircraft or on moving vehicles. The invention may, with somewhat further modification, be designed for use in connection with radar equipment for the operation and stabilization of radar antenna where, for purposes of comparison, the antenna is treated as a gun and the receiving scope constitutes the equivalent of the periscope or other sight associated with a tank turret.

The invention has been illustrated herein in connection with a tank and, in this regard, it should be noted at the outset that such a vehicle consists essentially of a tank body or hull having mounted thereon a turret, which is capable of rotation with respect to the hull in traverse only and which otherwise is fixed so as to be incapable of tilting movement relative to any vertical or longitudinal axis of the hull. The gun or guns with which the present stabilizing mechanism is associated, are mounted in the turret and project outwardly therefrom in such a manner that they are capable of swinging movements up and down in elevation only. Any traverse movements of the gun occur only by virtue of corresponding traverse movements of the turret. Armored tanks, as briefly described above, are purely conventional in design and no claim is made herein to any novelty associated with such tanks per se. The stabilized gun control mechanism comprising the present invention is adapted to be mounted wholly within or upon the turret portion of the tank and moves in traverse with the turret as the latter turns relative to the hull. The invention includes two almost entirely independent sets of instrumentalities, one set being employed for stabilized control of the gun as far as its movements in traverse are concerned, and the other set serving to accommodate the gun for its elevational movements. Each set of instrumentalities includes a gyroscopically controlled electrical system, the function of which is to in turn effect a control on an hydraulic system, the latter serving directly to control, in one instance, the rotational movement of the turret relative to the tank hull and, in the other instance, to directly control the elevational movements of the gun relative to the turret. The two electrical systems are totally independent of each other and the two hydraulic systems likewise are independent in effect, although the various hydraulic mechanisms employed involve a common oil pressure flow system or, in other words, receive their sources of motive fluid from a common reservoir or sump.

The present stabilized gun control mechanism differs in principle from conventional remote gun controls in that the latter involve movable sighting means for determining the position of the target and means whereby a gun or series of guns mounted on platforms or in turret installations turn in traverse and elevate on gimbals to follow the sighting means, suitable servo-motors being employed to synchronize the movements of the gun or guns

to cause the latter to follow the movements of the sighting means. In the present instance, where tanks are concerned, the sighting means is in the form of a periscope which is mounted on the turret and which is fixed so as to move in traverse therewith and which also is rotatably mounted or pivoted to the turret for vertical swinging or angular movement with the gun for elevational control thereof. In this manner sighting must be effected by moving the turret in traverse and the gun in elevation to obtain bearings on the target.

According to the present invention, actual driving power is applied to the turret in traverse or gun in elevation, as the case may be, by hydraulic means and this involves the use of an hydraulic motor, the direction of movement of which and the rate of movement of which is controlled by means of a sensitive hydraulic system, which in turn operates under the control of an electrical system, by means of which deviations of the turret in traverse or gun in elevation from gyroscopically maintained lines of reference are detected and discriminated and compensatory hydraulic functions made accordingly.

In so far as the theoretical fundamental considerations of the present gun control system are concerned, these are precisely the same for gun control and stabilization in traverse as for gun control and stabilization in elevation. In the former instance, it will be understood that the gun, being mounted on the turret and fixed in traverse relative thereto, is stabilized and controlled by the application of stabilization and control applied to the turret to move the latter in traverse. In the latter instance, stabilization and control of the gun occurs by virtue of direct application of power to the gun to move the same in elevation about the axis of its gimbals or trunnions. While it is true that the turret is physically interposed between the gun and the tank hull and that power tending to move the gun in one direction or the other in elevation is applied to the gun directly from the turret, the effect, nevertheless, is the same as if the power were applied to the gun from the hull. Although the turret is interposed between the gun and the hull, it is capable of only traverse movements on the hull, and, as a consequence, it may be disregarded as a consideration where stabilization and control of the gun in elevation is concerned.

It has been stated above that the theoretical considerations of the gun control system for both traverse and elevational control of the gun are identical. Thus, in either instance, there are five directional reference considerations or elements involved. Four of these are natural functions existing, as they do, by virtue of the natural relationships between the earth with respect to celestial space and between the relatively moving elements associated with the tank, i.e., (in the case of traverse control) the tank hull and the turret, or (in the case of elevational control) the tank hull and gun with respect to each other and to the earth and to celestial space. The other directional reference consideration or element involved is an artificial consideration employed in the present system for directional control and stabilization purposes. This directional reference element exists by virtue of the provision within the turret of a movable member which, for purposes of the present discussion, may be considered as a disc having a reference axis thereon and which, in the case of the traverse control system, is capable of turning movements in traverse relative to the turret and which, in the case of the elevational control system, is capable of turning movements in elevation relative to the gun. As will appear presently, this last artificial directional reference element in either system is normally maintained fixed with respect to the casing of the particular gyroscope, by means of which either system is controlled, and control for stabilizing

purposes is initiated by virtue of its deviation from coincidence with the axis of the gyroscope rotor. For purposes of target finding or tracking, means are provided whereby this artificial directional reference element may voluntarily be shifted relative to the casing of the gyroscope to establish a new directional axis which, when stabilizing operations are again resorted to, then becomes fixed with respect to the gyroscope casing.

For convenience of description in this preliminary discussion of the invention, only traverse control and stabilization considerations need be undertaken. It will be understood that, in such an instance, power will be applied from the hull directly to the turrent to move the gun traverse and, as a consequence, the gun itself will be brought to bear on the target in traverse. Elevational movements of the gun for the purpose of such a discussion may be ignored. The five directional reference considerations involved in such a discussion thus become as follows: (1) Universal or celestial direction, i.e., a fixed gyroscopic direction in space; (2) direction relative to the earth's axis, i.e., compass direction; (3) direction of the heading of the tank hull; (4) the artificial direction relative to the turrent established by virtue of the platform, disc or turn-table which, for stabilizing purposes, normally moves with the casing of the gyroscope in traverse but which, for target finding and tracking, may voluntarily be shifted relative to the casing, and, finally, (5) the direction of heading of the turret.

Celestial direction or direction in space is a factor which is normally associated with any universally supported and freely rotating gyroscopic member or rotor and exists as a consideration in the present system only until such time as it is brought under control and modified in a particular manner. In the present instance, as soon as the rotor of the gyroscope is energized or set into motion, a gravity factor inherent in the gyroscope and operating according to well-known gyroscopic principles causes the rotor to assume a position tangent to the surface of the earth and at any indiscriminately occasioned fixed angle relative to compass direction. Celestial direction thus becomes modified until it is identical with a compass direction on the surface of the earth shortly after the gyroscope rotor is set into operation. Thereafter, celestial direction disappears and is no longer a factor, so that of the five previously outlined directional reference elements only four of them need to be considered as significant in the gun stabilization system. These four directional reference elements then become (1) earth or compass direction, (2) hull direction, (3) reference disc or turn-table direction, and (4) turret direction (i.e., gun direction in traverse).

As indicated above, direction relative to the earth establishes a base line extending at right angles to the earth's diameter and tangent to the earth's surface and fixed, for all practical considerations, relative to any selected compass bearing. This line of reference is established and maintained with a high degree of stability by well-known gravity controlled gyroscopic actions. All positioning or sighting, ranging, i.e., target location, automatic target stabilization or maintenance, leading on the moving target and target tracking, are obtained from this base line.

This established gyroscopic line of reference is relatively constant and is reasonably free from rotation with respect to compass directions. No arbitrary compass direction is selected or forced upon the rotor and, fall where it may, upon initial energization of the gyroscope, this line will, nevertheless, be tangent to the earth's surface. At all latitudes on the earth's surface, except at zero latitude, i.e., on the equator, some variations of this base reference line will be caused by the earth's rotation, but these extend over a long period of time and reach a maximum of 360° at the earth's poles and, therefore, are negligible insofar as tank operation is concerned and do not affect the problems involved. The entire gun stabilizing and control mechanism (for traverse) operates from this base line of reference which, according to a preferred form of the present invention, is maintained by a fully free gyroscopic rotor. The turret (and gun thereon) is caused to follow this line of reference but sighting and target bearing must necessarily be obtained by altering the angular relationship between the turret and this line of reference. The present system is thus distinguished from well-known sighting systems such as are employed in connection with remote controls for anti-aircraft guns or the remote control gun turrets, such as are employed, for example, on gun installations in aircraft. In such instances, the guns are caused to follow the sighting means, suitable service motors being employed to effect such action. In such systems there is no line of reference other than the sight itself. In the present instance, the sighting means is incapable of being directly moved by the gunner, inasmuch as it is anchored to the turret in traverse. Thus, bringing the reticule of the sight to bear on the target is an indirect follow-up process.

According to the present invention, the artificially established direction, which exists by virtue of the rotatable platform, disc or turn-table, is normally maintained in coincidence with the base gyroscopic line of reference, but is capable of deviation therefrom by virtue of either an involuntary cause, as for example, when the tank deviates from its normal heading or direction, or by virtue of a voluntary cause, wherein it is purposely moved from coincidence. In either event, upon such deviation from the base reference line, automatic means are provided for turning the turret in traverse relative to the hull in the opposite direction to restore the artificially established line to coincidence with the base line. The stabilization mechanism is sensitive to extremely small involuntary deviations of the artificial reference line from the base line and such deviations are relied upon to effect perfect and accurate stabilization when the gun is trained upon a target. Insofar as these voluntary or manually produced deviations are concerned, manual control means are provided whereby the angular relationship of the turret with respect to the base line of reference may, in traverse, be altered throughout any desired angle and at any desired speed.

When the relationship between the artificial reference line and the base line is changed, by either voluntary or involuntary, i.e., automatic, means, an electrical pick-off device associated with the gyroscope serves to control the operation of an hydraulic system, the ultimate function of which is to move the turret relative to the hull until, in the case of an involuntary discrepancy, the gun has been restored to the target, or, in the case of a voluntary discrepancy, the gunner is satisfied with his bearing and with the moving or tracking of the gun.

The present system operates either under the control of the gunner or under the control of the tank commander, controls being afforded both men and the former having both fine and coarse controls whereby the gun may be brought to the range of the target and thereafter centered on the same, and the latter having only a coarse control which overrides or supersedes that of the gunner and by means of which the turret may be moved in traverse to bring the gun rapidly to the vicinity of the target. One of the more important problems which has been solved by the provision of the present invention has been creation of a sensitive electrical pick-off for the gyroscope which is of extreme accuracy and sensitivity. This pick-off or sensing mechanism as it may be termed, is attained mechanically without applying an appreciable load on the gyroscopic axis which would ordinarily cause undesired precession of the gyroscopic rotor. Furthermore, the pick-off is characterized by the absence of electronic or vacuum tubes and their association in amplifier circuits and other equipment of this nature which is un-

desirable, in general, because of its complexity and, in particular, because of the exigencies of tank operation and design, as for example, limited turret space, liability to damage because of shock, vibration or the like, susceptibility to humidity or other changes in atmospheric conditions, etc.

The electrical pick-off mechanism is capable, in conjunction with its associated electrical and hydraulic instrumentalities, of rendering three types of performance, namely, target finding, tracking and stabilization. By the first is meant the relatively rapid angular movement of the turret or gun from a remote angular position to a position wherein the gun is brought to a direction wherein in traverse it is fairly close to the target. By tracking is meant the movement of the turret angularly at a speed approximating the angular speed of displacement of the target with the gun being maintained as closely as possible trained on the target. By stabilization is meant the relatively minor movements of the turret in traverse which are required to maintain the gun substantially centered on the target. This latter consideration takes into account slight displacements of the target arising from such causes as vibration, overriding of target finding or tracking operations, as well as the tendency for oscillation of the turret to occur after the target has been located. To compensate for this latter tendency, certain electrical damping operations are resorted to, the nature of which will become clear as the invention is better understood.

Briefly, the electrical pick-off device involves a pick-off arm which at all times coincides with the gyroscopically maintained fundamental horizontal line of reference. The pick-off arm is, in effect, an electrical contact-carrying arm which cooperates with the previously mentioned rotatable platform, disc or turn-table and which establishes the artificial reference line or direction. This disc is in the form of a contact-carrying member which is capable of movements relative to the pick-off arm but which normally is maintained coincident with the axis of the latter. The disc, by virtue of its direction of deviation and of its extent of deviation from the axis of the pick-off arm, serves to establish certain sensing and signaling circuits which exert a control upon the hydraulic mechanism, which in turn controls the traverse or turning movement of the turret. These sensing circuits, by virtue of the direction of deviation of the auxiliary reference line associated with the disc, control the direction of rotation of the turret and, by virtue of the extent of deviation, control the rate of turning movements of the turret. By such an arrangement, where stabilization is concerned, the turret, by virtue of the shifting of the auxiliary line of reference, moves in such a direction as to cause the gun to automatically follow the target and in so moving the auxiliary line of reference is gradually restored to coincidence with the original or fixed line of reference. Where voluntary shifting of the auxiliary line of reference is concerned, as for example, during target finding or tracking, substantially the same conditions obtain, except that the rate of movement between the turret and gun may, if desired, be increased materially.

The pick-off device may thus be said to sense the deviation of the auxiliary line of reference from the base line of reference and also to discriminate the degree of such deviation. Upon such sensing and discrimination, electrical control means are exerted by the pick-off device upon the hydraulic system which operates under the principles of relative hydraulic displacements to translate deviation in one direction or the other into corresponding opposite directional turning movements of the turret and to effect such movements in one direction or the other at rates of speed which are commensurate with the extent of deviation.

The above discussion has been, for simplicity's sake, concerned only with stabilization and control of the turret in traverse. Such stabilization and control of the turret in traverse obviously results in corresponding stabilization and control of the gun in traverse inasmuch as the latter is mounted on the former and fixed thereto in traverse. Where stabilization and control of the gun in elevation is concerned, substantially the same theoretical considerations obtain, for although the gun is moved in elevation relative to the turret, traverse movements of the turret may be disregarded and, for all practical purposes, the gun may be considered as being moved in elevation directly from the tank hull. In this latter instance, all of the above mentioned considerations remain in effect, the principal difference in structural features being that the gyroscopically established base line of reference is at all times a true vertical, i.e., it is coincident with an axis passing through the center of the earth. No problem of drift arises, inasmuch as the gyroscope employed is a vertical gyroscope and is equipped with well-known gravity-operated control means for maintaining the rotor on a true vertical axis, regardless of the earth's latitude at the scene of tank operation. Another structural difference resides in the fact that the rotary disc which establishes the artificial reference line is positioned within the turret for shifting movements relative to the pick-off arm in a vertical plane instead of in a horizontal plane. Whereas in the former instance the disc is capable of turning movements in traverse relative to the turning movements of the turret, in the latter instance the disc is capable of turning movements in elevation relative to the turning movements of the gun. Another difference which obtains in connection with gun stabilization and control in elevation is purely an arbitrary one and is predicated upon the fact that the range of the gun in elevation is considerably less than 360° and that, therefore, in target finding operations the gunner may be relied upon to find the target in elevation after the tank commander has brought the gun to bear in traverse to the vicinity of the target. Thus the commander's control mechanism is not wired for elevational control purposes.

The provision of a system which operates upon the principles briefly outlined above being the principal object of the invention, another object thereof is the provision of a novel method of applying damping effects to either the turret in traverse or the gun in elevation to compensate for the normal tendency of either of these elements to overrun the target when closing in thereon and to prevent consequent hunting action which would ordinarily result. The means and mechanism for effecting such damping operations is, in the main, electrical and consists in the use of a damping transformer, the secondary winding of which operates in the manner of a choke coil to apply damping impulses to the electric circuit leading to the hydraulic system and by means of which the application of power to the turret or gun, as the case may be, is controlled. These damping impulses are applied to the circuit at the precise moment when they are required. The primary winding of the transformer normally remains unenergized and inoperative but means are provided whereby substantially at the precise moment when the gun arrives upon the target an electrical impulse may be applied to this winding and translated by induction to the secondary winding to effect further damping operations so that the gun in seeking the target will not traverse the same, thus positively precluding any possibility of a hunting action. This latter auxliary damping means exists by virtue of the primary winding of the damping transformer becoming effective only when the gun approaches the target at a relatively high rate of speed that would ordinarily result in excessive damping operations.

A still further object of the invention in the electrical system briefly outlined above is the provision of a regulating means whereby the tracking stiffness of the system will automatically be varied to accommodate the various rates of speed encountered by the gun in its turning movements.

Another object of the invention is the provision of an

adjustable regulating means whereby the stiffness of the system may be adjusted to accommodate the preferences of the gunner and to accommodate any electrical or hydraulic variances that may arise from time to time, as for example, changes in reluctance of any of the electrical coils or windings employed in the system, changes in capacitance of any of the electrical capacitors employed, or changes in the viscosity of the fluid in the hydraulic system due to changes in temperature or the like.

Yet another object of the invention, in connection with the hydraulic mechanism employed thereby, is the provision of a novel form of reversible flow, rotary, hydraulic displacement pump, the direction and speed of rotation of which is controlled by the provision of a laterally shiftable control element, together with means for eliminating the effect of static friction during shifting of the latter whereby the same may be moved to any of its positions with an application of an extremely small motive force.

Numerous other objects and advantages of the invention not at this time enumerated will become more readily apparent as the nature of the same is better understood. In the accompanying drawings forming a part of this specification one embodiment of the invention has been shown.

In the drawings:

FIG. 1 is a schematic view, partially mechanical and partially electrical in its nature, showing the electromechanical mechanisms employed in connection with the present invention for controlling certain hydraulic mechanism also associated with the invention.

FIGS. 2*a* and 2*b* are schematic views of the gun stabilized mechanism, the former representing elevational control mechanism for rotating the turret and the latter showing traverse control mechanism for tilting the gun.

FIG. 3 is a diagrammatic view in flow-sheet form illustrating the entire stabilized gun control mechanism.

FIG. 4 is a schematic view of the hydraulic relay and drive mechanism employed in connection with the present invention for rotating the turret in traverse and tilting the gun in elevation.

FIG. 5 is a fragmentary plan view, schematic in its representation, illustrating the manner in which the effective length of the gyroscopic pick-off arm employed in connection with the present invention is shortened.

FIG. 6 is a perspective view, somewhat schematic in its representation, of the disclosure of FIG. 5.

In all of the above described views, insofar as practicable, like characters of reference are employed to designate like parts throughout.

In referring to FIGS. 2*a* and 2*b* it should be borne in mind that the illustrations thereof are purely schematic in their representation and are not intended to give an accurate disclosure of an operative armored tank vehicle. Rather, these two views are presented to illustrate certain theoretical conditions that obtain in connection with gun stabilization in elevation (FIG. 2*a*) and in traverse (FIG. 2*b*). Since FIG. 2*a* is concerned only with gun stabilization in elevation, no means are shown for rotating the turret structure of this figure. Likewise, since FIG. 2*b* is concerned only with gun stabilization in traverse, no means are disclosed for imparting elevational movements to the gun. It will be understood, of course, that accurate gun stabilization consists in imparting both elevational and traverse components of motion to the gun and that in these two figures the two functions have been effectively isolated for illustrative purposes.

In FIG. 2*a* a section of irregular terrain is designated at E and a tank T is illustrated as traveling over the terrain. The tank T includes a conventional Caterpillar tread mechanism **10** having associated therewith the body or tank hull **12**. A turret **14** is rotatably mounted on the hull **12** and is capable of turning movements in traverse thereon, and by means of these turning movements a gun **16** carried on a gun platform or mount **17** which in turn is carried by the turret **14** is capable of being

brought to bear and maintained upon a selected target. The turret **14** is incapable of elevational movements with respect to the hull **12**, i.e., its vertical axis at all times extends in a direction perpendicular to the plane of the hull **12** and it is incapable of tilting movement relative to the hull. The gun **16** and its platform **17** are suitably pivoted as at **18** above the turret **14** on a pair of standards, one of which is shown at **19**, for elevational swinging movements, i.e., for swinging movements in a vertical plane, and it is incapable of swinging movements relative to the turret in traverse. The inner end of the gun **16** has pivoted thereto as at **20** (see also FIG. 4) one end of a piston rod **22** having associated therewith a piston **24** slidably disposed within an operating cylinder **26**, the casing of which is pivoted as at **28** to a stationary part of the turret **14**. The gun **16** and the operating mechanism, by means of which it is tilted in elevation, are thus movable in traverse with the turret, but inasmuch as FIG. 2*a* is concerned only with elevational stabilization of the gun, the effect of turret movements in traverse may be totally disregarded. The cylinder **26** is provided with a fluid admission port **30** above the piston **24** and a similar fluid admission port **32** below the piston, and thus selective admission of fluid to and egress of such fluid from opposite ends of the cylinder **26** will serve to impart elevational components of movement to the gun **16** with respect to the turret **14**. The ports **32** and **30** are connected by means of suitable pressure lines A and C respectively to an hydraulic control mechanism designated in its entirety at **38**. This latter control mechanism **38** is in turn controlled by suitable electrical mechanism, a full disclosure of which has been made in FIG. 1 and which, insofar as elevational control is concerned, operates under the initial control of a gyroscopic pick-off device schematically designated at **60'** in FIGS. 1 and 2*a*, and the nature of which will be made clear presently.

The hydraulic control mechanism **38** is shown in FIG. 4 as serving both the elevational control mechanism for the gun and the traverse turret control mechanism, but in FIG. 2*a* only such portions of this mechanism as are pertinent to gun control in elevation have been disclosed.

FIG. 2*b* is similar in its representation to FIG. 2*a* and discloses schematically the means for controlling the movements of the turret in traverse. It will be understood that the gun **16** and its platform **17** are tiltably mounted on the turret **14** for elevational movements with respect thereto, but since this figure is concerned with stabilization of the turret in traverse only, disclosure of the means whereby the gun may be tilted in elevation has been omitted. A stationary ring gear **42** is suitably attached or fixed to the hull **12** and cooperates with a pair of driving gears **44** to impart rotational movement to the turret. The driving gears **44** are associated with a turret driving unit or gear box designated in its entirety at **46** which operates under the conrol of a reversible hydraulic displacement motor **48**, the nature of which will become apparent presently. The hydraulic motor **48** is provided with a pair of fluid lines D and H leading to the hydraulic control mechanism **38**.

Whereas in FIG. 2*a* only such portions of the hydraulic control mechanism **38** as pertain to gun stabilization in elevation are disclosed, in FIG. 2*b* only such portions of this mechanism as pertain to gun stabilization in traverse are portrayed. The hydraulic control mechanism **38** of FIG. 2*b* operates under the control of a gyroscopic pick-off mehanism **60** similar in its construction and design to the mechanism **60'**. Impulses effected by the gyroscopic pick-off mechanism **60** operate through a damping unit designated in its entirety at **62** to control the action of the hydraulic control mechanism **38**, all in a manner that will subsequently be set forth.

Manual control means in the form of a crank handle **64** (FIG. 3) is associated with the gearing of the gear box **46** to permit turning of the turret in traverse inde-

pendently of the stabilizing mechanism. This manual control means, together with the specific arrangement of gearing contained within the gear box **46**, forms no part of the present invention and no claim is made herein to any novelty associated therewith. This subject matter is illustrated, described and claimed in a co-pending application, Serial No. 644,686, filed February 1, 1946, now Patent No. 2,934,653, for Lash-Free Gear Driving Mechanism.

It should be noted at this point that whereas in FIG. 2*a* limited tilting movement of the gun **16** relative to the turret **14** is possible, such movement being maintained throughout an angle of approximately 36°, the turret is capable of full 360° turning movement in either direction. For this reason, the hydraulic operating cylinder **26** of FIG. 2*a* is capable of performing all services required of it, whereas in FIG. 2*b* an hydraulic motor capable of continuous rotation in either direction is required for operation of the turret **14**.

In the previous statement of invention, five directional reference considerations or elements were identified. These considerations as illustrated in FIGS. 2*a* and 2*b* are as follows: (1) Universal or celestial direction, as exemplified by the axis *v*—*v* of a freely rotating gryoscopic member or rotor *r'* (FIG. 2*a*) associated with the pick-off device **60'**, or by the axis *h*—*h* of a rotor *r* (FIG. 2*b*) associated with the pick-off mechanism **60**; (2) direction relative to the earth's axis, i.e., compass direction, as exemplified by the terrain E (FIG. 2*a*); (3) direction of heading of the tank hull as exemplified by the hull **12** itself; (4) an artificial direction established by virtue of a platform, disc or turntable **70** (FIG. 2*a*) which cooperates with an electrical pick-off arm **72** for traverse control, or a similar platform, disc or turn-table **70'** which cooperates with a pick-off arm **72'** (FIG. 2*b*) for elevational control; and, finally, (5) direction of the gun as exemplified by the gun **16** itself. Where stabilization of the gun in traverse is concerned, gun direction actually becomes turret direction inasmuch as the gun is mounted on the turret and turns in traverse in unison therewith regardless of its particular elevational setting.

The two systems, i.e., the electrohydraulic system employed for control of the gun in elevation and traverse, operate substantially independently of each other and thus, for purposes of description, the two may be completely isolated. Actually, in practice, separate gyroscopes are employed in the two systems and separate hydraulic relay control and drive mechanisms are employed. These latter hydraulic mechanisms, however, are for convenience and conservation of space, mounted within the common casing **38** and utilize the same motive fluid or oil supply. Also, in the hydraulic mechanism, certain driving and driven elements are carried upon a common shaft, although these elements function entirely independently of one another in their respective hydraulic systems. To avoid repetition of description, the stabilizing system for control of the gun in traverse will be first set forth in detail, after which the similarities in the two systems, as well as their differences, will be pointed out, thus disposing of the elevational control system without necessitating a detailed description of the latter. To accomplish this, wherever possible, similar characters of reference are employed in describing the two systems and prime reference characters have been applied to the elevational system.

Referring now to FIGS. 1, 2*b* and 3 wherein the stabilizing system for control of the gun in traverse is best illustrated, this system employs a traverse sensing unit in the form of a gyroscope **74** (FIGS. 1 and 3), the rotor of which is schematically shown at *r* in FIG. 2*b*. The winding of the gyroscope motor is shown at **75**. The casing of the gyroscope **74** is suitably secured to a stationary part of the turret **14** and is thus constrained to follow the movements of the latter in traverse. Erecting means are associated with the gyroscope **74** whereby when the latter is in operation the axis *h*—*h* of the rotor *r* is normally urged to a horizontal position with respect to the surface of the earth. The specific compass direction attained by the axis of the rotor *r* is unimportant, it being sufficient that this axis be horizontal and reasonably stable. A slight amount of drift may take place during maneuvers, the rate and extent of which is dependent upon the particular geographical latitude of the scene of operations. Such drift, however, at its maximum cannot exceed 360° in the course of twenty-four hours and this only if operations were to take place at either the North or the South Poles of the earth. The duration of stabilizing operations during any particular maneuver is ordinarily extremely short, lasting but a few minutes at a time, and as a consequence any tendency for the axis of the gyroscope rotor to drift in traverse may, for practical purposes, be disregarded. The erecting mechanism, by means of which the axis of the gyroscopic rotor is caused to assume a horizontal position, forms no part of the present application and has not been illustrated herein. For a full disclosure of this mechanism, reference may be had to a co-pending application, Serial No. 638,397, filed December 29, 1945, now Patent No. 2,972,424, for a Gyroscopic Erecting Mechanism.

The pick-off mechanism **60** associated with the gyroscope or traverse sensing unit **74** is schematically illustrated in FIGS. 1, 2*b*, 5 and 6, and such schematic representation is deemed sufficient for purposes of discussion in connection with this specification. No claim is made herein to any novelty associated with this pick-off mechanism, it being fully illustrated, described and claimed in another co-pending application, Serial No. 638,395, filed December 29, 1945, for Electrical Gyroscopically Actuated Control Device, and now abandoned.

Referring now in detail to FIGS. 5 and 6, the rotor *r* of the gyroscope **74** is rotatably mounted in a gimbal structure including a horizontal gimbal ring **78** and a vertical gimbal ring **80**, the latter being pivotally connected to the casing **76** of the gyroscope. The pick-off arm **72** is fixedly secured to the vertical gimbal ring **80** and projects forwardly therefrom. The longitudinal axis of the pick-off arm **72** is thus, as far as traverse considerations are concerned, maintained at all times parallel with the axis *h*—*h* of the rotor *r*.

The pick-off arm **72** is relatively short and carries adjacent its outer or free end a depending pin **84** adapted to ride in an open ended slot **86** formed in an arm **88**. The arm **88** is mounted on a vertically extending shaft **90**, the ends of which are rotatably journaled between the rotary turn-table **70** and an overlying bracket **108**. The turn-table **70** is mounted within the casing **76** of the gyroscope **74** and during gun stabilization operations normally is fixed relative to this casing so as to turn therewith when the tank T encounters deviations in heading. The turn-table, however, is capable of being voluntarily rotated in either direction relative to the casing **76** by means of a turn-table motor M (FIG. 2*b*), which is mounted on the casing of the gyroscope and which is suitably geared to the turn-table as at **71**. The shaft **90** has mounted thereon below the arm **88** a contact-carrying arm **92** which projects in a direction opposed to the direction of the pick-off arm **72** and the outer or free end of this arm **92** has mounted thereon a contact element **94** designed for cooperation with a pair of spaced oscillatable contacts **96** and **98** carried by the turn-table **70** and movable at all times therewith insofar as rotational movements of the turn-table are concerned.

From the above description of parts it will be seen that with the contact **94** centered between the two contacts **96** and **98**, any slight angular movement of the turn-table or platform **70** relative to the axis *h*—*h* of the rotor *r* will cause shifting movement of the contact **94** in one direction or the other into partial or full register with one or the other of the contacts **96** or **98**. The length of the pick-off arm **72** and the proximity of the shaft **90** to the outer end

of this arm when the latter is in alignment therewith, and also the length of the contact-carrying arm **92**, are such that very slight relative movements between the pick-off arm **72** and the turn-table **70** are materially magnified, so to speak, in the movements of the arm **92**. In actual practice, a 1° deviation of the pick-off arm **72** from the axis *h—h* of the rotor *r* will result in a 12° deviation of the contact arm **92**, as illustrated in FIG. 5.

It is to be noted that when during relative movement between the pick-off arm **72** and the slotted member or arm **88** a certain degree of displacement is attained, the pin **84** rides completely out of the slot **86** leaving the arm **88** poised, as shown in dotted lines in FIG. 6. From this point, the turn-table **70** is capable of movement independently of the member **88** during restoration of the turn-table. As the gun approaches its heading upon the target, the pin **84** will again be returned to the slot **86** and the arm **88**, as a consequence will ultimately be restored to its initial position.

As shown in FIGS. 1, 2*b*, 5 and 6, the arm **72** carries a medially disposed contact **101** designed for selective engagement with a pair of contacts **103** and **105**. The contacts **103** and **105** are mounted on and rotatable with the turn-table **70** and, as will appear presently, they are electrically connected to the contacts **96** and **98** respectively in such a manner that when the angular displacement of the arm **92** is sufficiently great either of the contacts **103** or **105**, as the case may be, becomes, in cooperation with the contact **101**, effective to the exclusion of the contacts **96** and **98**.

The turn-table **70** is capable of rotational movements in opposite directions as indicated by the arrows in FIG. 2*b*. It will be understood that rotational increments of motion applied to the turn-table **70** may arise through one of two considerations, either they may be involuntary or automatic increments of motion such as are applied to the turn-table when the tank swerves, skews or otherwise is caused to deviate from its normal heading, or they may be voluntary or manual, as for example, when the motor M is energized for rotation in one direction or the other at the will of either the gunner or the tank commander. In either case, when the turn-table is initially moved from its established position relative to the heading of the turret to such an extent that the contact **94** engages either the contact **96** or the contact **98**, electrical and hydraulic operations are set-up tending to restore the turret to its original heading. In so restoring the turret to its original heading, the turn-table, too, will be restored. In the case of involuntary or automatic discrepancies in heading when the turret has been restored to its original heading, the turn-table will occupy its original position or direction relative to the turret. Where the voluntary discrepancies are concerned, and the parts have been thus restored, the turn-table will likewise be restored to its normal position relative to the turret, but the turret will have shifted to a new heading relative to the hull and any further involuntary discrepancies in heading on the part of the hull will be stabilized about the new heading.

The source of current supply for the electrical mechanism employed in connection with the stabilizing device is in the form of a battery B (FIG. 1) of medium voltage which is preferably in the neighborhood of 24-volts. One terminal of the battery is grounded as at G and the other terminal thereof is connected through a power line switch S and turret slip ring arrangement **100** to a distributor bar **102** from which branches *a*, *b*, *c* and *d* lead through suitable cut-out devices **104** to the various phases of tank operation, as for example, radio maintenance, lighting, motor ignition, gun firing and the like. An additional branch *e* leads through a switch S' to the electrical system of the gun control mechanism.

Engagement of the contact **94** with the contact **96** or the contact **98** serves to close respective electrical circuits leading to the hydraulic system and by means of which an hydraulic motor is set into operation and caused to turn the turret **14** in one direction or the other, depending upon which circuit has been closed. With the contacts **96** and **98** fixedly mounted upon and movable with the turn-table **70**, engagement between the contact **94** and either of the contacts **96** or **98** would ordinarily cause a continuous flow of direct current from the battery B through the closed circuit, regardless of the extent of deviation of the contact **94** from its normal or neutral position. This would result in the prolonged application of maximum torque to the turret to restore the turn-table to its neutral position and as a result thereof a violent hunting action of the contact **94** between the two contacts **96** and **98** would occur in a pronounced manner. In order to eliminate such hunting action, at least in part, and in order to apply periodic current impulses to the circuits, which are proportional to the extent of deviation as distinguished from a flow of direct current therein, and for other reasons that will be made clear hereinafter, an artificial mechanical means is provided for applying a simple harmonic motion to the contacts **96** and **98** in unison, such motion being continuous during the entire operation of the system. In addition to this, the shape of the contacts **94**, **96** and **98** is so designed that as the contact **94** deviates from its normal or center position correspondingly greater periods or increments of engagement with either of the contacts **96** or **98** is attained until such time as at a predetermined extent of deviation continuous engagement with one or the other of the contacts **96** and **98** is attained. The means for oscillating or otherwise moving the contacts **96** and **98** with a simple harmonic reciprocating motion forms a part of the subject matter of the previously mentioned co-pending application Serail No. 638,395, and now abandoned. Reference may be had thereto for a full disclosure thereof. For the purpose of the present application, a diagrammatic showing of this contact moving mechanism has been made and includes the provision of a slidable member **106** upon which the contacts **96** and **98** are disposed. The member **106** is mounted in guides **108** carried on the turn-table **70**. A pick-off motor M2 serves to drive a circular offset eccentric cam **110**, the periphery of which is confined within an opening **111** formed in the member **106**.

Current for the pick-off motor M2 is supplied whenever the switches S and S' are both closed from the battery B, switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wire *g*, pick-off motor M2 to ground G. A plurality of small capacitances **116** associated with the pick-off motor M2 are provided for by-passing of radio frequencies to eliminate radio interference.

The movable contact **94** of the pick-off mechanism **60** is connected to the ground G by means of a wire *j*. When in the course of operation the contact **94** engages the contact **96**, a circuit is established leading from the battery B, switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wires *k* and *l*, resistor **114**, parallel variable resistors **118** and **120**, wires *m*, *n*, *a'*, a coil **122** associated with an oscillating valve structure, hereinafter referred to as a teeter valve and designated in its entirety at **124**, wires *o*, *p*, contacts **96**, **94**, and wire *j* to ground. A similar parallel circuit exists for the contact **98** and leads through a teeter valve coil **126** and wires *q*, *s*, *t*, to the contact **98** and from thence through contact **94**, wire *j* to ground.

When the contacts **94** and **96** become engaged in the course of operation, a circuit also exists from the battery B, switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wires *k* and *l*, resistor **114**, parallel variable resistors **118** and **120**, wire *m*, coil **126**, wires *v*, *q*, *w*, coil **148** of a damping transformer **146**, wire *x*, a pair of normally closed contacts **152**, wires *y*, *z*, *u*, *o*, *p*, and contacts **96**, **94** to ground. This latter circuit, however, is a relatively high impedance circuit and while it does, in a small measure, have a slight counter-balancing effect which

tends to oppose the effect of the previously described circuit existing through the coil 122, this previous circuit is the controlling one. The low impedance circuit passing through the coil 122 and wires *o*, *p* and contacts 96, 94 includes the relatively low resistance of the coil 122 and its relatively low inductance. The impedance of the counter-balancing circuit described above includes the resistance of the coil 126, its inductance and, in addition, the relatively high resistance and inductance of the iron core winding 148 of the transformer 146. This latter circuit gives a slight damping effect but it is the other circuit leading through the coil 122 which is most effective for actual damping purposes. In actual practice, it has been found that effective damping will take place when the coils 122 and 126 each have a resistance of approximately 30 ohms and an inductance of about 3 henries. The iron core winding 148 of the transformer 146 may have a relatively higher resistance of 60 ohms and an inductance as high as 10 henries.

Referring now to FIGS. 2*b* and 4, the previously mentioned teeter valve construction 124 is embodied in the hydraulic control mechanism 38 and includes a pair of valve members 128 and 130, each valve serving to control the flow of motive fluid through their respective valve ports 132 and 134, these latter ports being associated with an hydraulic system, the nature and function of which will be made clear presently. At the present time, it is deemed sufficient to state briefly that the teeter valve assembly 124 operates upon the principles of differential pressures to apply motive fluid to a continuously rotatable off-center variable displacement pump 136 in such a manner as to cause shifting movement therein of a slide block 138, the position of which serves to determine the direction and rate of flow of fluid therethrough for the purpose of in turn applying motive fluid to the motor 48 which drives the turret 14 through the gear box 46 to determine the direction and rate of turning movement of the turret. The specific nature of the variable displacement pump 136 will be described subsequently, but for the present it is deemed sufficient to state that the slide block 138 is self-centering so that when equal pressures are applied to the opposite sides thereof the block will automatically find a center position wherein no fluid passes through the pump in either direction. The valves 128 and 130 are carried at the opposite ends of a cross head 140 and when the two valves are balanced or are in their neutral positions, pressure of fluid leaving the ports 132 and 134 is equalized so that the slide block 138 is in its neutral position and no movement of the turret results. When one of the valves 128 or 130 is urged toward its respective seat 132 or 134, as the case may be, the other valve is urged away from its seat so that unbalanced pressures result in the two fluid lines leading to the variable displacement pump 136. This results in an off-center position of the block 138 with consequent movement of the turret in one direction or the other and at a rate depending upon the extent of pressure differential at the teeter valves.

Each of the valve coils 122 and 126 has associated therewith iron core choke coils designated at 142 and 144 respectively in FIG. 1. Each of these choke coils is placed in an electrical circuit in series with its respective valve coil so that at all times a small leakage current flows through the valve coil. In the case of the valve coil 122, this circuit exists from the battery B, switch S, turret slip ring 100, distributor bar 102, branch *e*, switch S', wires *k*, *l*, resistances 114, 118 and 120, wires *m* and *n*, valve coil 122, wire *u* and choke coil 142 to ground. A similar circuit exists in the case of the valve coil 126 and choke coil 144. Because of these leakage currents, the coils of the two teeter valves are at all times maintained partially energized.

The previously mentioned damping transformer which has been designated in its entirety at 146 includes the secondary coil 148 and the primary coil 150. The secondary coil 148 is disposed in a local circuit in series relationship with the valve coils 126 and 122, and operates at certain times independently of the primary coil 150 as a damping choke. The local circuit just referred to exists in either direction through the coil 126, wires *v*, *q*, *w*, secondary coil 148, wire *x*, a pair of normally closed contacts 152, wires *y*, *z*, *u*, valve coil 122, wires *a'*, *n*, and back to the coil 126. This local damping circuit, together with certain other electrical damping instrumentalities that will be described subsequently, is necessary inasmuch as the electrical system involved generates its own cycles and it is necessary to prevent the gun from overrunning the target as it approaches the same in either direction and thus avoid a hunting action.

To better understand the description of the damping facilities which will follow subsequently, it is deemed pertinent first to describe the electrical system as it would occur if damping facilities were not provided. It has previously been described how the contacts 96 and 98 are given a simple harmonic motion so that they sweep in and out beneath the contact 94 when the latter is offset in either direction from its normal position coincident with the axis *h'—h'*. The two circuits involved leading from the battery B and passing through either the pair of contacts 94 and 96 or the contacts 94 and 98 have previously been traced. The resistance 118 regulates the response of the system by regulating the current which flows through the valve coils 126 and 122 at the moment either contact 96 or 98 engages the contact 94. The coils 126 and 122 actuate their respective valves 128 and 130 by creating pressure variations in the hydraulic system which are proportionate to the current variations in the coils 126 and 122. These current variations are effected by varying the relative time of engagement between the contacts 94 and 96, or 94 and 98 respectively. The contact 94 is grounded and is moved laterally relative to the other contacts by relative movements of the turn-table 70 so as to engage either the contact 96 or the contact 98, or both of them, in the center position. The pick-off motor M2 oscillates the contacts 96 and 98 at an angle of ninety degrees to the arc of movement of the contact 94 and at an approximate rate of thirty impulses per second. Normally the contacts 96 and 98 are located relative to the contact 94 in a center position so that both teeter valve coils 126 and 122 are given impulses simultaneously and are thus maintained under equal tension. Movement of the contact 94 relative to the other two contacts disturbs this balance, favoring the side to which it is moved. In actual practice a quarter-mil movement of the contact is sufficient to produce a corrective counter pressure and hence an appreciable pressure flow in the hydraulic system.

As the contact 94 becomes shifted in either direction, the impulses applied to the favored circuit represented by the contacts 96 or 98 become of longer duration, while at the same time the duration time between impulses become correspondingly shorter. As the contact 94 approaches either of its extreme positions, wherein it completely overlies either the contact 96 or the contact 98, a condition obtains wherein these impulses cease altogether and a continuous flow of direct current occurs in the particular circuit involved.

The wave form of the impulses applied under such conditions is somewhat complex and irregular. This form may generally be described, however, as far as voltage is concerned, as a chopped, substantially square top voltage wave in which the duration of current progressively increases as the contact is moved toward either of its extreme positions. In any event, however, the net result is the application to either of the two valve coils 126 or 122, or both of them simultaneously, in the center position of a voltage impulse which has an effective mean value derived from the chopped wave form produced by the oscillations.

The pressure induced in the hydraulic system is in proportion to the time-current factor. When the displacement between the contact 94 and the other two contacts reaches approximately 2.5 mils in either direction, a con-

dition obtains which produces the maximum pressure called for by the variable sensitivity adjustment resistor **118**. Current is maintained at a maximum and consists of a steady direct current flow until the error falls below that represented by 2.5 mils displacement of the contacts. Below this point the current is chopped or broken up into voltage impulses which gradually decrease in intensity as the error becomes smaller during restoration of the turret and turn-table to the line of reference represented by the axis *h'—h'*.

The simple system outlined above is by nature not stable inasmuch as certain hunting tendencies prevail. As a consequence, it must be electrically damped. It takes a certain amount of time to build up a magnetic field in a coil due to inductance effect and, therefore, the desired action in the hydraulic system is delayed. Additional time is required to transmit power through the hydraulic system to its point of use. Similar delays in the reverse order occur after the center position of the contact **94** is reached and thus, with no damping effects, actual practice has shown that the system will oscillate between limits ranging from 4 to 50 mils. As a result of this, automatic damping in proportion to the tendency of the system to oscillate is required.

The local circuit passing through the two choke coils **142** and **144**, and through the secondary coil **148** of the damping transformer **146**, constitutes a primary damping means, the nature of which will be treated separately. Further damping arrangements are provided for and a description thereof will be made subsequently.

When the contact **94** is displaced in either direction relative to the other two contacts of the pick-off mechanism, current is caused to flow, as previously described, in either of the two circuits leading from the battery and passing through the valve coils **122** or **126**, as the case may be. Simultaneously with such passage of current, however, energy becomes stored in the secondary damping winding **148** during the restoring operation when the turret and the turn-table are moved in such a direction as to restore a condition of equilibrium between the pick-off contacts. The charging circuit for the secondary winding **148** of the damping transformer **146** leads from the battery B through the switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wires *k*, *l*, resistance **114**, variable resistances **118** and **120**, wires *m*, *n*, *a'*, valve coil **122**, wires *u*, *z*, *y*, contacts **152**, wire *x*, secondary coil **148**, wires *w*, *s*, *t*, contacts **98** and **94**, and wire *j* to ground. The above charging circuit is in effect when contacts **94** and **98** are in engagement. When the contacts **94** and **96** are in engagement, a similar circuit exists passing through the coil **148** in the opposite direction from the battery B through the switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wires *k*, *l*, resistance **114**, variable resistances **118** and **120**, wire *m*, coil **126**, wires *v*, *q*, *w*, coil **148**, wire *x*, contacts **152**, wires *y*, *z*, *u*, *o*, *p*, contacts **96** and **94**, and wire *j* to ground.

When a break occurs between either pair of contacts, the magnetic field in the transformer collapses and superimposes an electric impulse in the system which is resisted by the choke coils **142** and **144** and which is thus deflected to both of the valve coils **122** and **126**. This impulse effects a rapid decrease in hydraulic pressure and since the impulse acts in opposite directions on the two coils **122** and **126**, it may even induce a negative pressure in the system. The extent of this pressure is proportional to the rate at which restoration of the turn-table is taking place and, in any event, it is sufficient to prevent overriding of the target. By the electrical arrangement described above, a true anticipation of a possible overriding of the target takes place before the center position is reached. The values of the various coils in henries and of the other electrical factors involved are chosen, according to engineering exigencies, in such a manner that the turret will come to a stop exactly on the line of reference within one-half cycle. As previously mentioned, it has been found that efficient results are attained if the coils **122** and **126** each have a resistance of approximately 30 ohms and an inductance of approximately 3 henries with the primary coil **148** of the transformer **146** having a resistance of approximately 60 ohms and an inductance of approximately 10 henries. In other words, there will be no overriding of the target, regardless of any reasonable moderate rate of speed at which restoration takes place.

Where extremely high rates of restoration are concerned with the simple damping circuit just described, several oscillation cycles may be required to absorb the total energy. In actual practice it was found that even with the use of the secondary winding **148** of the transformer **146**, about ten cycles were required to absorb oscillations of 100 mils amplitude. Since each oscillation may take as long as two-thirds of a second, the time required for comp'ete stabilization on the reference line is too long for such magnitudes of displacement. For this reason it is necessary to employ additional sets of damping oscillations which absorb such amplitudes within one-half cycle. These latter damping waves behave similarly to those previously described but are considerably more powerful and are differently timed. Their principal operating range is at angular displacements of from 50 to 100 mils.

The means for effecting additional damping oscillations for use when the gun approaches the target from widely displaced latitudes consists of the primary winding **150** which is center tapped by means of the wire *b'* to ground. The ends of the winding **150** are connected by means of wires *c'* and *d'* to two pairs of normally open contacts **154** and **156** respectively which operate under the control of respective relay magnets RM1 and RM2. The relay magnet RM1 exists in an electrical circuit in series with a condenser **158**, while the magnet RM2 exists in a similar circuit in series with a simi'ar condenser **160**. The reluctance of the coils of the magnets RM1 and RM2 and the capacitances of the condensers **158** and **160** are such that small potentials in the respective circuits will not trip the respective relays to close either the contacts **154** or **156**. Higher potentials, however, will create sufficient current flow through the windings of the magnets RM1 and RM2 to momentarily energize the same and cause momentary closing of their respective contacts **154** or **156**, as the case may be. Such a surge of current occurs when the contact **94** is displaced from its center position and moves into constant engagement with either of the contacts **96** or **98** at a point representing about 10 to 30 mils displacement. In the case of the magnet RM1, the circuit involved leads from the battery B, through switch S, turret slip ring **100**, distributor bar **102**, branch *e*, switch S', wires *g*, *e'*, *f'*, *g'*, *h'*, magnet RM1, condenser **158**, wires *w*, *s*, *t*, contacts **98**, **94**, wire *j* to ground. In the case of the magnet RM2, the same circuit from the battery B to the wire *f'* exists and from thence the circuit continues through wire *i'*, magnet RM2, condenser **160**, wires *z*, *u*, *o* and *p*, contacts **96** and **94**, wire *j* to ground.

In the case of energization of the relay magnet RM1 in the manner previously described, closure of its controlled pair of contacts **154** serves to establish a brief impulse circuit leading from the battery B through switch S, turret slip ring **100**, bar **102**, branch *e*, wires *g*, *e'*, *f'*, *g'*, *g''*, contacts **154** and wire *c'* and one-half of the primary coil **150** through wire *b'* to ground. Similarly, upon energization of the magnet RM2 and consequent closure of the contacts **156**, a similar circuit exists including the wires *g*, *e'*, *j'*, contacts **154**, wire *d'*, one-half of the winding **150** and wire *b'* to ground.

The nature and direction of the flow of current through the half sections of the primary coil **150** is such that there is injected into the secondary coil **148** of the transformer **146** an impulse which is superimposed upon the normal damping impulse of the latter in such a manner that the voltage of the latter impulse is substantially

doubled, thereby presenting a powerful damping effect at the teeter valve coils. This additional damping effect in some measure affects both of the valve windings 122 and 126 but in different degrees and in opposite directions electrically.

The auxiliary damping arrangement just described goes into effect at such time as the contact 94 leaves its engagement with either of the contacts 96 or 98. At the time either of these pairs of contacts become open two current impulses are released, one resulting from discharge of the stored-up energy of the secondary coil 148 and the other is a delayed current impulse from the relay controlled primary winding 150. The second impulse may extend well into a succeeding half cycle of gun movement. The impulses are related and timed with respect to the contact points but the reversal of the impulse is related to the center position of the gun. The impulses from the primary winding 150 are sufficient to stop rotation of the turret with respect to the axis *h'—h'* within the first oscillation cycle. Thus, by means of the transformer 146, small oscillations are completely eliminated from the system, regardless of the extent of deviation of the gun from the target or of its rate of turning movement during stabilization thereof on the target. In actual operation in a tank, motion of the turret rarely comes under the influence of the above described secondary oscillations. These oscillations come into play only when the equipment is subjected to extreme conditions, as for example, a quick change in tracking or a sharp voluntary or involuntary turn of the tank hull.

From the above description it will be seen that as far as the electrical instrumentalities of the present invention are concerned, accurate tracking of the gun, as far as traverse is concerned, is made possible from a rapidly moving tank. Long range targets may be held within the gun sights with precision and nearby moving targets may readily be followed. The pick-off and damping means are free of vacuum tubes or other fragile parts and the electrical control mechanism for the hydraulic system has thus been developed to a point of reliability.

Referring now to FIGS. 1 and 2*b*, the gyro turn-table motor M, which is used for target finding and tracking operations, is adapted to be voluntarily energized at the will of either the commander at a commander's station CS or of the gunner at the gunner's station GS. One common means for varying the speed of a motor is to apply to the motor current of varying potential. Ordinarily, the higher the potential applied the faster will be the rate of speed of the motor and, as is customary, the ordinary means for varying the potential applied to a motor is to introduce into the motor circuit a suitable variable resistance. The use of variable resistances in the present instance for varying the speed of the tracking motor M is not a satisfactory solution to the problem of moving the turn-table, inasmuch as the motor M must necessarily be of small size to accommodate the confines of the gyroscope casing with a correspondingly small voltage rating. The use of varying potentials for the motor M is not altogether dispensed with, however, for in the system about to be described the voltage applied to the motor may, for particular reasons that will be set forth presently, be varied within relatively narrow limits. The principal means relied upon for varying the speed of the tracking motor M is to apply substantially the full rated voltage to the motor intermittently by means of impulses. These impulses range from zero to infinity, or, in other words, a mechanism is provided by means of which the impulses applied to the motor M become longer and longer as the speed of the motor increases until the point is reached wherein the impulse is continuous and the motor runs at full speed under full line voltage which is constantly applied thereto.

The means for varying the speed of the motor M is illustrated, described and claimed in a co-pending application, Serial No. 638,398, filed December 29, 1945, for Circuit Making and Breaking Mechanism, and now abandoned, and no claim is made herein to any novelty associated with the same. Since, however, a means must be employed for varying the speed of the motor M, a diagrammatic illustration of a variable impulse mechanism has been disclosed. The system herein diagrammatically shown serves substantially the same purpose as the complete system shown in the said co-pending application.

The tracking motor M is of the reversible type and its direction of rotation is adapted to be changed by the reversal of current flow through the wires *l'* and *m'* which leads to its field windings. For right traverse, parallel circuits under the control of the commander's station CS or of the gunner's station GS exist. The commander is provided with a commander's control handlye 404 (FIG. 3) which, upon manipulation thereof, serves to actuate a wiper arm 163 associated with a pair of resistances 164, 166. The handle also, upon manipulation thereof, serves to open a pair of cut-out contacts 168.

The gunner is provided with a traverse control handle which appears at 408 in FIG. 3 and which, upon manipulation thereof, operates a contact 174 capable of moving into engagement with one or both of a pair of contacts 176, 178, or into engagement with one or both of a pair of contacts 180, 182. At the commander's station the right traverse control tracking circuit leads from thhe battery B through the cut-out assembly and wires *k, l, n', o'*, a pair of contacts 162 under the control of a cut-off relay magnet CM, wires *p', q'*, variable resistance 164, wires *s', m'*, motor M to ground. For control of the motor in left traverse, a similar circuit exists from the wire *q'* through the resistance 166 and wires *t', m'*, and motor M to ground. The above circuits operate solely under the control of the commander.

The gunner's control circuit for the motor M in right traverse leads from the battery B through the cut-out relay, through wires *k, l, n', o'*, contacts 162, wires *p', u'*, commander's cut-out contacts 168, wire *v'*, resistance 170, variable closing contacts 172, contacts 174, 176, wires *w', m'*, and motor M to ground. The above circuit operates for normal tracking conditions at relatively low speeds. A higher speed control is provided for the gunner, and toward this end means are provided whereby a second resistance 184 may be thrown into parallel with the resistance 170 to reduce the total over-all ohmage in the former circuit and supply more current to the motor. Toward this end, the contact 174 is designed when thrown to its extreme position for right traverse control to bridge the contacts 176 and 178 so that the current is divided between the resistances 170 and 184, with an additional current flow being carried through the wire *x'* and through both contacts 178 and 176 to the wire *m'* and from thence to the motor M. It will be seen that the commander's control supercedes that of the gunner so that at any time the commander may decide to institute target finding operations, as for example, to locate a new target, he will, upon manipulation of his handle, assume broad control over traverse operations to the exclusion of the gunner.

The circuits for left traverse control on the part of the gunner need not be traced in detail inasmuch as they are similar in every respect to the right traverse control circuit. It is deemed sufficient to state that for left traverse control the contacts 180 and 182 are employed in place of the contacts 176 and 178 and thus current will flow to the motor M through the line *l'*, instead of the line *m'*, to cause rotation of the motor shaft in the opposite direction.

The variable impulse mechanism previously mentioned, which includes the contacts 172 for traverse control of the tracking motor M, is diagrammatically illustrated as consisting of an elongated rotatable shaft-like cam 186 having formed thereon two cam projections 188 and 190 which progress in eccentricity from the center

of the shaft outwardly. The contacts 172 are capable of being shifted longitudinally of the cam 186 under the control of the gunner's traverse control handle which simultaneously actuates the contact 174. The means whereby the two instrumentalities are interconnected in the present instance is represented simply by a connecting link 192. The cam 186 is illustrated as having associated therewith an additional pair of contacts 172' but these latter contacts perform similar functions in the elevational control system, subsequently to be described, and need not be considered in the present discussion. It will be seen that when the contacts 172 are in their center position along the longitudinal axis of the cam 186, they are in register with a low point or cylindrical portion on the cam and rotation of the cam will not cause closing movements of these contacts. As the contacts 172 are shifted either to the left or to the right along the axis of the cam 186, as viewed in the drawing, they will become positioned in the path of movement of the cam projections 188 and 190. Depending upon their extent of displacement from the center of the cam 186, their length of closing time during each revolution of the cam will become increasingly longer. At such time as the contacts 172 approach either end of the cam 186, a condition will obtain wherein they will remain permanently closed and a continuous flow of current to the tracking motor M will result.

The cam 186 is adapted to be rotated by means of a worm and gear device mechanism 194 associated with a cam driving motor M2. The motor M2 is adapted to cause rotation of the cam 186 at relatively high speeds so that although very short impulses of current may be applied to the motor M, rotation of the latter at any speed gives the visual appearance and has the effect of being continuous. The circuit for the tracking motor M exists from the battery B through the cut-out mechanism and wires *k*, *y'*, *z'*, *f* and motor M to ground.

The cut-off relay magnet CM exists in a circuit leading from the battery B, switch S, turret slip ring 100, cut-out device 104, wires *k*, *l*, *n'*, *h*, magnet CM, wire *i*, contact strip 200 and contact 202 to ground. The contact 202 is carried by the pick-off arm 72. The contact 202 normally assumes a neutral position out of engagement with the contact strip 200 during extremely small stabilizing movements of the pick-off arm. At such time as the pick-off arm assumes a displacement great enough that the maximum restoring force is applied to the gun, contact 202 engages the contact strip 200, thus causing energization of the magnet CM and consequent opening of the contacts 162 so that current supply through the wire *p'* to either the commander's station CS or the gunner's station GS is discontinued. In this manner, neither the commander nor the gunner has any control over the turntable. As soon as the turn-table has been restored to such an extent that the contact 202 becomes disengaged from the strip 200, the contacts 162 again become closed, thus restoring control to the commander and the gunner.

In regard to the three resistances 114, 118 and 120, these three resistances are disposed in the circuit leading to the teeter valve coils 122, 126 in a series parallel relationship wherein the resistances 118 and 120 are arranged in parallel with each other but in series with the resistance 114. The resistance 114 is a fixed resistance. The resistance 118 is a variable resistance and is adapted to be manually adjusted to accommodate such electrical and mechanical functions of the system as variance in the reluctance of any of the coil windings employed or changes in viscosity of the hydraulic fluid due to heating or the like. The resistance 120 is a variable resistance and has associated therewith a movable arm 121 which turns in unison as the contact 174 is shifted under the influence of the gunner's control handle. With the arm 121 in its center position, current passing through the circuit wires *k*, *l*, and resistance 114, divides and part of it flows through the resistance 118, while the remaining portion of the current flows to the arm 121 and divides again and passes through the opposing parts of the resistance 120, after which it flows through wire *m* or wires *m* and *n* to the teeter valve coils. With the arm 121 in the center position, the effective value of the resistance 120 is at a maximum. This value of resistance approaches a minimum as the arm is swung in either direction under the control of the gunner's handle, thereby lowering the over-all resistance of the circuit and increasing the stiffness of the system. When the cut-off relay CM becomes energized, the pair of contacts 162 become open, while at the same time a pair of contacts 165 become closed and the effect of these latter contacts is to short the three resistances 114, 118 and 120 from the teeter valve coil circuits so that the full maximum effect may be applied to the hydraulic system to drive the turret at its maximum rate of speed.

The circuit for the gyroscope rotor driving motor extends from the wire *g* through the motor winding and directly to ground. The gyroscope has associated therewith a caging device including a caging coil 196 operating under the control of a pair of contacts 198 associated with a caging mechanism which forms the subject matter of an additional co-pending application, Serial No. 638,396, filed December 29, 1945, and now abandoned, for Gyroscopic Caging Device. This last mentioned mechanism has not been fully illustrated herein and no claim is made in this application to any novelty associated therewith.

The elevational control system, as far as electrical instrumentalities and functions are concerned, is similar in many respects to the traverse control system just described and the only differences in the two systems reside in the omission from the elevational control system of certain devices necessarily inherent in the traverse control system but not required in the other system. For this reason, it is believed that a detailed description of the elevational control system need not be resorted to and that by the simple expedient of applying similar reference characters to the corresponding parts in the two systems an understanding of the elevational control system may readily be obtained. Similarly, in the hydraulic system of FIG. 4, the corresponding parts of the two teeter valve assemblies 124 and 124' have been assigned similar reference numerals wherein the valves themselves are designated at 128' and 130' and the coils at 122' and 126'. The instrumentalities that are present in the traverse system, but which have been omitted from the elevational system, will now be pointed out in detail.

Whereas for stabilizing purposes in traverse the turret is capable of 360° movements to accommodate widely separated targets, in elevation no such complete turning movement of the gun is desired or is it possible. The gun is capable of elevation on the turret to approximately 30° and for nearby ground targets the gun is capable of a 10° depression, making approximately 40° swinging movement available. No extensive tracking operations are encountered in elevation and for this reason the cut-off relay CM, the controlling contact 202 and contact strip 200 therefor, as well as the controlled contacts 162, 165 and 152, are omitted.

Whereas in the case of traverse control the commander's control handle supercedes that of the gunner, in the elevational control system no means is provided for discontinuing current to the circuit of the tracking motor M' under the control of the gyroscope. Instead, in this circuit, there are provided a pair of limit switches 204 and 206 respectively, which are adapted to become open whenever the gun reaches the limit of its elevational movements in either direction. These limit switches 204 and 206 operate under the control of the gyroscope and, toward this end, they are mounted in the base of the latter and are affected when the base and turn-table have become displaced angularly from each other throughout an angle of approximately 20°. The automatic variable resistor 120 of the traverse control system does not appear

in the elevational control system, inasmuch as no means is provided in this latter system for modifying the action of the valve coils 126' and 122' in the manner previously described by means of the resistor 120. A duplicate of the variable resistor 118, however, is employed and is designated at 118'. Various other elements of the circuit are maintained in common with the traverse system. These, for example, include the relay magnets RM1' and RM2', the function of which has previously been set forth.

With the exception of the condensers 158, 158', 160, 160', which perform very material and useful damping functions, in their respective circuits, additional capacitances appear and these have all been assigned the common reference numeral 116. It will be understood that wherever these capacitances appear in the drawing they are designed for radio interference purposes and, as a consequence, their capacitance values are relatively small existing as they do in the neighborhood of approximately two mfds. The electrical value of the condensers 158, 158', 160 and 160' are considerably larger since these condensers must perform useful work in tripping their respective relays.

Referring now to FIGS. 2*a*, 2*b* and 4 wherein the hydraulic system is schematically illustrated, this system involves in its general organization the previously mentioned closed sealed hydraulic casing 38 in which both of the teeter valve assemblies 124 and 124' for traverse and elevation respectively disposed together with a traverse driving gear unit or pump assembly 302 and a similar elevational driving gear unit or pump assembly 304 and also a supercharge pump assembly 306. The teeter valve assemblies and the three pump assemblies are shown diagrammatically in FIG. 4 as being disposed within the same casing 38. In FIG. 2*a*, however, purely for convenience of schematic representation, only the elevational driving gear assembly 304 has been included within the casing 38. Similarly, in FIG. 2*b*, only the traverse driving gear assembly 302 is shown within the casing 38. In this manner the two assemblies have been effectively isolated for descriptive purposes.

Referring now specifically to FIG. 4, a main driving shaft 310 projects into the casing 38 and has mounted thereon a gear 311 associated with the supercharged pump assembly 306. The shaft 310 also has mounted thereon the rotor 312 of the previously mentioned variable displacement pump 136. It will be understood that the gear 311 and rotor 312 are, in actual practice, mounted on the shaft 310 in axial alignment but in the schematic representation of FIG. 4, these two elements are shown displaced from each other and, as a consequence, the shaft 308 appears in two places. The dual disclosures have been connected together by dotted lines to indicate that they are one and the same shaft. The gear 311 meshes with a similar gear 314 and the two gears cooperate to form the continuously operable fluid supercharge pump 306 by means of which the body of motive fluid F disposed within the casing 38 is continuously circulated through the system from the pump through conduit lines I, J, a fixed orifice device 316, conduit K, heat dissipating expansion tank 318 and strainer 320, conduits L, N, O, P, to the interior of the casing 38. The fixed orifice 316 is designed to accommodate a normal pressure of approximately twenty pounds within the system. The gear 311 meshes with an idler gear 309, which latter gear serves to drive other gear instrumentalities associated with the traverse driving gear assembly 302. The shaft 310 has mounted thereon a worm wheel 313 which meshes with a worm 315 associated with the motor shaft 317 of an electric motor M3. The circuit for the motor M3 becomes effective as soon as the switch S is closed. This circuit exists from the battery B through the switch S, turret slip ring 100 and motor M3 to ground.

Briefly, it may be stated that the function of the traverse driving gear pump 302 is to effect shifting of the slide block 138 associated with thhe variable displacement pump 136 to either side of a center position a predetermined distance to cause fluid to be passed in one direction or the other at a predetermined rate of flow to the constant displacement motor 48 which drives the turret. Similarly, the function of the elevational control pump system 304 is to supply fluid to the opposite ends of the cylinder 26 which moves the gun in elevation.

Referring to FIG. 4, the variable displacement pump 136, as schematically illustrated, includes the slide block 138 which is movable in opposite directions and for which purpose it is supported in roller bearings 322. The rotor 312 includes a rotary cylinder block 324 in which there is formed a plurality of radially mounted cylinders 326 having slidably disposed therein pistons 328. The cylindrical block 324 is formed integral with the driving shaft 308. The pistons 328 are confined by means of an internal cylindrical surface 330 provided in the slide block 138, and thus it will be seen that when the slide block is in its center position the pistons 328 will rotate with the cylinder block 324 with their ends bearing frictionally on the cylindrical surface 330 under the influence of centrifugal force, but there will be no relative motion of the pistons in the cylinders. When the slide block is shifted in one direction or the other to an off-center position, reciprocation of the pistons in their respective cylinders and the extent of such reciprocation will be determined by the amount of off-center displacement of the slide block. The variable displacement pump 136 is provided with reversible fluid inlet and outlet ports 332 and 334 communicating with conduits Q and R.

The opposite ends of the slide block 138 have connected thereto guide rods 336 which are connected to pistons 338 and 340 disposed in small cylinders 342 on opposite sides of the casing 38. The cylinders 342 communicate with conduits U and V leading to the traverse driving gear pump 302. It will be seen that when fluid pressure is balanced within the two conduits U and V the slide block 138 will assume its center position. However, when the pressure in these two lines becomes unbalanced, the slide block 138 will be moved in one direction or the other to an extent commensurate with the amount of pressure differential.

The constant displacement motor 48 is provided with a pair of ports 344 and 346 which become inlet or outlet ports depending upon the direction of fluid flow to the motor. The inlet-outlet port 346 is connected to the inlet-outlet port 332 of the variable displacement pump 136 through conduits H and R. The inlet-outlet port 344 of the constant displacement motor is connected to the inlet-outlet port 334 of the variable displacement motor through conduits D and Q.

In order to overcome the effects of static friction, which normally opposes any initial movement of the slide block 138 from a position of rest, it has been found advantageous to construct the rotor so that the same will at all times impart a slight trembling motion to the slide block 138 and this may conveniently be accomplished by constructing one or more of the pistons 328 of heavier material than the remaining pistons, thus imparting a degree of instability to the slide block 138. Accordingly, in FIG. 4, one of the pistons 328' is shown in heavy lines, this representation being intended to indicate that the mass of this piston is greater than the mass of any of the other pistons. In carrying out this principle of the invention, if desired, all of the lighter pistons 328 may be constructed of steel, while the heavier piston 328' may be constructed of relatively heavier brass. Irrespective, however, of the choice of materials for creating a tremor in the slide block 138, the essential features of the invention are at all times preserved.

A high pressure relief valve 348 is provided with a chamber 350 in which there is disposed a compression spring 351 which cooperates with a plunger 360. The plunger 360 is provided with an enlarged head 362. The

relief valve 348 has associated therewith a pair of chambers 354 and 358 which communicates with each other through a port 356. The port 356 is normally maintained closed by means of a valve end portion 362 of the plunger 360. The head 362 of the plunger 360 is slidably disposed in an opening 352 between the chambers 350 and 354. The spring 351 normally maintains the plunger 360 in such position that the port 356 is closed. Movement of the plunger 360 against the action of the spring 351, however, serves to open the port 356. The chamber 354 communicates through conduits W, X and R with the inlet port 332 of the variable displacement pump 136 and through the conduits W, X and H with the port 346 of the constant displacement motor 48. The chamber also communicates through conduits W and Y to a check valve 368. The check valve has communication through conduits Z, A', J and K with the expansion tank 318 and through conduits Z, A' and I with the supercharge pump 306. It also communicates through conduits Z and B' with a supercharge relief valve 370 which is connected to the interior of the chamber 350. The chamber 350 in turn communicates through conduit E' with the interior of the casing 38. The chamber 358 communicates through conduits C', D' with a check valve 372 and through conduits C', Q with the outlet port 334 of the variable displacement pump 136. The chamber 358 also communicates through conduits C', D with the port 344 of the constant displacement motor 48.

As in the case of the description of the electrical instrumentalities associated with the stabilizing mechanism it is deemed pertinent to first discuss the traverse considerations which are associated with the operation of the hydraulic system and subsequently to discuss elevational considerations. Accordingly, reference may now be had to FIG. 2*b*, in conjunction with FIG. 4, wherein the traverse control hydraulic mechanism is shown.

The traverse driving gear system includes a medial gear 374 and a pair of driven gears 376 and 378, each of these gears being disposed within respective communicating gear chambers in the casing 38. The gear 378 is adapted to be driven by the previously mentioned idler gear 309 and, consequently, its direction of rotation and the direction of rotation of the driven gears 376 and 378 are as shown by the arrows in FIG. 2*b*. Such rotation of the gears 374 and 376 extends to draw fluid through an inlet port 380, from whence a portion of it is transmitted through a conduit F' to the port 132 to be expelled therefrom. Another portion of the fluid entering the port 380 is transmitted to a conduit G' from whence it is expelled through the port 134. The gears 374 and 378 cooperate to take in fluid through a port 382 and transmit a portion of the same to the conduit G' and another portion thereof to the conduit F'. This circuitous flow of fluid is continuous and substantially all of the fluid enterinng the ports 380 and 382 is ultimately expelled through the ports 132 and 134, regardless of the position of the two valve members 128 and 130. The function of these latter valves is not to prevent passage of fluid through their respective ports but merely to obstruct such passage in varying degrees to build up commensurate pressures within the fluid lines or conduits U and V to cause shifting of the slide block 138 in one direction or the other.

Whenever, either through an involuntary action, as for example, shifting of the axis of the turret hull, or a voluntary action on the part of the commander or gunner resulting in angular displacement of the turn-table 70 with a consequent engagement between the contacts 94 and 96, current is supplied to the coil 126 of the teeter valve assembly 124, consequent energization of the coil will tend to move the valve 128 downwardly to resist the flow of fluid through the port 132. Simultaneously, because of the cross head 140, the valve 130 will move away from the port 134 to permit a more free flow of fluid through this port. A pressure will then be built up in the fluid lines F', U, while pressure will be relieved in the conduit lines G', V, and, as a consequence, the slide block 138 will be moved toward the right, whereupon a fluid circuit will be established through the variable displacement pump 136 leading from the port 332 through conduit H to the constant displacement motor 48, through this motor and back to the port 334 through conduit D. The above circuit is applicable to the simplified schematic view of FIG. 2*b*. In FIG. 4 the same circuit through the variable displacement pump exits from the port 332 through conduits R, H, constant displacement motor, conduits D, Q, to port 334. Flow of fluid through the constant displacement motor will operate through the gear box or turret driving unit 46 to drive the turret in azimuth in one direction. Whenever the teeter valve assembly 124 is urged in the opposite direction tending to move the valve member 130 against its port 134, a pressure is built up in the conduit G', V, tending to move the block 138 in the opposite direction to reverse the flow of fluid through the constant displacement motor and cause the turret to be turned in the opposite direction. It will be understood that the amount of pressure differential existing in the conduits U and V is the controlling factor which determines the amount of displacement of the slide block 138.

The elevational driving gear mechanism includes a medial gear 386 and driven gears 384 and 388 similar in their operation and function to the gears 376 and 378. The medial gear 386 is mounted on a common shaft with the gear 374 and is rotatable in unison therewith. The flow of fluid through the elevational driving gear device is shown in FIG. 2*a*. The hydraulic system shown in FIG. 2*a* is substantially identical with the system shown in FIG. 2*b*. Whenever the contact 94' engages the contact 96', pressure is developed in a conduit H', from whence it is transmitted to the conduit C, thus forcing the piston 24 downwardly in the cylinder 26. Conversely, whenever the contact 94' engages the contact 98' pressure is developed in a conduit I' which is applied to the conduit A, thus tending to elevate the piston 24 to tilt the gun 16 forwardly and downwardly.

The proper operation of the variable displacement pump 136 and of the constant displacement motor 48 is based upon the maintenance of a full pressure head within the two pump systems as determined by the two check valves 368 and 372. This pressure is supplied to the intake sides of the check valves by means of the supercharge pump 306 in the manner previously described. Whenever the pressure in either of the two systems falls below a predetermined value, the loss is immediately compensated for by the admission of fluid through the check valves.

Whenever the pressure in the supercharge lines exceeds the rated pressure determined by the supercharge pump 306, as for example, should the strainer 320 become clogged, fluid will pass through the conduit I, by-pass the conduit J and continue through the conduit A', supercharge relief valve 370 and into the chamber 350.

Whenever an undue pressure builds up in the circuit of the variable displacement pump 136, as for example, by failure of the turret to yield in either direction, fluid will flow through the circuit defined by the conduits Q, C', chamber 358, port 356, chamber 354, conduits W, X and R, the direction of flow depending, of course, upon the direction of operation of the pump. With the fluid flowing through the pump 136 from the port 332 to the port 334, the pressure in the chamber 358 will materially exceed the pressure afforded by the spring 351 and this pressure will act upon the end of the plunger 360 to move the same to the left to uncover the port 356 and permit fluid to flow from the chamber 358 to the chamber 354. With the pump operating in the opposite direction, the high pressure built up in the pressure chamber 354 will act upon the enlarged head 362 to move the plunger 360 against the action of the spring

351 so that fluid may pass from the chamber 354 to the chamber 358. In either event, a localized circuit through the high pressure relief valve 348 and pump 136 is set up.

It will be understood that FIGS. 1, 2*a*, 2*b* and 4, which have been described above in detail, are purely schematic in their representation and are not intended to disclose the invention as it is actually constructed. These views, however, illustrate the principles of the invention adequately. In FIG. 3 an arrangement of parts more nearly representative of an actual installation is shown. Reference to this figure will serve to illustrate that the damping mechanism including the transformer 146 of FIG. 1 and its associated relays RM1 and RM2, choke coils 142, 144, and many other electrical instrumentalities which are provided for damping purposes may be contained within a common casing 400. The commander's station CS is represented by a casing 402 from which the commander's handle 404 projects. This handle 404, it will be understood, serves upon manipulation thereof to actuate the wiper arm 163, as well as to manipulate the cut-out contacts 168. The gunner's station GS is represented by a handle control unit 406 having associated therewith a traverse handle 408 and an elevation handle 408'. In the case of the traverse handle 408, manipulation of this member serves to impart longitudinal shifting movement to the contacts 172 associated with the cam member 186 and also to control the movements of the contact 174. Furthermore, this handle serves to operate the movable arm 121 associated with the variable resistance 120. The elevation handle 408' controls the longitudinal position of the contacts 172' relative to the cam member 186 and also to control the movements of the contact 174'. In actual practice, the handle control unit includes numerous details of construction, such as suitable panel lamps, swtiches, as well as vernier controls illustrated in FIG. 3. As previously described, the pick-off devices 60 and 60' are associaed with their respective gyroscope units 74 and 74'. With the exception of the expansion tank 318, the constant displacement motor 48 and the cylinder 26, the arrangement of hydraulic mechanisms and of the teeter value assemblies 124 and 124', shown in FIG. 4, are in FIG. 3 associated with a power unit designated at 412. The pertinent instrumentalities of this power unit are suitably labeled on the drawings and require no further description. The traverse drive unit including the lash-free gear box 46, constant displacement motor 48 and manual control handle 64 appears as a separate unit in FIG. 3. The expansion tank 318 is also shown as a separate unit and has been labeled Oil Reservoir and Filter. Suitable conduits, cables and the like serve to connect the various units of the system together and in actual practice these are so constructed as to be entirely water-tight so that the system in its entirety is submergence-proof. Various auxiliary accessories, such as coaxial and cannon firing coil devices, lighting and radio circuit wires and the like, fluid level indicators, etc., appear as incidental showings in FIG. 3 and no claim is made herein to any novelty associated therewith.

In the operation of the gun stabilizing system utilizing a typical maneuver for illustrative purposes wherein both target finding and target tracking operations are concerned, it may be assumed that upon initial appearance of a moving target at a particular range and elevation, the gun turret 14 is so oriented that the gun 16 is pointed away from the target by a relatively large angle in traverse and a relatively large angle in elevation. It is, therefore, necessary for either the tank commander or the gunner to first resort to a target finding operation.

It will be remembered that the commander is capable of performing target finding operations in traverse only and that all elevational considerations must be left to the gunner. If it is the commander who takes over the target finding operation after initial discovery of the target, he will manipulate the handle 404 (FIG. 3) at the commander's station CS in the manner previously described to actuate the wiper arm 163 and to open the cut-out contacts 168 and thus deprive the gunner of any control whatsoever over movements of the turret.

A previously stated, the commander's right traverse control tracking circuit leads through the variable resistance 164, while his left traverse control tracking circuit leads through the variable resistance 166 to drive the motor M in one direction or the other as occasion demands.

After the commander has located the target and brought the turret to an angular position wherein the gun is either in line with the target or pointed to the approximate vicinity of the target, he may restore control of the turret to the gunner who may perform the tracking operations. For traverse tracking, the gunner will manipulate the handle 408 (FIG. 3), while for elevational movements of the gun he will manipulate the handle 408'. The circuit for traverse tracking operations leads through the resistance 170 (FIG. 1), contacts 172, 174, 176, to the motor M to provide for normal tracking conditions at relatively low speeds. When the gunner turns the handle 408 throughout a relatively wide angle, the contacts 174 and 178 will become engaged to throw the resistance 184 into parallel with the resistance 170 and reduces the over-all ohmage of the motor circuit to supply more current to the motor and increase its speed.

If at any time during tracking operations on the part of the gunner the commander decides to take over the control, as for example, when a new and more important target is located, he will, upon manipulation of his handle 404, assume broad control over traverse operations to the exclusion of the gunner. The contacts 176 and 178 control right traverse tracking, while the contacts 180, 182 control left traverse tracking.

The speed of the tracking motor M is adapted to be varied by the mechanism including the contacts 172 which, as previously stated, constitutes the subject matter of a copending application, Serial No. 638,398, filed December 29, 1945.

If a target has been located and the gun 16 brought into line therewith, any involuntary change in the heading of the tank will be automatically compensated for without any volunatry action on the part of any member of the tank crew. It will be understood, of course, that as soon as the switch S (FIG. 1) is closed the motor M3 (FIG. 4) which drives the center shaft 310 of the variable displacement pump 136 and which also drives the gear pump assembly contained within the casing 38 will be energized. Whenever shifting of the axis of the turret hull occurs either through an involuntary action, as for example, the tank striking an obstruction, or through a voluntary action on the part of the driver of the tank, the turn-table 70 is displaced relative to the axis *h—h* of the gyroscope. The arm 72 and pin 84 (FIG. 6) operating through the slot 86 will cause rotational movement of the shaft 90 and consequent shifting of the contact 94 into engagement with either the contact 96 or the contact 98, as the case may be, depending upon the direction of relative movement between the turn-table and axis of the gyroscope. When the contact 94 engages the contact 96, for example, current will be supplied to the teeter valve coil 122 (FIG. 1) and consequent energization of the coil will tend to move the valve 128 (FIG. 2*b*) downwardly to resist the flow of fluid through the port 132. Simultaneously because of the cross head connection 140, the valve 130 will move away from the port 134 to permit a more free flow of fluid through this port. As previously explained, a pressure will then be built up in the fluid lines *f'*, *u*, and pressure will be relieved in the fluid lines *g'*, *v*, thus moving the slide block 138 of the variable displacement pump 136 to the right, as viewed in FIG.

2b, and supplying fluid to the constant displacement motor 46 in such a direction as to cause the turret to be turned in a direction opposite to the direction of initial displacement of the turn-table 70. Thus the gun 16 will automatically be maintained in alignment with the target, regardless of the involuntary shifting of the axis of the turret hull.

The above description of gun stabilization in traverse is substantially duplicated by the elevational stabilization mechanism, the contacts 94', 96' and 98' serving to control the ultimate movements of the gun elevation motor 26 to cause pivotal movement of the gun 16 about the axis of the trunnions 18.

As previously explained, means are provided for effectively preventing overriding the target by the gun 16. This is done in effect by an automatic anticipation of a possible overriding of the target before the center position of the gun is reached. The damping transformer 146 is provided for this purpose and operates in the manner previously described to bring the turret to a stop with the gun 16 on the reference line of the target within one-half cycle. Where extremely high rates of restoration are concerned, means are provided for effecting additional damping operations and this means includes the relay magnets RM1 and RM2 which control the opening and closing movements of the contacts 154 and 156 respectively in the manner previously described. By means of these magnets and contacts, a series of powerful damping waves are provided for absorbing the movements of the turret as the gun closes in upon the target rapidly from a wide angular displacement.

The invention is not to be limited to the precise arrangement of parts shown in the accompanying drawings or described in this specification inasmuch as the disclosure thereof is, in the main, diagrammatic. Only insofar as the invention has been particularly pointed out in the following claims is the same to be limited.

What is claimed is:

1. The combination with a tank having a hull, a rotatable turret mounted on the hull and capable of turning movements in azimuth relative to the hull in opposite directions, of stabilizing mechanism for said turret comprising gyroscopic means mounted on the turret and establishing a fixed reference line in space, a turn-table rotatably mounted on the turret and normally fixed relative thereto, said turn-table establishing an auxiliary line of reference normally in coincidence with said fixed reference line, said turn-table normally following the involuntary movements of the hull and consequently of the turret upon changes in direction of the heading of the hull so as to establish angular displacement between said auxiliary reference line and said fixed reference line, a commander's control station and manually controlled means operable thereat for voluntarily rotating said turn-table relative to the turret to cause angular displacement between said reference lines, a gunner's control station and manually controlled means operable thereat for similarly rotating the turn-table, means operable when said turn-table becomes angularly displaced from its normal position thus causing displacement between said reference lines for applying torque to the turret in a degree sufficient to move the same at a predetermined rate of speed in such direction as to restore the turn-table to its normal position and reestablish coincidence between said reference lines, means operable when the extent of such displacement between said reference lines reaches a predetermined degree for applying an increased amount of torque to the turret to restore the same to its normal position at an increased rate of speed, and means operable when the extent of displacement between said reference lines reached a predetermined maximum for rendering both of said manually controlled means inoperative.

2. The combination with a tank having a hull, a rotatable turret mounted on the hull and capable of turning movements in azimuth relative to the hull in opposite directions, of stabilizing mechanism for said turret comprising gyroscopic means mounted on the turret and establishing a fixed reference line in space, a turn-table rotatably mounted on the turret and normally fixed relative thereto, said turn-table establishing an auxiliary line of reference normally in coincidence with said fixed reference line, said turn-table normally following the involuntary movements of the hull and consequently of the turret upon changes in direction of the heading of the hull so as to establish angular displacement between said auxiliary reference line and said fixed reference line, a commander's control station and manually controlled means operable thereat for voluntarily rotating said turn-table relative to the turret to cause angular displacement between said reference lines, a gunner's control station and manually controlled means operable thereat for similarly rotating the turn-table, means operable when said turn-table becomes angularly displaced from its normal position thus causing displacement between said reference lines for applying torque to the turret in a degree sufficient to move the same at a predetermined rate of speed in such direction as to restore the turn-table to its normal position and reestablish coincidence between said reference lines, means operable when the extent of such displacement between said reference lines reaches a predetermined degree for applying an increased amount of torque to the turret to restore the same to its normal position at an increased rate of speed, means operable during rotation of said turn-table under the manual control afforded at said commander's station for rendering the manual control afforded at said gunner's station inoperative.

3. The combination with a tank having a hull, a rotatable turret mounted on the hull and capable of turning movements in azimuth relative to the hull in opposite directions, of stabilizing mechanism for said turret comprising gyroscopic means mounted on the turret and establishing a fixed reference line in space, a turn-table rotatably mounted on the turret and normally fixed relative thereto, said turn-table establishing an auxiliary line of reference normally in coincidence with said fixed reference line, said turn-table normally following the involuntary movements of the hull and consequently of the turret upon changes in direction of the heading of the hull so as to establish angular displacement between said auxiliary reference line and said fixed reference line, a commander's control station and manually controlled means operable thereat for voluntarily rotating said turn-table relative to the turret to cause angular displacement between said reference lines, a gunner's control station and manually controlled means operable thereat for similarly rotating the turn-table, means operable when said turn-table becomes angularly displaced from its normal position thus causing displacement between said reference lines for applying torque to the turret in a degree sufficient to move the same at a predetermined rate of speed in such direction as to restore the turn-table to its normal position and reestablish coincidence between said reference lines, means operable when the extent of such displacement between said reference lines reaches a predetermined degree for applying an increased amount of torque to the turret to restore the same to its normal position at an increased rate of speed, means operable during rotation of said turn-table under the manual control afforded at said commander's station for rendering the manual control afforded at said gunner's station inoperative, and means operable when the extent of such displacement between said reference lines reaches a predetermined maximum for rendering the manually controlled means at both the commander's station and the gunner's station inoperative.

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