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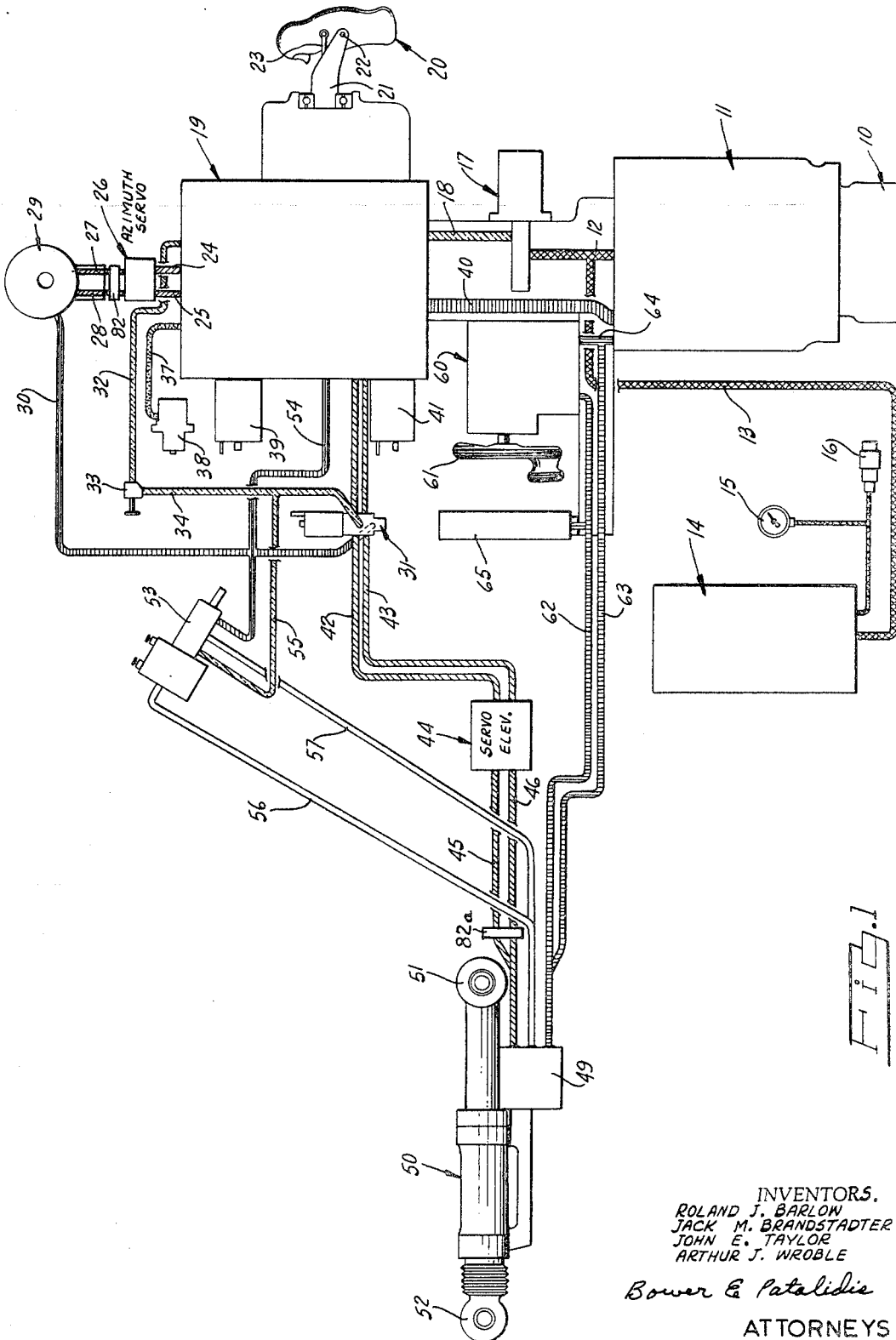
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3,405,599

WEAPON STABILIZATION SYSTEM

Filed Dec. 2, 1964

3 Sheets-Sheet 1



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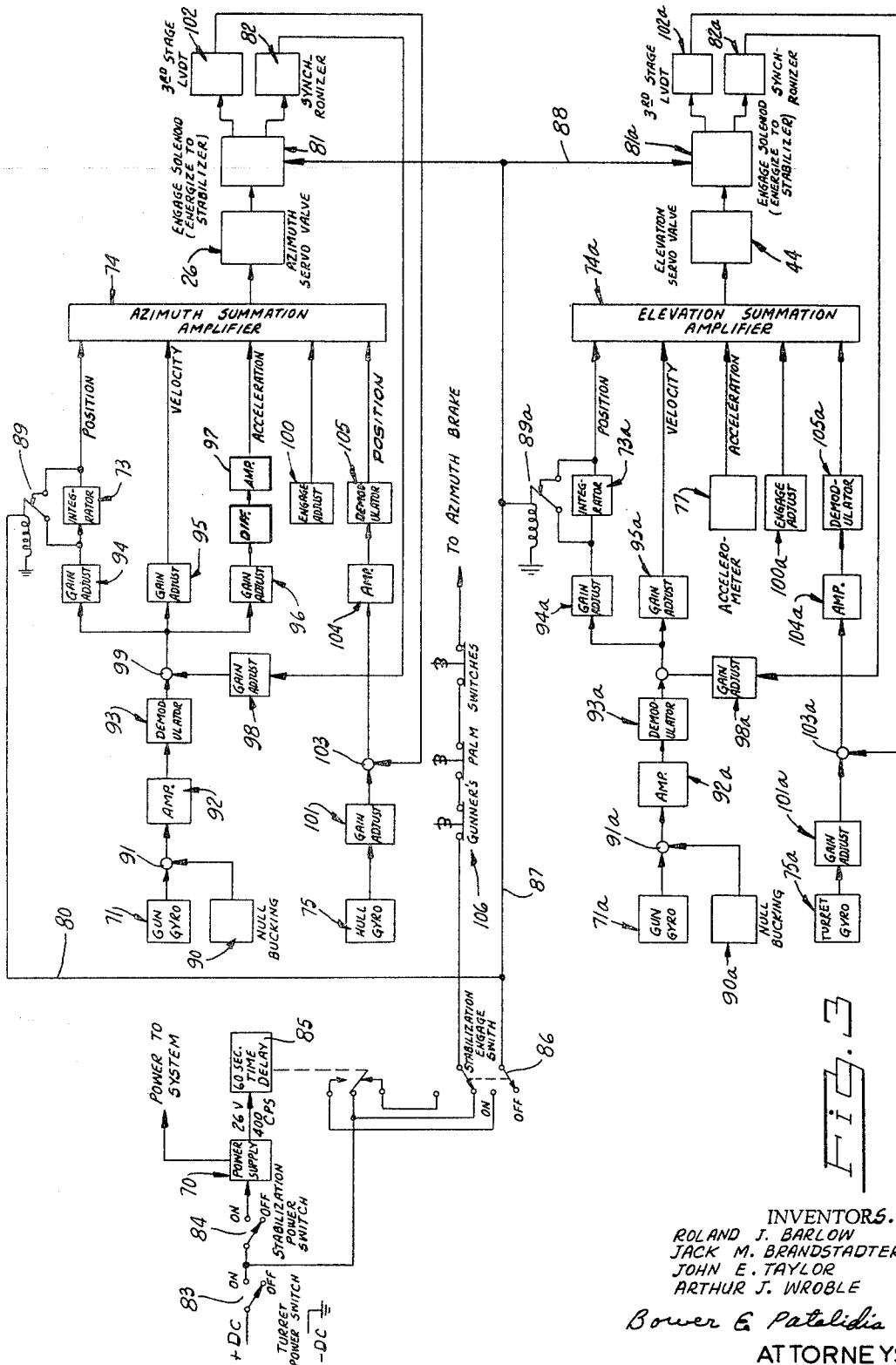
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WEAPON STABILIZATION SYSTEM

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6 Claims. (Cl. 89-41)

This invention relates generally to stabilization systems and, more particularly, to a stabilization system for stabilizing the position of an object, such as a gun, in space. The invention is of general application, and it may be adapted for stabilizing a turret-mounted gun on a moving vehicle, such as a tank, and it will be described hereinafter as applied to a turret-mounted tank gun.

Heretofore, it has been very difficult to maintain the position of a gun mounted on a moving vehicle after it has been laid on a target so as to hit the target with accuracy. The efficiency of military tanks and the like has been improved in the past by the provision of various types of power control systems which incorporate hydraulic actuation equipment by which a gunner can aim a gun quickly and accurately at fixed and moving targets through power control of the traverse and elevating mechanisms of the tank when it is stationary. An example of such hydraulic power control systems is disclosed in detail in U.S. Patent No. 2,893,355, issued to Russell E. Bauer. While such power control systems have increased the overall effectiveness of military vehicles, they have not solved the problem of accurate aiming and firing of a weapon from a moving vehicle.

Accordingly, it is an important object of this invention to provide a novel stabilization system for use with the existing power control system in a vehicle to maintain the predetermined aim of a turret mounted weapon on the vehicle after it is laid on a target despite the pitch, roll and yaw of the vehicle when it is moving.

It is another object of the present invention to provide a novel weapon stabilization system which assures a far greater probability of a first round hit on a target than was heretofore possible by a weapon mounted on a vehicle traveling at high speed and over rough ground. The stabilization system nullifies the vehicle transients caused by irregular terrain or weapon recoil, so that a gunner can acquire and lay on a target faster and with greater accuracy than was heretofore possible, and he need correct only for movements of the target or for translational movements of his own vehicle. The corrections are made in conventional fashion by manipulation of the vehicle power system controls.

It is still another object of the present invention to provide a novel stabilization system which is compact, lightweight and rugged in construction.

It is a further object of the present invention to provide a novel stabilization system which can be attached to the power control system of a vehicle without impairing the use of all of the features of the power control system so that they can still be utilized while the vehicle is traveling as well as stationary and thereby increase the effectiveness of the vehicle, and wherein the stabilization system can be switched in or out of the power control system at will so that the power control system will continue to function normally when the stabilization system is not in use.

It is still a further object of the present invention to provide a novel stabilization system which is economical because it may be attached to a vehicle conventional power control system and use the same hydraulic fluid and electrical power sources.

It is another object of the present invention to provide a novel stabilization system which reduces the manipula-

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tive skills needed by an operator, is simple to operate, and accordingly, reduces operator training time.

It is still another object of the present invention to provide a novel stabilization system which is adapted to conserve ammunition, provide more effective second rounds, improve gunner observation, reduce gunner fatigue, improve capability for firing and maneuvering, increase maneuverability in an attack, and provide effective reconnaissance by fire in an attack.

It is still another object of the present invention to provide a novel stabilization system which is reliable, designed to function with a vehicle power control system, adapted to provide maintenance-free long life operation, and which is so arranged that the vehicle power control system will operate in a normal fashion regardless of any malfunction in the stabilization system units which are attached to the power control system.

It is a further object of the present invention to provide a novel stabilization system which may employ a rate gyro to produce an output signal which is integrated to produce a position signal which is in turn used to actuate an electro-hydraulic servo in the power control system of a vehicle.

It is still a further object of the present invention to provide a novel stabilization system which includes a position system having a feedback loop to incorporate velocity and acceleration factors, and additionally a unity velocity command system adapted to provide a signal which is added to the position system signals for controlling the operation of an electro-hydraulic servo in a vehicle power control system.

It is another object of the present invention to provide a novel reference stabilization system which incorporates a gyro reference system.

It is still another object of the present invention to provide a stabilization system for stabilizing an object in space with respect to a reference axis, which comprises a sensor means for detecting angular variations of the objects from said axis and to produce electrical output signals proportional to said angular variations, a prime mover operatively connected to said object, and controlling means responsive to said output signals for controlling power to said prime mover for moving the object in accordance with said output signals to maintain the position of the object with respect to said reference axis in space. The sensor means may comprise an attitude or rate gyro which produces a position reference. The prime mover means may comprise a hydraulic operated actuator. The controlling means may comprise a closed center electro-hydraulic servo valve means.

It is a further object of the present invention to provide a stabilization system for stabilizing an object in space with respect to a reference axis which comprises a first sensor means for detecting angular variations of the object from said axis to produce electrical position reference signals proportional to said angular variations, and a second sensor means for detecting movements of a support member upon which said object is mounted relative to said reference axis to produce a separate support member velocity signal which is added to the position reference signal to minimize position error.

It is another object of the present invention to provide a novel stabilization system for stabilizing a weapon mounted on a turret which is in turn movably mounted on a hull, and for stabilizing the weapon in reference to an elevation and an azimuth reference axis, and wherein separate sensors are mounted on the weapon and on the hull to provide position reference and vehicle velocity reference signals, respectively, for azimuth axis control, and wherein separate sensors are mounted on the weapon and on the turret to provide position reference and turret

velocity reference signals, respectively, for elevation axis control.

Other objects, features and advantages of this invention will be apparent from the following detailed description, appended claims, and the accompanying drawings.

In the drawings:

FIG. 1 is a diagrammatic view in flow chart form illustrating a conventional gun and turret power control system to which is attached the electro-hydraulic stabilization system of the present invention;

FIG. 2 is a schematic view of the stabilization system, and showing the connection with the gun power control system illustrated in FIG. 1; and,

FIG. 3 is a block diagram of the complete traverse and elevation electro-hydraulic elements of the stabilization system of the present invention, and showing their functional relationship.

GENERAL

The stabilization system of the present invention is illustrated hereinafter as applied to a typical gun and turret power control system of a vehicle, such as a tank or self propelled artillery. The stabilization system is illustrated as being added-on, or attached to, the vehicle power control system so as to take advantage of and use the hydraulic fluid and power sources of the power control system.

POWER CONTROL SYSTEM

FIG. 1 illustrates a typical gun and turret power control system which is operatively connected to the electro-hydraulic servo valves of a gyro-stabilizing system made in accordance with the principles of the present invention. The power control system of FIG. 1 is shown and described in detail in the aforementioned U.S. Patent No. 2,893,355, and the disclosure of said patent is incorporated by reference herein. The power control system may be called an open loop hydraulic system which employs a liquid pump (not shown) which is driven by the electric motor generally indicated by the numeral 10. The pump is operatively mounted in a reservoir and the combination pump and reservoir structure is generally indicated by the numeral 11 in FIG. 1. The electric motor driven pump does not run continuously but runs only on demand. The pump supplies hydraulic fluid under pressure to a suitable accumulator, generally indicated by the numeral 14, through conduits 12 and 13. Operatively connected to the accumulator 14 is a pressure gauge 15 and a pressure switch 16. The demand for pump operation is established by the pressure switch 16 which causes the motor 10 to operate when the pressure in the accumulator reaches a lower limit value. The pressure switch 16 also functions to stop the operation of the motor 10 when the pressure in the accumulator reaches an upper limit value.

As shown in FIG. 1, the fluid under pressure flows through the conduit 12 to the pressure regulator valve generally indicated by the numeral 17. The pressure regulator valve 17 holds the pressure in the power control system at a value slightly below the lower limit at which the pressure switch 16 causes the pump motor 10 to operate. Accordingly, there is a constant pressure in the power control system at substantially all times in spite of the fact that the pump motor 10 may be turned off most of the time.

As shown in FIG. 1, the pressurized hydraulic fluid is conveyed from the pressure regulating valve 17 through the conduit 18 to a valve block generally indicated by the numeral 19. Operatively mounted in the valve block 19 is a pair of control spool valves (not shown) which are adapted to be operated by the gunner's control handle generally indicated by the numeral 20. The control handle 20 is connected to one of the spool valves by means of the control member 21 which is pivotally connected to the handle 20 at the point 22. The handle 20 is con-

nected to the other valve spool by means of the control rod 23.

The control spool valves are normally positioned in an inoperative position. When the control handle 20 is rotated, either to the left or right from the center or neutral position, the control member 21 rotates one of the spool valves to admit fluid under pressure to the conduits 24 or 25, depending upon the direction of rotation. The conduits 24 and 25 are connected to the azimuth or traverse servo valve 26 which functions as a part of the stabilization system as more fully explained hereinafter. The pressurized fluid is then conveyed through the conduits 27 or 28 to the traverse hydraulic motor 29 which is operatively connected to a gear train (not shown) which is meshably engaged with a large ring gear (not shown) that is fixed to the turret of the vehicle. Accordingly, when the control handle 20 is rotated, the displacement velocity of the turret is commanded. The control member 21 is constructed in such a way that for the first degrees of rotation, a very slow output is obtained. As rotation of the handle is continued, outputs increase greatly in speed. This action permits the operator to track very slowly and put the gun on the target very carefully. The exhaust hydraulic fluid from the traverse hydraulic motor 29 flows back to the reservoir 11 through the conduits 30, 54 and 40.

The gun is elevated or depressed by moving the control handle 20 forwardly and backwardly about the pivot point 22 which causes the control rod 23 to actuate the other spool valve and control the flow of hydraulic fluid to the elevation cylinder or actuator generally indicated by the numeral 50 in FIG. 1. The actuator 50 is connected at the end 51 to the hull of the vehicle and the rod end 52 is operatively connected to a pivot point on the gun. The pressurized hydraulic fluid is directed to the desired end of the actuator 50 through the conduits 42, 43, 45 and 46, and the stabilization system servo valve 44 and synchronizer 32a.

A deck clearance valve 31 is connected in the hydraulic fluid system for the elevation cylinder 50 and functions with a plurality of sensing switches which detect possible interference with the gun and prevent it from going any lower than it can go without hitting portions of the tank, as for example, the rear deck where the engine compartment is disposed. The deck clearance valve 31 is supplied with pressure fluid through the conduits 32 and 34, and the valve 33. The valve 31 is connected to the reservoir 11 through the conduits 30, 54 and 40.

The numeral 38 in FIG. 1 is a pin lock means for a gear box shifter (not shown) which is spring operated in one direction and fluid pressure operated in the other direction. It is connected by the conduit 37 to a source of fluid pressure in the valve box 19. The numerals 39 and 41 are electric solenoids which operate master flow control valves in the valve box 19. The numeral 49 generally indicates a combined safety relief valve and lock valve connected in the fluid pressure circuit to the elevation cylinder 50.

The numeral 53 is a super-elevating actuator which is supplied fluid pressure from the valve box 19 by means of the conduits 32, 34 and 55, and which exhausts to reservoir 11 through the conduits 54 and 40. The super-elevating actuator 53 is connected to the elevating cylinder 50 by the conduits 56 and 57. The super-elevating actuator 53 is adapted to keep the gunner's sights on the target during elevation changes due to abrupt changes of range. As for example, when it is required to fire at a greater range and it is necessary to quickly elevate the gun to take care of the required trajectory.

As shown in FIG. 1, the power control system is also provided with a manual elevating pump 60 which is operated by the hand crank 61 and which is operatively connected to the elevation cylinder 50 through the conduits 62 and 63. The conduit 62 is connected to a manual

elevating accumulator 65. The conduit 63 is operatively connected to the reservoir 11 by means of the conduit 64.

STABILIZATION SYSTEM

The stabilization system functions to complement the aforescribed power control system and provide maintenance free, long life operation. The stabilization system will first be described generally in relation to FIG. 2, and then described in more detail in relation to FIG. 3.

FIG. 2 shows a schematic of the stabilization system operatively attached to the aforescribed power control system. In FIG. 2, the stabilization add-on unit is indicated generally by the numeral 69, and the power control system is indicated generally by the numeral 68. It will be understood from the description of FIG. 2, that the illustrative embodiment of the stabilization system is basically a feedback positioning system which utilizes conventional rate gyros with integrators as reference elements. A sensor or rate gyro 71a is mounted on the gun 72 on the elevation reference axis and is supplied with electrical power from the power supply 70. The output signal from the rate gyro is amplified and demodulated in appropriate electronic circuitry and it is then fed through the integrator 73a to the amplifier 74a. The integrator provides a position reference signal which is proportionate to the change in position or angular variation of the gun gyro 71a from the elevation axis. The output of the amplifier 74a is fed into the hydraulic portion of the stabilization system where it is applied to the electro-hydraulic servo valve 44 which in turn supplies hydraulic fluid under pressure to the elevation cylinder or actuator 50, to correct the attitude of the gun according to the gyro command. The actuator 50 may also be called a prime mover. The servo valve 44 may be called a controlling means which is responsive to the output signals of the electrical control circuitry, for controlling power to the prime mover 50 for moving the gun, or other object, in accordance with said output signals to maintain the position of the gun with respect to the reference axis in space. The aforescribed elements constitute the basic position reference feedback loop.

Because of certain existing vehicle and system parameters, as for example, the great masses of the turrets and the relatively low power capability, the aforescribed basic position reference feedback loop does not provide sufficient inherent damping to allow high feedback gains and corresponding accurate system performance. To overcome this condition, a velocity input 78 and an accelerometer such as 77 may be provided in each axis to provide velocity and acceleration damping signals. These signals when properly added to the position reference feedback loop allow for greater damping and greater loop feedback gain than is otherwise possible. In the position stabilization system so far described, a position error must be maintained in order to command a velocity of the system. In order to minimize this position error, a rate gyro 75a is included in the system. The rate gyro 75a develops a vehicle velocity reference signal which is inserted into the system through the amplifier 74a on a unity control basis which allows the gun to move as a function of hull movement without demanding an error on the part of the position reference system.

The aforescribed elements comprise the basic stabilizing control elements of the stabilization system. However, it will be seen that the stabilization system must be provided with some means for the operator to superimpose corrections of his own choosing upon the system. Accordingly, a synchronizer 82a is added to the system, and as illustrated, it may consist of a velocity generator driven by a hydraulic motor. The synchronizer 82a may comprise any other suitable apparatus, as explained hereinafter. The hydraulic motor of the illustrated synchronizer 82a is inserted in series in the hydraulic fluid control system for the elevation axis, as shown in FIG. 2, when the stabilization system is engaged. When hydraulic fluid

is displaced through the manipulation of the control handle 20, the hydraulic motor drives the velocity generator at a speed proportionate to that of the output actuator. The output of this generator is fed into the electrical control circuitry 73a, 74a and 78, as shown in FIG. 2, to compensate for the apparent error signal developed in the gun reference rate gyro 71a as a result of the command input at the manual control valves. It will be seen that any attempt on the part of the operator to apply manual correction commands would be frustrated with a counter reaction on the part of the servo valve 44 if it were not for the synchronizer 82a. When the stabilization system is disengaged, the hydraulic motor of the synchronizer 82a is also disengaged from the power control circuit.

As shown in FIG. 2, the hydraulic portion of the stabilization system includes a shut-off solenoid operated valve 81a which is adapted to switch the synchronizing member 82a in and out of the power control circuit, and it is also utilized to control the flow of hydraulic fluid to and from the servo valve 44. The solenoid shut-off valve 81a when de-energized completely isolates the stabilization system from the power control system 68 leaving the power control system 68 fully operational in the event of a gyro control malfunction. FIG. 2 illustrates the application of the stabilization system to the elevation axis, and it will be understood that the stabilization system may be applied in a similar manner to the traverse axis.

It will be seen from the foregoing, that the illustrative embodiment of the stabilization system of the present invention employs a gyro reference to attempt to keep the gun in a given plane regardless of pitching, rolling or yawing motions of the hull of the vehicle. This is an advantage, because at least theoretically, a gunner may fire the gun with improved chances of success while the vehicle is moving. Heretofore, it has been almost impossible to maintain the position of a gun on a target accurately from a moving tank. The stabilization system of the present invention gives the operator an advantage similar to that of being in a stationary tank and shooting at a moving target. The stabilization system does not take its reference from the target since it has no knowledge where the target is situated, and it has only knowledge of where the gun should be in space, and it attempts to maintain that relationship regardless of what motions the hull goes through. The basic reference for the illustrative embodiment of the stabilization system is a gyro and it maintains a direction in space regardless of how it is moved.

Referring now to FIG. 3, the stabilization system of the present invention is shown as applied to both the elevation and traverse axes. The traverse or azimuth axis control system will first be described and the minor differences between the elevation axis control system and the traverse axis control system will then be separately described. The elements employed for controlling operation in each axis are the same and the elements in the elevation axis control system have been marked with the same reference numerals used for the corresponding elements in the traverse axis control system, followed by the small letter "a".

Electrical power for the stabilization system is supplied by a voltage regulator (not shown) and a static inverter unit (not shown) which in turn derives power from the vehicle batteries. Regulation of this unit is such that voltage variations caused by other electrical systems in the vehicle do not affect the performance of the stabilization system. Hydraulic fluid to operate the servo valves 26 and 44 is taken from the power pack of the vehicle power control system 68 (FIG. 2). The stand-by fluid requirements of the servo valves 26 and 44 are low and are well within the capability of the power control system 68.

In FIG. 3, the numeral 83 generally indicates a turret power control switch and the numeral 84 generally in-

dicates the stabilization power switch. The switch 84 functions as a master switch to energize the stabilization system to a standby condition. The power supply 70 supplies the various voltages necessary for the electronic control portion or system of the stabilization system.

The sensor means or gyro 71 is mounted on the gun on the azimuth reference axis, and it is a velocity type gyro which provides an electrical output signal only while it is moving and at a proportionate rate to the velocity of rotation or the rate at which it is being moved. The output signal from the rate gyro 71 is fed through the summing point 91 to the amplifier 92. The output signal from the gyro 71 is an alternating current which is fed from the amplifier 92 into the demodulator 93. The gyro output signal is proportional in polarity and amplitude to angular variations of the gun from the azimuth reference axis. The demodulator 93 puts out a direct current signal which is proportional to the in-phase component of the reference frequency which is fed into it. The demodulator 93 responds only to alternating current of the aforementioned phase or that phase plus 180°. It rejects all other frequencies and phases since it is both frequency and phase sensitive. If the phase changes by 180°, the demodulator 93 puts out a direct current of the opposite polarity.

The demodulator 93 thus takes the amplified gun gyro alternating current signal and feeds out a direct current signal which is proportional in amplitude to the rate at which the gyro 71 is moving and which has a polarity that is an indication of the direction that the gyro 71 is moving relative to the azimuth plane. If it moves from left to right, for example, it may be a positive signal. If it moves from right to left, it would then be a negative signal, and the amplitude would be proportional to the velocity rate. The direct current velocity signal is fed to the point 99 from where it is used in several ways.

The fundamental portion of the stabilization system is a positioning system; that is, it is a null seeking system and will null a position signal. A position reference signal is developed by feeding the direct current velocity signal from the gyro 71 through the gain adjustment means 94 and into the integrator 73. The integrator 73 electronically integrates the gyro velocity signal and provides a position reference signal which tells where the gun is positioned. The position reference signal is proportionate to the change in position of the gyro 71, if there is any.

The position reference signal output of integrator 73 is fed into an all purpose amplifier 74 which is a direct current amplifier and which sums up various signal inputs, as more fully described hereinafter. The output signal of the amplifier 74 is then fed into the hydraulic portion of the stabilization system which includes the traverse or azimuth servo valve 26. The servo valve 26 then operates as a controlling means on the azimuth hydraulic fluid motor 29 (FIG. 1) which moves the turret on the azimuth plane in accordance with the command of the servo valve 26 to maintain the position of the gun with respect to the reference azimuth axis. It will be seen that the last described combination of control elements comprises a stabilizing system in and of itself. Any suitable apparatus may be used to carry out the controlling function of the servo valve 26. The illustrated servo valve 26 operates on direct current and controls a flow of oil proportionate to the amount of current supplied to it.

It will be understood that the last described stabilization system may incorporate other type sensing means instead of the rate gyro 71, for example, an attitude gyro, and that in such case, the integrator 73 would be eliminated, because the attitude gyro produces an output signal which is proportionate to the position to which the gyro has been moved. The rate gyro is preferable since it is rugged and inexpensive as compared to an attitude gyro.

Referring to the null bucking element 90, it will be understood that this device is provided to add a signal to the output of the gyro 71 to artificially set the gyro at

zero externally, without having to adjust the gyro to take care of small changes in the gyro null setting due to temperature and other atmospheric changes, and the like. The null bucking signal is a vernier type signal of small value for correcting the gyro null error.

The position system operating efficiency may be increased by increasing the gain in the system so as to permit it to more accurately move large masses such as the gun and turret. The improved gain in the system is accomplished by adding damping factors into the position system by means of velocity feedback and acceleration feedback as shown in FIG. 3. The velocity signal is fed into the summing amplifier 74 through the gain adjust means 95. The acceleration signal derived by differentiation of velocity is fed into the summing amplifier 74 through the gain adjust 96 and the amplifier 97. The velocity and acceleration signals are fed into the summing amplifier 74 in the proper phase relationship and are added into the servo valve signal.

In order to minimize the errors caused by velocity demands on the position system, a second gyro 75 is mounted on the hull and produces a rate signal or a velocity signal which indicates how fast the hull is moving in the azimuth plane. The velocity signal is fed through the gain adjust 101, the summing point 103, the amplifier 104 and the demodulator 105 and into the amplifier 74 from whence it is fed into the servo valve 26, on a unity control basis. The amplifier 104 and demodulator 105 will be of a type similar to the type used in the position system. The velocity signal produced by the hull gyro 75 produces a demand on the servo valve 26 for moving the turret in one direction at the same rate as the hull is moving in the other.

In FIG. 3, the numeral 102 designates a third stage which has been added to the closed center, two stage, electro-hydraulic, servo valve 26 in order to boost the flow of hydraulic fluid. The third stage is electrically controlled by means of an electric transducer which feeds a demand signal back into the hull gyro circuit through the summing point 103.

It will be understood that the stabilization system of the present invention is a space orientated system and not a target orientated system. Accordingly, means must be provided to permit an operator to correct the system if he has a parallax correction to make caused by the fact that the tank is moving at an angle to the target. The operator may make the desired correction by moving the control handle 20, FIGS. 1 and 2 to cause the gun and turret to move as desired. The stabilization system has an inherent tendency to take out any correction which the operator wishes to put into the system, and accordingly, suitable means such as the synchronizer 82 must be provided to overcome this problem. As shown in FIG. 1, the illustrated synchronizer 82 is incorporated into the conduits 27 and 28 which feed fluid to the hydraulic azimuth motor 29. The synchronizer 82 comprises a hydraulic motor which drives a tachometer that measures the flow of oil which is being supplied by the control handle 20 to the motor 29. A velocity signal or tachometer signal proportionate to the amount of oil put into the system by the operator is produced, and as shown in FIG. 3, the signal is fed through the gain adjust 98 to the summing point 99 and mixed with the gyro signal from the gyro 71 to overcome the aforescribed tendency of the stabilization system. It will be understood that the function of synchronizing the operator's corrections with the stabilization system may be carried out in other ways and with other means. For example, another way of providing a synchronization signal is to measure the motion of the control handle mechanism 20 to produce a signal which can be mixed in with the signal of the gyro 71.

The numeral 100 in FIG. 3 designates an engage adjust means which may comprise any suitable means for producing a bias adjustment that would permit the adjusting out of the system of any unbalance created by the ampli-

fier 92, the demodulator 93, the amplifier 97, the integrator 73, and other system elements.

As shown in FIG. 3, the numeral 81 indicates an electrically operated solenoid shut-off valve which permits the operator to switch the stabilization system in and out of the power control system of a vehicle. This solenoid operated valve 81 functions to shut off the flow of fluid to and from the electro-hydraulic servo valve 26 so that when it is shut off the system reverts back to the original power control system regardless of whether or not the electronics of the stabilization system are operating. The solenoid shut-off valve 81 is operated when the operator closes the power switch 84 and the stabilization engage switch 86. Upon initial engagement of power switch 84 there is a time delay provided by the time delay 85 to allow speed up of the gyros before the system operates. The engage switch 86 connects the servo valves 81 and 81a to the power supply 70 through the wires 87 and 88.

It will be seen that if a gyro fails, or an amplifier fails, or the power supply fails, that the engage solenoid shut-off valve 81 will function to shut the stabilization system off and the power system 68 will then take over sole control of the gun control system.

The traverse system motor 29 (FIG. 2), because of its inherent construction, will leak fluid internally and cause the system to drift if the motor 29 were not braked and held in place. In the illustrated power system, this brake is disconnected by squeezing the gunner palm switches on the control handle 20, and these switches are generally indicated in FIG. 3 by the numeral 106. In the stabilized mode of operation this brake is maintained in a disengaged position at all times. The power supply is connected by the wire 80 to the bypass relay 89 in the bypass circuit around the integrator 73. Whenever the stabilization system is disengaged closure of relay 89 shorts out the integrator 73 resulting in a zero signal until the stabilization system is re-engaged. The stabilization system for the elevation axis is shown in FIG. 3 and it is similar to the system for the traverse axis and corresponding parts have been provided with the same reference numerals followed by the small letter "a". The elevation axis stabilization system functions in the same manner as described hereinbefore for the traverse axis stabilization system. One difference is that the elevation axis system is provided with an accelerometer 77. The accelerometer 77 is used in the elevation axis system because of the required higher frequency which is needed for elevation purposes as compared to traverse purposes. It is the difference in physical limitations which makes it desirable to use the accelerometer 77 in the elevation axis system. Another difference is that the gyro 75a is mounted on the turret in the illustrative embodiment.

The various elements of the aforescribed stabilization system may be any suitable conventional elements adapted to carry out the required functions.

OPERATION

As described hereinbefore, the stabilization system of the present invention may be added to, or combined with, conventional power control systems and, accordingly, operators who have had experience with the power control system require virtually no training in the use of the combined system. The advantages of stabilized gun performance are thus provided without any significant increases to the duties of the operator.

The stabilization system is put into operation by actuating the main power switch 84 and engage switch 86. The time delay relay 85 prevents utilization of the stabilization system until sufficient time has elapsed for speed up of the gyros. At the completion of this time, the stabilization system may be engaged and disengaged at will through the use of the stabilization engagement switch 86 which operates the servo shut-off solenoid operated valves 81 and 81a. Drift of the system is nulled out by the operator through the use of null bucking adjustments 90 and 90a. With the stabilization system disengaged, the power

control system functions in the usual manner. Upon engagement, the stabilization system counteracts the effects of terrain variation and vehicle transients on the aiming of the gun. The operator has only to make corrections for movements of the target and relative positioning changes due to displacement of his own vehicle. These corrections are made by the normal procedural manipulation of the power system control handle 20.

In the subjoined claims the term object is used to designate the gun or other member which is to be stabilized. The term body or support member is used to designate the unstable member on which said gun or other member is mounted, as for example, either the turret or vehicle hull, or both. The term inertial type sensor means refers to the gyros 71, 71a, 75, and 75a.

While it will be apparent that the preferred embodiments of the invention herein disclosed are well calculated to fulfill the objects above stated, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the proper scope or fair meaning of the subjoined claims.

What we claim is:

1. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to a first inertial reference axis, and a second inertial reference axis, the combination comprising:
 - (a) first gyro sensor means affixed to said object to detect angular velocity variations of said object from said first inertial reference axis and to yield electrical output signals correlative to said angular velocity variations;
 - (b) second gyro sensor means affixed to said object to detect angular velocity variations of said object from said second inertial reference axis and to yield electrical output signals correlative to said angular velocity variations;
 - (c) third gyro sensor means affixed to said unstable body to detect angular velocity variations of said unstable body from said first inertial reference axis and to yield electrical output signals correlative to said angular velocity variations for summation with the output signals of said first gyro sensor means;
 - (d) fourth gyro sensor means affixed to said unstable body to detect angular velocity variations of said unstable body from said second reference axis and to yield electrical output signals correlative to said angular velocity variations for summation with the output signals of said second gyro sensor means;
 - (e) means for deriving the first integral of said electrical output signal of said first gyro sensor means to yield a signal correlative of position error of said object relative to said first inertial reference axis;
 - (f) means for deriving the first integral of said electrical output signal of said second gyro sensor means to yield a signal correlative of position error of said object relative to said second inertial reference axis;
 - (g) means for deriving the first derivative of said electrical output signal of said first gyro sensor means to yield a signal correlative to the acceleration of said object with respect to said inertial space;
 - (h) means for deriving the first derivative of said electrical output signal of said second gyro sensor means to yield a signal correlative to the acceleration of said object with respect to said inertial space;
 - (i) means for summation and amplification of said velocity signals, said position signal, and said acceleration signal of said first and third gyro sensor means with respect to said first inertial reference axis to result in a first composite control signal;
 - (j) means for controlling fluid flow correlative to said first composite control signal;
 - (k) prime mover means for displacement of said object relative to said unstable body with respect to said first inertial reference axis as a function of said fluid flow of said first composite control signal;

(l) means for summation and amplification of said velocity signals, said position signal, and said acceleration signal of said second and fourth gyro sensor means with respect to said second inertial reference axis to result in a second composite control signal; 5
 (m) means for controlling fluid flow correlative to said second composite control signal; and
 (n) prime mover means for displacement of said object relative to said unstable body with respect to said first inertial reference axis as a function of said fluid flow of said second composite control signal; 10
 whereby stabilization of a weapon mounted on a military vehicle moving over uneven terrain is effected in at least two axes substantially normal thereto.

2. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to an inertial reference axis, the combination comprising: 15

- (a) first gyro sensor means affixed to said object to detect angular velocity variations of said object from said inertial reference axis and to yield an electrical output signal correlative to said angular velocity variations; 20
- (b) means for deriving the first integral of said electrical output signal to yield a signal correlative of position error of said object relative to said inertial reference axis; 25
- (c) means for deriving the first derivative of said electrical output signal to yield a signal correlative to the acceleration of said object with respect to said inertial space; 30
- (d) means for summation and amplification of said velocity signal, said position signal, and said acceleration signal to result in a composite control signal;
- (e) means for controlling fluid flow correlative to said composite control signal; and
- (f) prime mover means for displacement of said object relative to said unstable body as a function of said fluid flow; 35

whereby said object will be constrained to small displacement variations from said inertial reference axis as in stabilizing a weapon in a military vehicle, moving over uneven terrain. 40

3. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to an inertial reference axis, the combination as defined in claim 2, including: 45

- (a) synchronizer means for summation with said electrical output signals of said first gyro sensor means to allow discriminate alteration of said inertial reference axis, 50

whereby the operator of a stabilized weapon control system may at his discretion alter said inertial reference axis of said object to one or more alternate inertial reference axes, thereby maintaining said weapon to be tracking a target and to be stabilized with respect to said one or more alternate inertial reference axes regardless of the relative movements of said body and target. 55

4. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to an inertial reference axis, the combination comprising: 60

- (a) first gyro sensor means affixed to said object to detect angular velocity variations of said object from said inertial reference axis and to yield an electrical output signal correlative to said angular velocity variations; 65
- (b) second gyro sensor means affixed to said unstable body to detect relative angular velocity variations of said unstable body relative to said inertial reference axis and to yield an electrical output signal correlative to said relative angular velocity variations for 70

summation with said first named electrical output signals of said unstable body;

- (c) means for deriving the first integral of said electrical output signal of said first gyro sensor means to yield a signal correlative of position error of said object relative to said inertial reference axis;
- (d) means for deriving the first derivative of said electrical output signal of said first gyro sensor means to yield a signal correlative to the acceleration of said object with respect to said inertial space;
- (e) means for summation and amplification of said velocity signal, said position signal, and said acceleration signal of said first gyro sensor means to result in a composite control signal;
- (f) said means for summation and amplification of said electrical output signals to include said second sensor electrical output signals;
- (g) means for controlling fluid flow correlative to said composite control signal; and
- (h) prime mover means for displacement of said object relative to said unstable body as a function of said fluid flow; 75

whereby introduction of said second gyro sensor means electrical output signals to said means to control fluid flow results in reduction of displacement variations as allowed by said first gyro sensor means and associated controlling means of said object from said inertial reference axis, as in stabilization of a weapon mounted on a military vehicle moving over uneven terrain.

5. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to an inertial reference axis, the combination as defined in claim 4, including: 80

- (a) synchronizer means for summation with said electrical output signals of said first gyro sensor means to allow discriminate alteration of said inertial reference axis, 85

whereby the operator of a stabilized weapon control system may at his discretion alter said inertial reference axis of said object to one or more alternate inertial reference axes, thereby maintaining said weapon to be tracking a target and to be stabilized with respect to said one or more alternate inertial reference axes regardless of the relative movements of said body and target.

6. In a stabilizing system for stabilizing an object, on an unstable body, in inertial space with respect to an inertial reference axis, the combination as defined in claim 2, further including a means for stabilizing said object with respect to a plurality of orthogonal inertial reference axes, whereby said weapon is stabilized in at least two inertial reference axes, as on a vehicle moving over uneven environment. 90

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