United States Patent

Chatham et al.

[15] **3,640,178**

[45] **Feb. 8, 1972**

[54] RATE STABILIZATION SYSTEM FOR A VEHICLE MOUNTED DEVICE

[72] Inventors: **James R. Chatham**, Laurel; **William H. Licata**, Silver Spring, both of Md.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy**

[22] Filed: **Apr. 29, 1970**

[21] Appl. No.: **32,947**

[52] **U.S. Cl.** .....**89/41 CE**, 89/41 LE

[51] **Int. Cl.**.....**F41g 5/22**

[58] **Field of Search**.....89/41 R, 41 D, 41 LE, 41 CE

[56] **References Cited**

UNITED STATES PATENTS

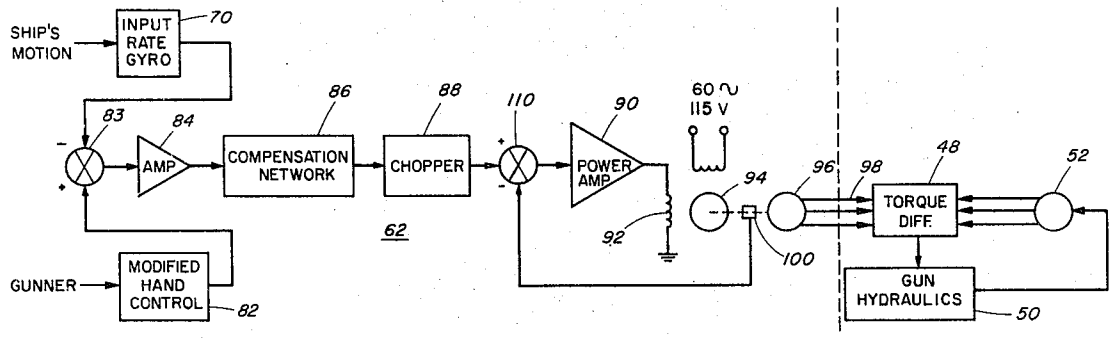
2,586,817	2/1952	Harris	89/41 CE
3,396,630	8/1968	Hinterthur et al.	89/41 CE
3,405,599	10/1968	Barlow et al.	89/41 CE

Primary Examiner—Benjamin A. Borchelt
Assistant Examiner—Stephen C. Bentley
Attorney—R. S. Sciascia and J. A. Cooke

[57] **ABSTRACT**

A rate stabilization system for a vehicle mounted tracking device employing an open loop control system that is interfaced with the existing control system of the device. Rate gyros detect movement of the vehicle and produce an error signal corresponding to this movement that is electronically processed to produce movement of the device in a direction that nulls out vehicle movement.

11 Claims, 6 Drawing Figures



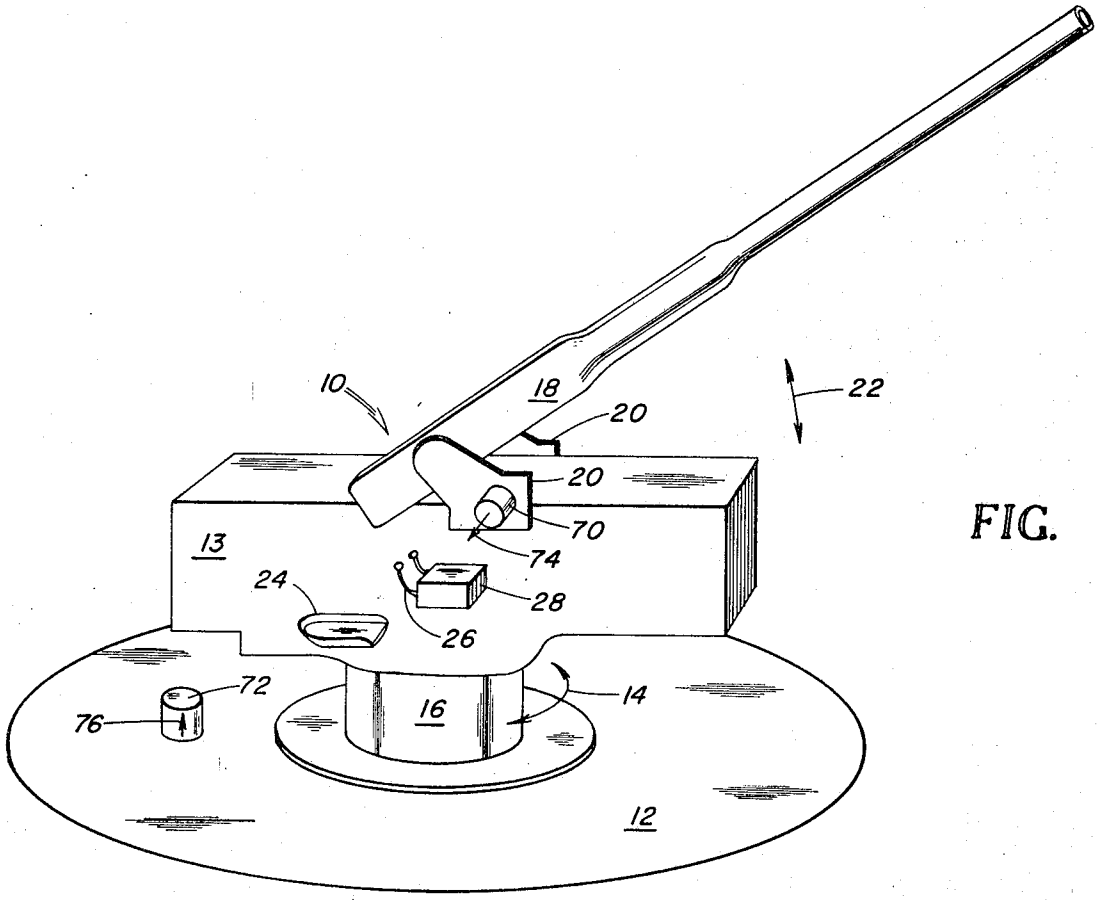


FIG. 1

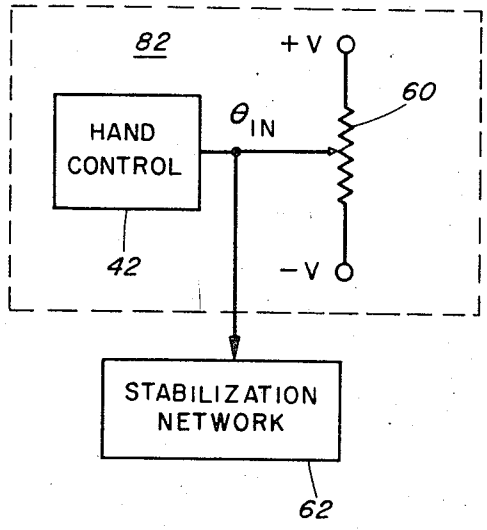


FIG. 3

INVENTORS
James R. Chatham
William H. Licata

BY

ATTORNEY

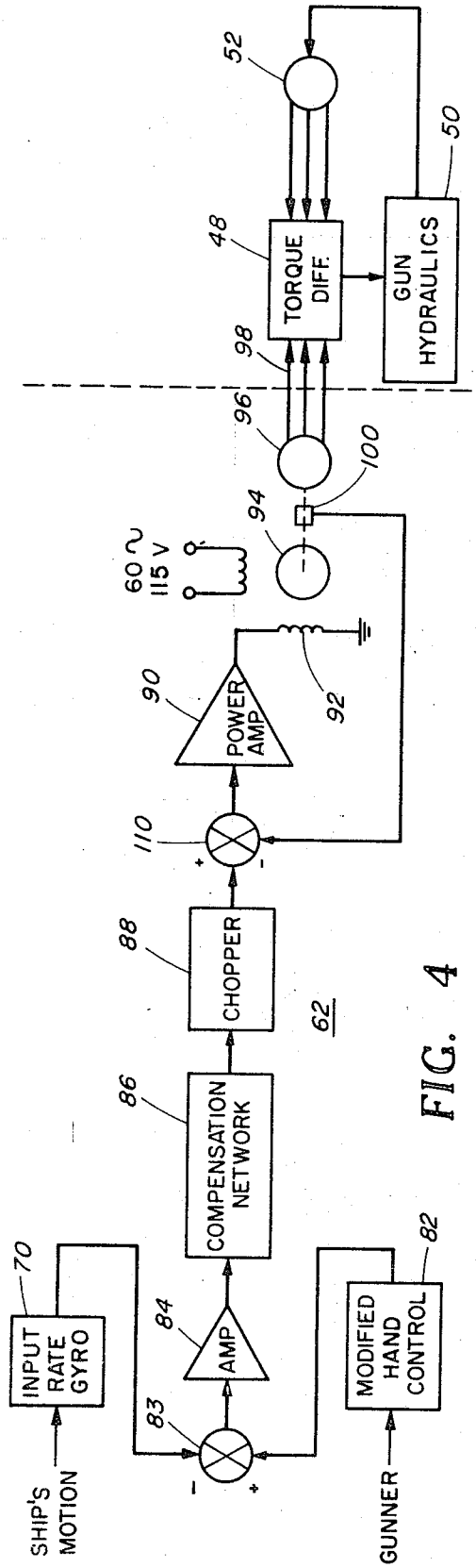

SHIP'S MOTION
INPUT RATE GYRO
70
GUNNER
MODIFIED HAND CONTROL
82
AMP
84
COMPENSATION NETWORK
86
CHOPPER
88
POWER AMP
90
92
60 ~ 115 V
94
96
98
100
TORQUE DIFF.
48
GUN HYDRAULICS
50
52
110
62

FIG. 4

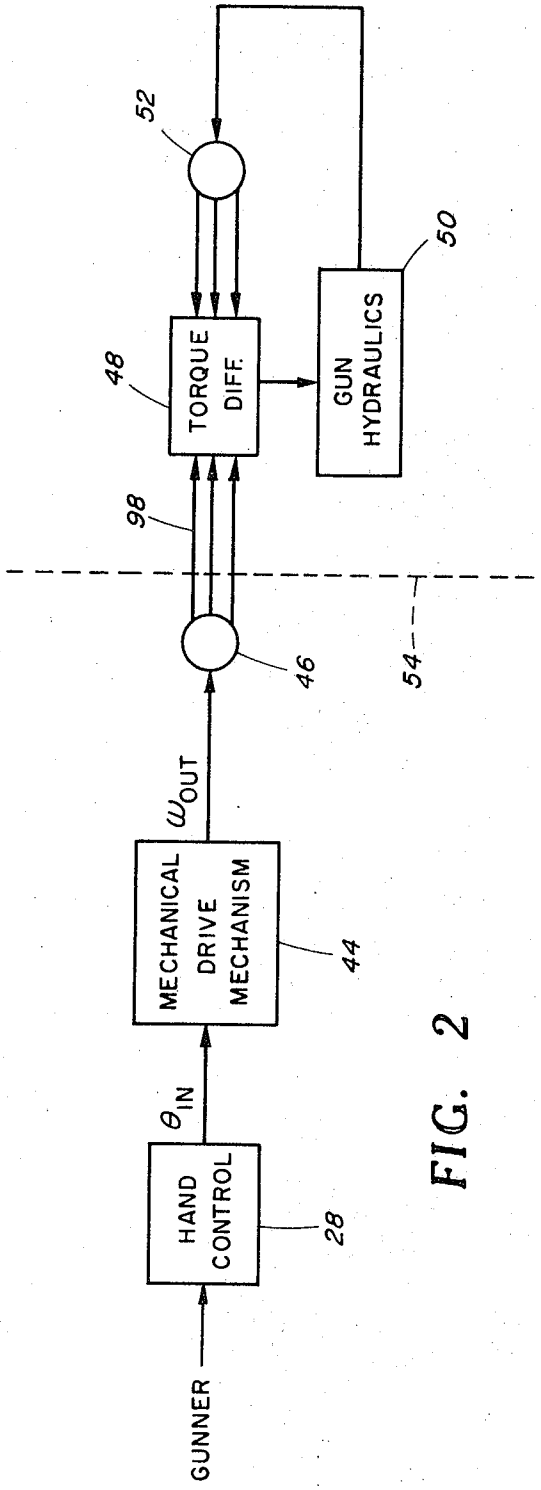

GUNNER
HAND CONTROL
28
θ_{IN}
MECHANICAL DRIVE MECHANISM
44
ω_{OUT}
46
54
98
TORQUE DIFF.
48
GUN HYDRAULICS
50
52

FIG. 2

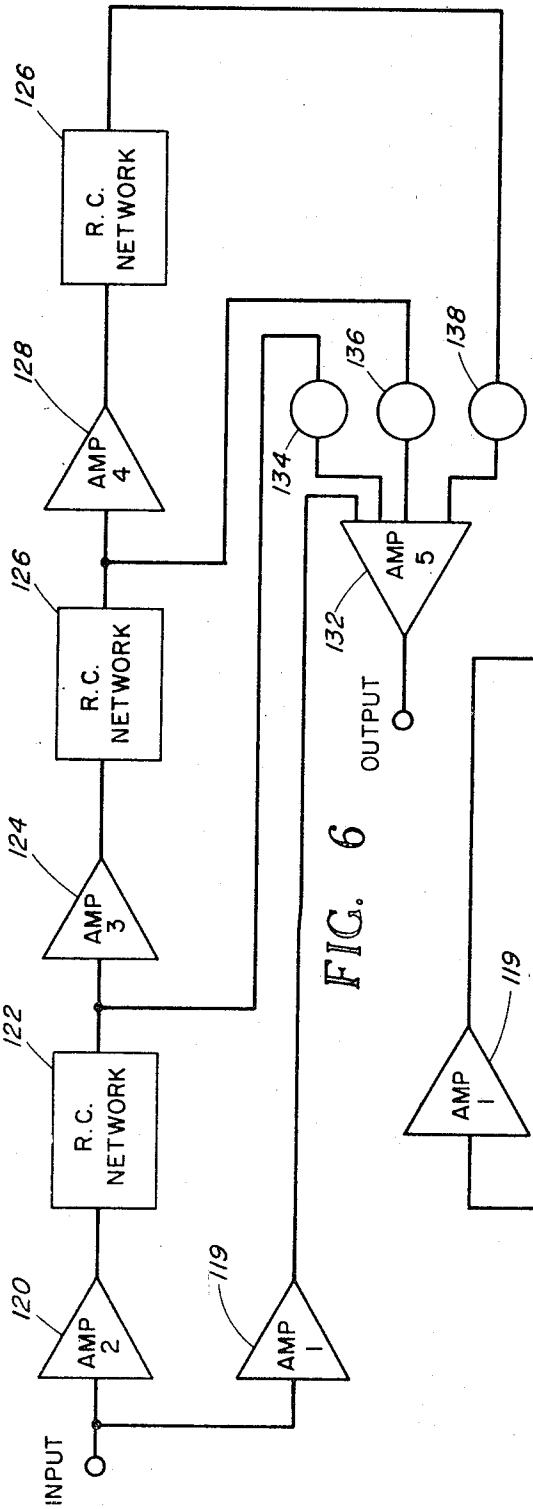

126
R.C. NETWORK
128
AMP 4
126
R.C. NETWORK
124
AMP 3
122
R.C. NETWORK
120
AMP 2
119
AMP 1
INPUT
134
136
138
AMP 5
132
OUTPUT

FIG. 6

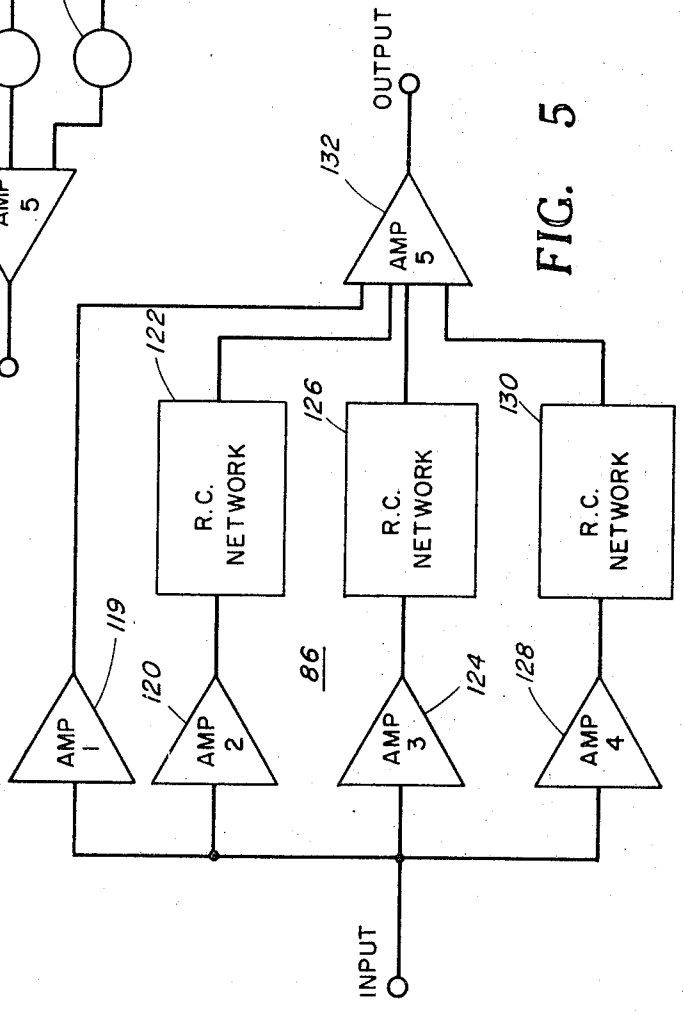

OUTPUT
132
AMP 5
122
R.C. NETWORK
126
R.C. NETWORK
130
R.C. NETWORK
119
AMP 1
120
AMP 2
86
AMP 3
124
AMP 4
128
INPUT

FIG. 5

RATE STABILIZATION SYSTEM FOR A VEHICLE MOUNTED DEVICE

BACKGROUND OF THE INVENTION

This invention relates generally to stabilizing mechanisms and more particularly to a system for stabilizing the motion of an ordnance vehicle launcher with respect to inertial space.

In general, stabilizing methods for vehicle mounted devices, such as turret guns or missile launchers on a ship, involve attempts to stabilize in inertial space the platform on which such devices are mounted. In the prior art stabilization was achieved by the use of several well-known methods, including position control, rate control, and acceleration control feedback systems and combinations thereof. Such control systems are generally very complex since they employ multiple feedback loops, integrating and differentiating circuits, and numerous sensing devices. As a result, these systems are expensive to produce and to maintain, are not very rugged, and are subject to frequent malfunctions. In addition, these prior art control systems can not be readily integrated with existing ordnance systems without major modification to the aiming and control mechanisms thereof.

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a simple, inexpensive and rugged stabilization system for use with existing vehicle mounted movable tracking devices.

It is another object of the instant invention to provide a weapon launching stabilization system which can be readily and easily integrated with existing weapon launching control systems.

Still another object of the instant invention is the provision of an open loop control system for stabilizing the position of a vehicle mounted gun in inertial space.

A further object of this invention is the provision of a stabilization system for a ship mounted gun wherein the stabilization system is responsive to the ships motion and corrects aiming errors introduced by this motion.

Briefly, in accordance with the invention, these and other objects are attained by providing an open loop rate stabilization system for a weapon launcher which employs similar networks for compensating vehicle motions about a training axis and an elevation axis. In each network a rate gyro senses vehicle motion about the appropriate axis and develops a signal related to the rate of such motion. Operator input commands produce a signal related to the rate at which it is desired to move the weapon launcher. The stabilization system distinguishes between these two inputs in a manner such that the launcher moves opposite to vehicle motion, thereby cancelling out this unwanted motion, yet directly moves in response to operator input commands, thereby enabling tracking of the target. Additionally, the present invention employs a compensation network to reduce phase lag between desired launcher motion and actual launcher motion and to improve the frequency response characteristics of the weapon launcher control mechanism. The output signal from the compensation network is power amplified and then used to control the speed of a servomotor which in turn drives a synchro generator that supplies the input signal to the launcher control mechanism. The launcher control mechanism responds to this input signal and moves the weapon launcher at the rate determined by this signal.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a perspective view of a gun mounted on a vehicle, such as a ship.

FIG. 2 is a block diagrammatic view of a conventional gun control mechanism before the addition of the stabilization system.

FIG. 3 is a schematic view combined with a block diagrammatic view of a modified gun hand control.

FIG. 4 is a block diagrammatic view of the gun control mechanism of FIG. 2 coupled to the stabilization system of the present invention.

FIG. 5 is a block diagram of one embodiment of a compensation network that may be used in the present invention.

FIG. 6 is a block diagram of a preferred embodiment of a compensation network for use in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings wherein like reference characters represent identical parts throughout the several views and more particularly to FIG. 1 whereon a weapon launch system such as a conventional gun assembly **10** is shown mounted on a movable vehicle, or platform, **12** such as a ship. It will be understood that the gun **10** is capable of swiveling in either direction in the horizontal plane or train direction, generally indicated by arrow **14**, about a fixed base **16**. A gun barrel **18** is pivotally connected to a gun mount **13** as by trunnions **20** for movement in the vertical plane, or elevation direction, indicated by arrow **22**. A seat **24** is provided on the mount **13** to seat an operator, such as a gunner, who controls movement of the gun **10** in train and elevation by means of control handles **26** which are part of gun control system **28**. In a typical gun control mechanism **28** the position of control handles **26** determines the slewing rate of the gun. Thus, positioning the handles a greater distance from the null or rest position increases the velocity of gun movement. Typically, control handles of this type produce train movement, i.e., rotation about the base **16**, by moving the handles left or right, and produce elevation movement, i.e., rotation of the barrel **18** about trunnions **20**, by moving the handles up or down. As may be readily seen from FIG. **1**, any yaw roll or pitch movement of the vehicle on which the gun is mounted will produce aiming errors in the gun in the absence of any stabilization. It will also be noted that the gun barrel is not free to move in the roll direction and thus the present invention makes no attempt at stabilization about the roll axis. However, it should be noted that motion about the roll axis of the gun produces little if any aiming error if the elevation angle of the gun is small and can be easily corrected by the gunner.

Referring now to FIG. **2** there is illustrated in block diagram form the elevation control system for the gun assembly **10** of FIG. **1**. Since a conventional gun control mechanism, such as employed in the instant invention, has essentially identical control systems in both train and elevation, it will be understood that the following description of the elevation control system also applies to the train control system.

If the gunner in the unstabilized system desires to track a target moving in elevation he moves the control handle **26** to the appropriate position, producing an angular rotation, θ_{in}, at the output of the hand control mechanism **28**. A nonlinear function of θ_{in} is mechanically integrated and thereby converted into an angular rotation in a conventional mechanical drive mechanism **44**. The mechanical rotation produced by this mechanism drives an input synchro **46** which, in turn, produces a three-phase electrical signal which is a function of the synchro shaft speed. A torque dependent upon the signal from input synchro **46** is developed by a conventional torque differential **48** and drives the gun's hydraulic systems **50**.

As the hydraulic system **50** moves the gun barrel **18** in elevation the shaft of an output synchro **52** rotates at a speed corresponding to the slewing rate of the barrel **18**. The torque differential **48** compares the signals from the input synchro **46** and output synchro **52** to produce a torque proportional to the difference between the two electrical signals. When the actual slewing rate of the barrel, represented by the output signal of synchro **52**, equals the commanded slewing rate, represented by the output signal of synchro **46**, a constant torque will be developed in torque differential **48** and the barrel **18** moves at a constant speed.

The stabilization system of the present invention will interface with the conventional gun control mechanism hereinbe-

fore described in connection with FIG. 2 in a simple, straightforward, and economical manner. First, as shown in FIG. 2, the input synchro 46 is disconnected electrically from the torque differential 48 by disconnecting leads 98. This is represented schematically by broken line 54. Second, as illustrated in FIG. 3, the output, θ_{in}, of hand control 28 is connected to the wiper arm of a potentiometer 60 to convert the mechanical angular position of control handles 26 into an electrical signal directly related to the position thereof. Thus, when the gunner moves the control handles 26 away from the null or rest position to track a target at a desired slewing rate, an electrical tracking signal will be generated that is related to this slewing rate. The resulting modified hand control 82 is contained within the dotted lines of FIG. 3. Finally, the electrical signal from the modified hand control 82 is fed to the input of a stabilization network 62, and the output thereof is connected to the torque differential input leads 98 shown in FIG. 4.

The stabilization network 62 for elevation of the gun barrel 18 is shown in greater detail in block diagrammatic form in FIG. 4. It is to be understood that since the stabilization networks for train and elevation are essentially identical, only the elevation network will be described. However, one fundamental difference between the train and elevation systems should be noted; namely, it is desirable to mount an elevation rate gyro 70 on the rotatably movable portion of the gun so that its sensitive axis 74 will always be perpendicular to the gun's actual axis of elevation rotation. As shown in FIG. 1, the elevation rate gyro 70 is mounted on trunnions 20. It should also be understood that gyro 70 may be mounted anywhere on the movable base, and all such locations are contemplated by the present invention. Additionally, it will be appreciated that a train rate gyro 72 with sensitive axis 76 is mounted on the deck of the ship 12, away from the gun as shown in FIG. 1. Since the gun assembly 10 is securely mounted to the ship, the rotation of the gun in train will always be perpendicular to the sensitive axis 76 of the train gyro 72 if it is mounted on the ship's deck. Thus, by positioning gyro 72 at a distance from the gun the train gyro is made less sensitive to high-frequency transient movements of the gun, such as those that occur from recoil during firing.

The position of the two rate gyros 70 and 72 indicates the open loop nature of the instant stabilization system. To be a closed loop stabilization system the two gyros would need to be mounted on the gun barrel 18. In such a system any unwanted motion in the barrel would generate a gyro output signal which the stabilization network would use for cancelling out the unwanted motion. Actual motion would then be compared with desired motion until they were identical. However, such a system would have to be designed to compensate for recoil motion. The design of such a system would be difficult since great care would be required to guarantee system stability, and there would be no guarantee that the desired frequency bandwidth of the closed loop stabilization system could be attained.

If there are no inputs to the open loop system of FIG. 4 from either the ship's motion or the gunner, no signal will be generated to drive the gun barrel and it will remain motionless. However, should the ship move in elevation and the gunner simultaneously desire to track a target moving in elevation relative to the ship the velocity of the ship's motion will be detected by input rate gyro 70 and converted into an error signal, and a tracking signal will be developed at the output of modified hand control 82 in response to a movement of the control handles 26. In the system of the present invention the rate gyros produce a DC signal but it should be understood that a rate gyro producing an AC signal also may be used, provided that suitable means, such as a demodulator, are employed to convert the AC into a DC signal. The modified hand control 82 produces a DC tracking signal related to the position of the handles 26 relative to the null or rest position. As hereinbefore described, the position of the handles will determine the speed or slewing rate of the gun barrel 18 in elevation.

The signals from the input rate gyro 70 and the modified hand control 82 are summed in a summing device 83, such as a resistive network, and then amplified in an amplifier 84, such, for example, as an operational amplifier. The signals into amplifier 84 are summed in such a way that the signal representing ship's motion will cause the gun barrel to move in the direction opposite this motion, thereby effectively cancelling it out, while the signal representing the desired slewing rate of the barrel will cause the barrel to move the desired direction. Stated differently, the system distinguishes between the positive command of the gunner and the negative command of the ship's motion by using the appropriate polarity signal from both input signals. This operation is conveniently achieved, for example, by inverting the polarity of the signal from input rate gyro 70 and summing this signal with the noninverted signal from modified gun control 82. This is indicated schematically in FIG. 4 by the negative input sign to summing device 83 from input rate gyro 70, and the positive input sign to summing device 83 from modified hand control 82. By this technique, if the rate gyro output signal indicates ship's motion in the upward elevation direction, it will be inverted and treated as a signal commanding gun barrel movement in the downward direction to cancel out the ship's motion. However, a gunner's command for movement in the upward direction will be treated directly as a command for movement in the upward direction. Alternatively, the inversion signal may be generated in the input rate gyro itself by the appropriate connection of leads.

The output signal from amplifier 84 is fed to a compensation network 86 which processes the signal, as more fully described hereinafter. Compensating network 86 improves the overall frequency response of the gun thereby enabling response to higher frequency transients than would be possible if the gun control system were uncompensated, and reduces the large phase lag between desired slewing rate and actual slewing rate characteristic of a heavy gun. The varying DC signal from compensation network 86 is applied to and amplitude modulated by a chopper 88, such as a conventional transistor chopper. The output of chopper 88 is fed to a summing device 110, such as a resistive network, and its output is amplified by a conventional AC power amplifier 90. Power amplifier 90 supplies current to a control field winding 92 of a servomotor 94 such as a two phase AC servomotor thereby directly relating the velocity of rotation of the shaft of motor 94 to the magnitude of the input signal on control winding 92. Thus, the input signals from the gunner and ship's motion have been converted to servomotor rotational rates through the system thus far described.

Servomotor 94 is mechanically connected to an input synchro 96, such as by a conventional gear arrangement or by a common shaft. The input synchro 96 converts the mechanical rotation imparted thereto into a three-phase electrical signal, similar to that produced by input synchro 46 of the original gun control mechanism of FIG. 2. This electrical signal is supplied to torque differential 48 over three input leads 98 which previously had been disconnected from original input synchro 46. Additionally, the shaft rotation speed of servomotor 94 is detected and converted into an electrical signal by a rate rotation sensing device 100, such as a tachometer, and fed back to the input of summing device 110 wherein it is added with the output of chopper 88. This rate feedback adds damping to the system thereby preventing motor runaway and ensuring that the actual motor shaft rotation is the same as the desired shaft rotation.

A form of compensation network 86 suitable for use in the invention to reduce the phase lag and to improve the frequency response characteristics of the gun control mechanism at higher frequencies is illustrated in FIG. 5. The compensating network uses three stages of lead compensation wherein in both train and elevation the transfer function of the compensation network has the general form:

$$G(s)=\frac{(as+1)(bs^2+cs+1)}{(ds+1)(es-1)^2} \quad (1)$$

wherein the constants are determined by the gun parameters and operational characteristics. Compensation network **86** can be produced by taking a standard partial fraction expansion of the transfer function of equation (1) and producing each of the terms by an impedance network, such as an RC network, in conjunction with an amplifier, or by an amplifier alone. Thus, a network results wherein each term is produced separately by an amplifier alone, such as **119**, or an amplifier, such as **120**, **124**, or **128**, in combination with an RC network such as **122**, **126**, or **130**, the parameters of each amplifier and each RC network depending on the particular term produced, and the outputs from the signal amplifier and all amplifier-RC network combinations are summed in an amplifier **132**.

In the present invention, the compensation network is produced by a chain of amplifier-RC networks connected in series, wherein the output of each succeeding stage in the chain represents a term in a modified partial fraction expansion. The resulting network is shown in block diagram form in FIG. **6**. Using this arrangement, a savings in the number of components over the standard partial fraction technique is effected.

The basic difference between the modified form and standard form of partial fraction expansion is that in the latter, each of the factored terms in the denominator of the function to be expanded is the denominator of one of the expansion terms, whereas in the former, the denominator of each successive term of the expanded function is the product of the denominator of all succeeding terms. For purposes of illustration, a method of expansion will be developed for the transfer function G(s) of equation (1). Using a standard partial fraction expansion, there results:

$$(2) \qquad G(s)=K_1+\frac{K_2}{ds+1}+\frac{K_3}{es+1}+\frac{K_4}{(es+1)^2}$$

while using the modified partial fraction expansion of the present invention, there results:

$$(3) \quad G(s)+K_1+\frac{K_2'}{ds+1}+\frac{K_3'}{(ds+1)(es+1)}+\frac{K_4'}{(ds+1)(es+1)^2}$$

The modified expansion of equation (3) is produced by the network of FIG. **6**. Since the transfer function from the input of the compensation network to the output of any particular stage is simply the product of the transfer functions of all previous stages, it will be seen that each RC network need only produce a simple pole of the form:

$$(4) \qquad \frac{K_i}{A_i s+1}$$

whereas in the network of FIG. **5**, it is necessary to have one RC network produce the double pole:

$$(5) \qquad \frac{K_4}{(es+1)^2}$$

Thus, the modified expansion reduces the number of components required in the system. The same RC networks producing the simple poles of FIG. **5** can be used in FIG. **6** by inserting gain adjustments **134**, **136** and **138**. It should be noted that the last RC network **126** of FIG. **6** is the same as the proceeding RC network **126** since they both produce the same simple pole, and together produce the double pole as described above.

It will be evident from the foregoing that an apparatus for stabilizing a gun in inertial space has been disclosed which is simple in design, easy to interface with existing gun control mechanisms, and relatively inexpensive to build. It will be apparent that although the invention has been described for use on a moving platform such as a sea going vehicle, it can also be used on moving land vehicles, such as a railroad train or tank, for example. Also, it is apparent that although the stabilization networks are employed only in the two rotational axes of train and elevation, these networks may also be used in the roll axis and the three translational direction. Roll correction requires the addition of a third gyro whose output is resolved through the elevation angle and added to the train stabilization input. Correction for linear motion require a knowledge of target range.

Other modifications to the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A stabilization system for a tracking device mounted on a vehicle comprising:
- means responsive to movement of said vehicle for generating an error signal corresponding to said movement,
- means for generating a tracking input signal,
- means for summing said error signal and said tracking input signal to produce a sum output signal,
- means for compensating said sum output signal to provide improved frequency response of said device to transient movements of said vehicle,
- means for amplitude modulating the output of said compensating means to produce an amplitude modulated control signal,
- means for power amplifying said amplitude modulated control signal to produce a power amplified control signal,
- means for converting said power amplified control into mechanical rotation, and
- means for converting said mechanical rotation into an electrical signal for effecting the movement of said tracking device.

2. The stabilization system of claim **1** wherein said means responsive to movement of said vehicle is a rate gyro.

3. The stabilization system of claim **1** wherein said tracking device is **9** gun and said means for generating said tracking signal comprise a modified gun control handle system that produces an electrical signal corresponding to the movement of a set of control handles in said modified gun control handle system.

4. The stabilization system of claim **1** wherein said compensation means comprises:
- a plurality of network synthesis means, each of said means comprising an amplifier coupled to an impedance network, and each of said means yielding an output, and
- means for summing said outputs of each of said network synthesis means.

5. The stabilization system of claim **4** wherein said impedance network is an RC network.

6. The stabilization system of claim **5** wherein each of said network synthesis means has a transfer function corresponding to a term in a partial fraction expansion of a generalized network transfer function and said plurality of network synthesis means are connected in series.

7. The stabilization system of claim **6** wherein the product of said transfer functions for the first n stages of said network synthesis means (n=1,2,3, . . .) corresponds to a term in a modified partial fraction expansion of said generalized network transfer function.

8. The stabilization system of claim **1** wherein said amplitude modulating means is a chopper.

9. The stabilization system of claim **1** wherein said means for converting the output signal from said power amplifying means into mechanical rotation comprises a synchro motor.

10. The system of claim **9** wherein the means for converting said mechanical rotation into an electrical signal comprises a synchro generator coupled to said synchro motor.

11. The system of claim **10** wherein a tachometer yielding an output is responsive to said synchro motor, and said tachometer output is fed back to said power amplifying means for damping said synchro motor.

* * * * *