United States Patent [19]

Duberley

[11] **3,738,304**

[45] **June 12, 1973**

[54] **SHIP STABILIZATION APPARATUS**

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[22] Filed: **Oct. 26, 1970**

[21] Appl. No.: **84,108**

[30] **Foreign Application Priority Data**

Nov. 3, 1969 Great Britain 53,743/69

[52] **U.S. Cl.** **114/126**, 114/122, 318/585, 318/621

[51] **Int. Cl.** **B63b 39/06**

[58] **Field of Search** 114/121, 122, 126; 235/150.51, 150.53, 183; 318/585, 621; 328/127

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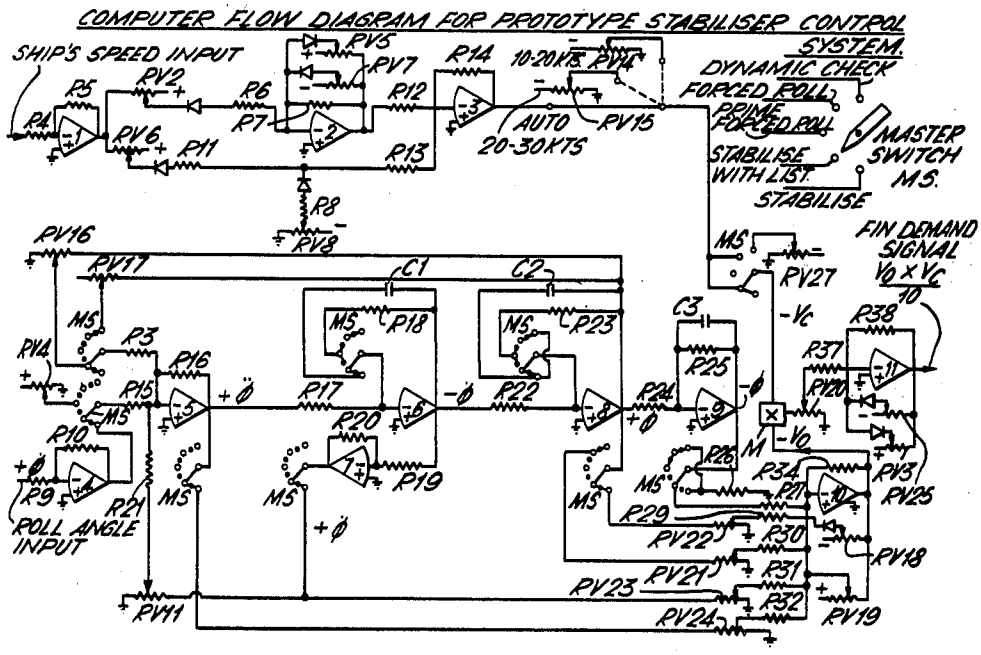
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[57] **ABSTRACT**

The invention is concerned with an anti-roll stabilization system for ships of the kind in which a fin, in operation, protrudes from the ship below the water-line and is angularly displaced about its axis by power means in response to a fin control signal, wherein a primary signal produced by a sensing device responsive to rolling motion of the ship is processed by a configuration of operational amplifiers programmed to produce a fin control signal having the required phase advance, gain/frequency characteristic to position the fin to reduce the rolling moment of the ship.

8 Claims, 4 Drawing Figures



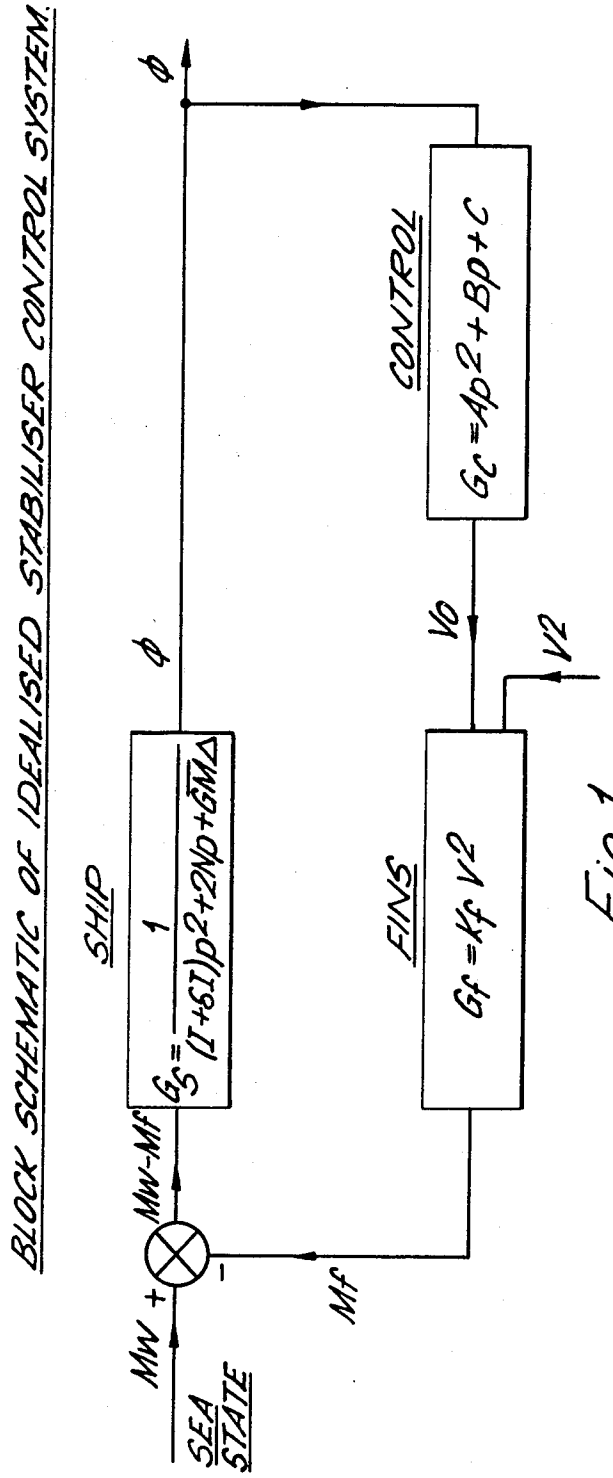

BLOCK SCHEMATIC OF IDEALISED STABILISER CONTROL SYSTEM.
SEA STATE
MW +
MW-MF
SHIP
$G_S = \frac{1}{(I+\delta I)p^2+2Np+\delta M\Delta}$
ϕ
ϕ
MF
FINS
$G_f = K_f V_2$
V_2
V_0
CONTROL
$G_c = Ap^2+Bp+C$

Fig. 1.

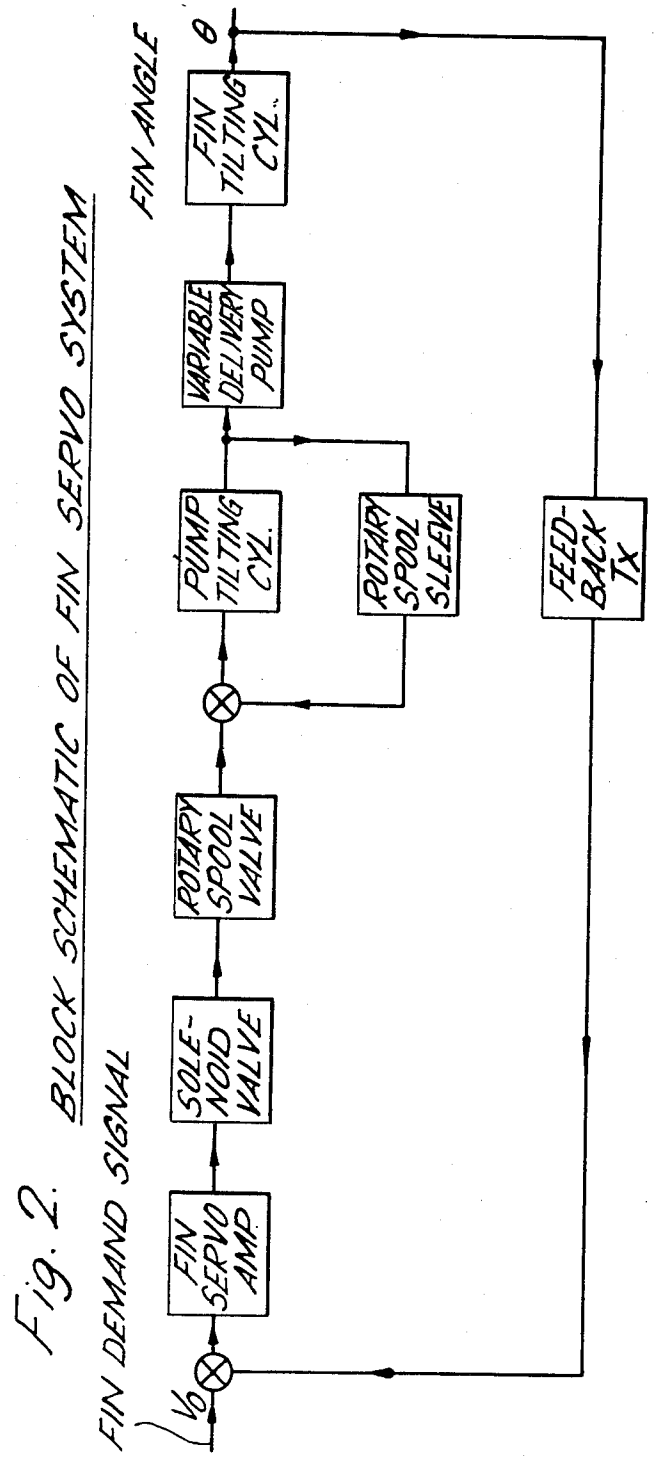


Fig. 2. BLOCK SCHEMATIC OF FIN SERVO SYSTEM

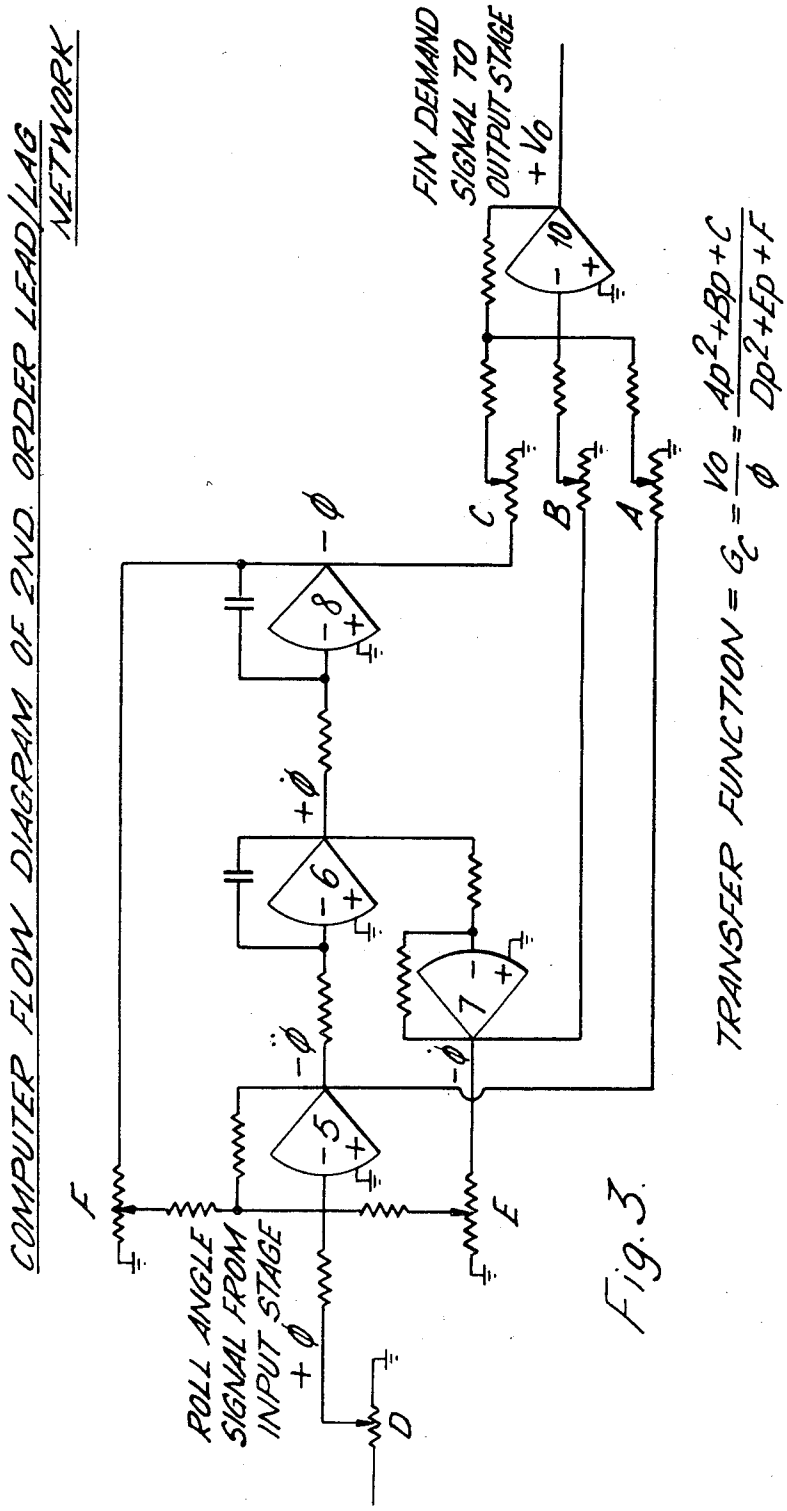
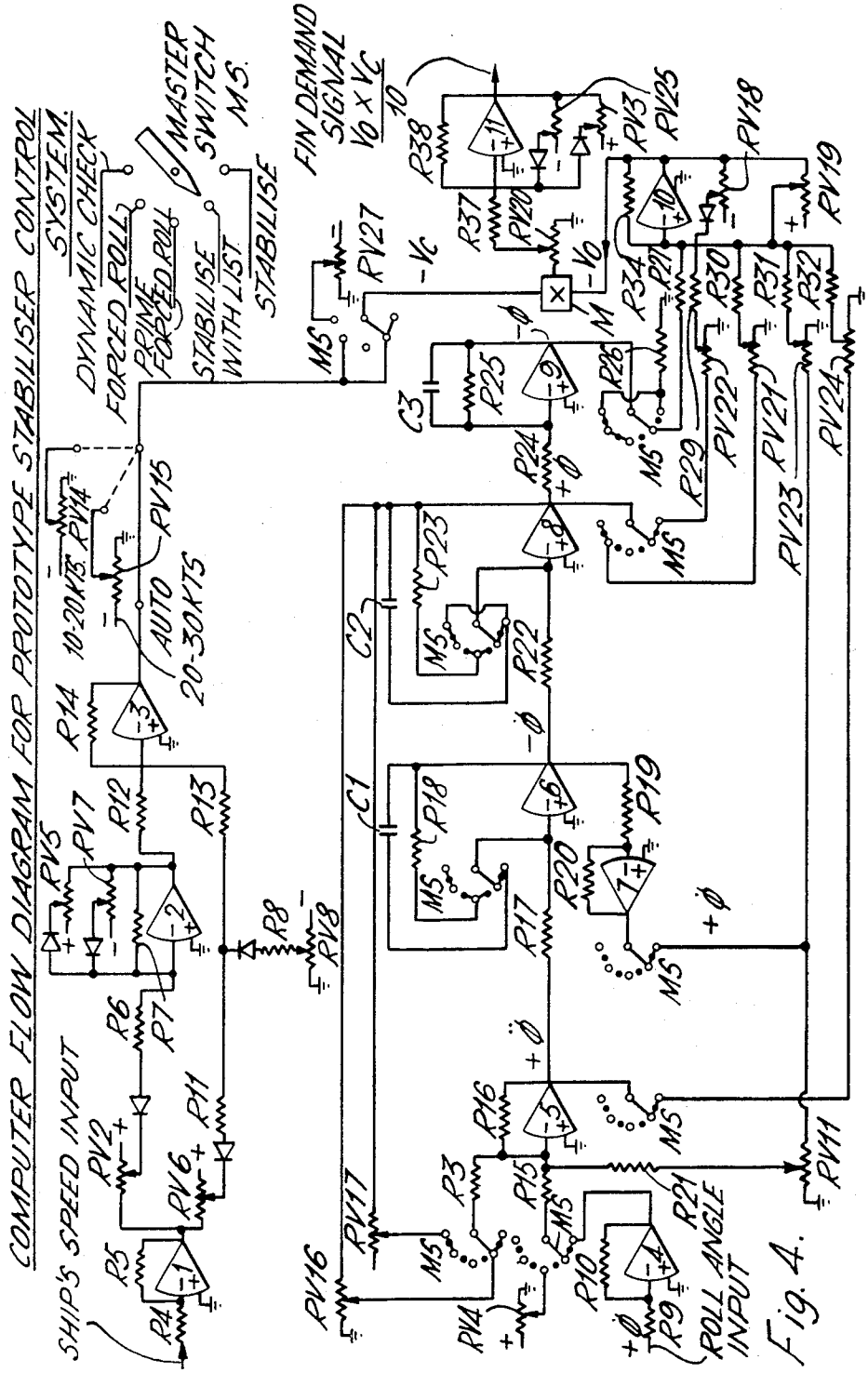

COMPUTER FLOW DIAGRAM OF 2ND. ORDER LEAD/LAG NETWORK
FIN DEMAND SIGNAL TO OUTPUT STAGE + Vo
ROLL ANGLE SIGNAL FROM INPUT STAGE + φ
TRANSFER FUNCTION = Gc = Vo/φ = (Ad²+Bp+C)/(Dp²+Ep+F)

Fig. 3


COMPUTER FLOW DIAGRAM FOR PROTOTYPE STABILISER CONTROL SYSTEM.
SHIP'S SPEED INPUT
DYNAMIC CHECK
FORCED ROLL
PRIME FORCED ROLL
STABILISE WITH LIST
STABILISE
MASTER SWITCH M5.
FIN DEMAND SIGNAL
Vo x Vc
10
10-20KTS
AUTO
20-30KTS
ROLL ANGLE INPUT
-Vc
-Vo
+Vo
-φ
+φ
+φ̇
+φ̈
M1
M5
C1
C2
C3
R3
R4
R5
R6
R7
R8
R10
R11
R12
R13
R14
R15
R16
R17
R18
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R27
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R29
R30
R31
R32
R34
R37
R38
PV2
PV4
PV5
PV6
PV7
PV8
PV11
PV12
PV13
PV14
PV15
PV16
PV17
PV18
PV19
PV20
PV21
PV22
PV23
PV24
PV25
PV27
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
X
Fig. 4.

SHIP STABILIZATION APPARATUS

The present invention relates to ship stabilization apparatus.

While numerous types of stabilizer systems have been tried in the past, the active fin now dominates the market. The reason for this dominance is that the majority of systems in service are installed in warships, passenger liners and ferries, where stabilization at low ship speed is seldom required and under these conditions, the active fin system excels. The active fins, installed in one or more pairs, protrude from the ship's side and develop hydrodynamic lift proportional to their angle of attack. The fins are positioned by an hydraulic servo system, whose motion is ordered by a signal computed from roll angle and its derivations. In an ideal system the stabilizing moment generated by the fins will oppose the rolling moment and the residual roll will tend to zero.

In the known stabilizer system, roll angle is sensed by a vertical seeking gyro, the gimbal of which is coupled to a transducer which gives a signal proportional to roll angle. Roll velocity is measured by a rate gyro with an arthwart-ship axis, the casing of which is spring restrained and damped with a viscous damper. The casing position is proportional to roll velocity and this quantity is measured with a suitable transducer. Roll acceleration is derived from roll velocity, via a mechanical filter and viscous damper, by energizing a motor/tacho-generator set with a signal proportional to roll velocity. The tacho-generator output is proportional to the rate of change of roll velocity i.e., acceleration.

The three signals (angle, velocity and acceleration) are added vectorially in a summing network, in the proportions required to complement the dynamic characteristics of the ship. This combined signal is then amplified before being fed to the fin servo as a fin demand signal.

The present invention is concerned with a new system for generating the required fin control signal. This new system requires only a roll angle (or roll velocity) input signal which is processed using analogue computing techniques to derive a control unit transfer function in terms of roll angle, roll velocity and roll acceleration.

The present invention comprises an anti-roll stabilization system for ships of the kind in which a fin, in operation, protrudes from the ship below the water-line and is angularly displaced about its axis by power means in response to a fin control signal, wherein a primary signal produced by a sensing device directly responsive to rolling motion of the ship is processed by a configuration of operational amplifiers arranged to produce a fin control signal comprising a second order lead/lag transfer function having the required phase advance, gain/frequency characteristic to position the fin to reduce the rolling moment of the ship.

An example of the present invention will now be described with reference to the accompanying drawings, in which:

FIG. 1 is a block schematic diagram of an idealized stabilizer control system;

FIG. 2 is a block schematic diagram of the fin servo system;

FIG. 3 is a computer flow diagram to produce the required control unit transfer function; and

FIG. 4 is a computer flow diagram of the stabilizer control system.

The general linear equation describing the motion of an unstabilized ship is:

$$[(I+\delta I)\ddot{\phi}_o + 2N\dot{\phi}_o + \overline{GM}\,\Delta\,\phi_o] + [\delta I\ddot{\alpha}_2 + 2N\alpha_2 + K\alpha] \quad (1)$$

This equation takes account of the ship's heading relative to the direction of advance of the waves and the effect of this is to vary the frequency and the slope of waves encountered by the ship. If the investigation is confined to sinusoidal beam seas over the frequency band $(\omega_s/4)$ to $2\omega_s$ (where ω_s = natural roll frequency of ship) then equation (1) can be re-written as:

$$[(I+\delta I)\ddot{\phi}_o + 2N\dot{\phi}_o + \overline{GM}\Delta\phi_o] + [\delta I\ddot{\alpha} + 2N\dot{\alpha} + K\alpha] \quad (2)$$

Where α is the effective wave slope, a function of maximum wave slope and ship's draught. The first part of equation (2) gives ship motion in terms of roll angle (ϕ) and the second part the exciting force in terms of wave slope (α).

Now let M_w be the disturbing moment exerted by the waves on the ship. Then the open loop transfer function of the ship may be written as:

$$G_s + \phi/M_w = 1/(I+\delta I)_p 2 + 2N_p + \overline{GM}\,\Delta \quad (3)$$

This shows the transfer function of the ship to be a second order or quadratic lag, with a natural frequency determined by $\overline{GM}$ and Δ and a hydrodynamic damping coefficient with a value of 2N, where:

I = ship inertia about roll axis
δI = added inertia due to entrainedwater
N = hydrodynamic damping coefficient
$\overline{GM}$ = metacentric height
Δ = ship displacement
$\phi, \dot{\phi}$ & $\ddot{\phi}$ = roll angle, roll velocity and roll acceleration
α = wave slope
p = d/dt
M_w = disturbing moment due to waves.

Consider now an idealized system where (*a*) the ship equation is linear (*b*) fin lift is proportional to angle of attack (c) fin servo dynamics are ideal (*d*) the control signal generation process is ideal and gives an uncorrupted signal proportional to roll angle, roll velocity and roll acceleration. These assumptions give the following open loop transfer functions for the ship, control and fins:

$$\text{SHIP} = \phi/M_w\,32\,1/(I+\delta I)_p 2 + 2N_p + \overline{GM}\,\Delta \quad (4)$$

$$\text{CONTROL} \quad = Vo/\phi = Ap^2 + B_p + C \quad (5)$$

$$\text{FINS} \quad = M_F/Vo = K_F\,V^2 \quad (6)$$

Where A = acceleration control term sensitivity
B = velocity control term sensitivity
C = angle control term sensitivity
V_o = controller output signal to fin servo
M_F = stabilizing moment exerted by fins
K_F = fin moment per unit ship's speed
V = ship's speed

FIG. 1 shows equation (4) (5) and (6) in block diagram form and the closed loop transfer function of this system may be derived as:

Closed loop transfer function = forward transfer function/1 + open loop transfer functions. $\therefore \phi/M_w = Gs/1 + Gs\,Gc\,Gf = Gs\,(1\ /1 + Gs\,Gc\,Gf)$ (7)

By substitution, this closed loop transfer function can be written as:

$$\frac{\phi}{M_w} = \frac{1}{[(I+\delta I)+AK_FV^2]-p^2+(2N+BK_FV^2)p+(GM\Delta+CK_FV^2)} \quad (8)$$

Equation (8) shows some significant facts about the dynamic behavior of this idealized stabilizer control system.

The system is basically stable and increasing the sensitivity of the acceleration, velocity and angle terms reduces roll angle. Increasing the acceleration term (A) increases the apparent inertia. Increasing the velocity term (B) increases the apparent hydrodynamic damping. Increasing the angle term (C) increases the apparent restoring moment. The sensitivity of the acceleration, velocity and angle terms increases as the square of ship's speed (V^2).

Unfortunately the performance of this idealized system cannot be realized in practice and in particular, the control signal generation process and the fin dynamic performance both fall short of the ideal.

The stabilizer system is a large regulator system that comprises (a) the ship (b) the control system and (c) the fin servo system. As a stabilizer system, it is required to reduce roll angles to near zero, despite the sea disturbing moment. This is achieved by using a relatively small electrical control signal to control the powerful fin servo system, whose fins utilize the ship's propulsive power to produce the required stabilizing moment.

The power to position the fins is usually obtained from a variable displacement hydraulic pump and it transmits its power to the fins by means of change of fin angle which is proportional to fin servo error signal, and fin angle is fed back to the servo input to form a closed loop. A block schematic of a typical fin servo is shown in FIG. 2. The natural frequency of the fin servo loop (ω_F) is usually arranged to be well above the ship's natural frequency (ω_s).

The lifting force (L) produced by a single fin is:

$L = \int A V^2/2 K_L$ per unit angle of attack. The moment produced by a pair of fins acting at effective radius (R) is:

$MF = 2R$ per unit angle of attack or $MF = \int ARK_LV^2 \phi$ (9)

where $\int$ = specific density of working fluid

A = area of fins

K_L = lift coefficient

R = effective radius of fins

V = ship's speed

MF = moment produced by fin

ϕ = angle of attack of fin.

Equation (9) shows that the moment (M_F) produced by the fin is proportional to the angle of attack (ϕ) and in addition, increases as the square of ship's speed (V^2). The linear relationship between fin moment and angle of attack only holds true up to a limited fin angle and thereafter, falls off because of fin cavitation effects. Furthermore, the fin angle of attack at which cavitation commences, decreases as ship's speed increases and consequently, if stabilization is required over a wide speed range, fin angles should be progressively limited as ship's speed increases.

It has been shown that the ideal transfer function for the stabilizer control unit is a second order lead of the form shown in equation (5). If a lead/lag can be generated in which the lag component is small in comparison with the lead, then the transfer function will approximate to that of a second order lead. If, in addition, the sensitivity terms can be made non-interacting, then the task of optimizing control sensitivities will be simplified. The transfer function described would have the form (where D, E, & F are the lag coefficients):

$$Gc = \frac{V_o}{\phi} = \frac{(A_P^2+B_P+C)}{D_P^2+E_P+F} \quad (10)$$

The generation of this transfer function, using D.C. operational amplifiers, forms the basis of the present roll stabilizer control system.

Equation (10) can be realized with the computer network shown in FIG. 3, and where the simplest form of stabilizer control will suffice, this arrangement, with suitable input and output stages, will generate the required stabilization control signal. When additional facilities are required, such as stabilize with list, forced roll, automatic speed compensation, etc, then the signal generation process becomes more complex. The addition of these facilities to the basic system are discussed later.

The second order lead/lag network using operational amplifiers **5, 6, 7, 8** and **10**, shown in FIG. **3**, requires only a roll angle input signal and, from this, functions of roll angle, roll velocity and roll acceleration are produced and scaled in the proportions required to complement the dynamic characteristics of the ship. A positive roll angle signal is applied to the input of operational amplifier **5** together with the negative roll angle signal fed back from the output of operational amplifier **8** and the negative roll velocity signal produced in operational amplifier **7** to produce a resultant negative roll acceleration output which is then integrated by operational amplifier **6** to give a positive roll velocity signal output which is then, in turn, integrated by operational amplifier **8** to produce a negative roll angle signal output. Operational amplifier **7** is a sign reversing amplifier converting the positive roll velocity signal output of operational amplifier **6** to a negative roll velocity output signal so that the functions of roll angle, roll velocity and roll acceleration produced are all of the same sign so that they can be summed. Potentiometers A, B, and C adjust the roll acceleration, roll velocity, and roll angle sensitivities respectively. Potentiometer F adjusts the natural frequency and potentiometer E adjusts the damping of the lag portion of the transfer function.

A computer flow diagram of the stabilizer control system is shown in FIG. **4**. Operational amplifiers **5, 6, 7, 8** and **10** together with their associated components comprise the control transfer function computing network shown in FIG. **3**, operational amplifier **4** being an input stage buffer amplifier provided to match the input roll angle signal to operational amplifier **5**. To avoid overloading the operational amplifiers in the computing network, in the presence of very large roll angle input signals, the input stage is designed to saturate when the roll angle exceeds some specified amplitude. Additional precautions can be taken against overload by limiting the output voltage in some of the amplifiers by using pairs of diodes in the feedback path.

Theoretically, the stabilizing moment generated by active fins is proportional to (ship's speed)^2 and since the fins form part of a closed loop system, it follows that the closed loop gain of the system will increase as (ship's speed)^2. If this change in gain is not compensated loop instability is likely to occur at high ship's speed. To maintain the loop gain constant over the

speed range of the ship the loop gain must be reduced as the reciprocal of (speed)^2 i.e., $1/V^2$.

To achieve the required changes in gain to maintain loop stability, a signal derived from the ship's log which is proportional to ship's speed is shaped in a computing network including operational amplifiers **2** and **3** (FIG. **4**). This characterized speed signal (Vc) is then fed into a multiplier *M* together with the fin demand signal (Vo) wherein the two signals are multiplied together. The gain of the fin loop is thus modified in the multiplier by the characterized speed signal and this automatically compensates the stabilizer loop gain as a function of ship's speed.

In the event of a failure of ship's speed signal, a high (20–30 knots) or low (10–20 knots) speed signal, can be selected from RV **15** or RV **14** (FIG. **4**) and fed into the multiplier in place of the characterized speed signal. Operational amplifier **1** is an input stage buffer amplifier matching the ship's speed input signal to the computing network. Potentiometer RV **20** adjusts the overall loop gain to vary the magnitude of the fin demand signal and operational amplifier **11** matches this signal to the fin servo system.

If a ship developes a natural list due to trim or wind conditions the stabilizer system will attempt to keep it in a true vertical position by applying an appropriate amount of fin angle. This causes the fins to operate about a datum other than zero and results in unnecessary drag to forward motion. Natural list compensation is produced by switching master switch MS to the stabilize with list position which enables stabilization to take place about the natural list datum rather than the true vertical. The 'list' signal is produced by averaging the roll angle signal in operational amplifier **9**, (FIG. **4**) this being an amplifier with a large time constant (100 seconds) which is large compared with the natural period of the ship and the resultant signal is then subtracted from the roll angle signal in operational amplifier **10**. This effectively introduces a new datum about which the stabilizers operate.

For some applications, provision must be made in the control system to force roll the ship in calm seas by means of the stabilizer fins. This is achieved by switching to the forced roll position in which the operating mode of amplifiers **5, 6, 8** and **10** (normally lead/lag network) form a sine wave generator. The output amplitude of the generator is preset by RV **4**; this determines the initial conditions on capacitors C **1** and C **2** when 'prime forced roll' is selected on the mode switch. In the 'forced roll' mode the generator will oscillate with a constant amplitude at a frequency determined by RV **17**. The forced roll frequency is normally adjusted to be equal to the natural roll frequency of the ship i.e., within the range 8 seconds to 20 second period. The generator output signal is scaled in amplifier **10**, and RV **21** enables forced roll amplitudes to be adjusted between zero and maximum. The speed compensation remains operative in the 'forced roll' mode so that maximum permitted fin angles are not exceeded at high ship speeds.

Static and dynamic check facilities are incorporated into the control system described and these enable functional and fault-finding tests to be carried out without the need for external test equipment. Calibration signals can be fed into the lead/lag and speed compensation networks, via biased toggle switches, and the steady state output of each operational amplifier checked on a built-in DC voltmeter (not shown).

In the 'dynamic check' mode, produced by switching to the 'Dynamic check' position, amplifiers **5, 6, 8** and **10** are switched to sine wave generator configuration, and in addition, a 10 volt signal is applied to the multiplier from RV **27** in place of the normal output signal from the speed compensation network. The resulting sinusoidal fin demand signal can be fed to each fin, in turn, and the dynamic response observed on the DC voltmeter.

When the system is in use in the 'stabilize' mode, each fin movement can be monitored on the DC voltmeter by selecting the appropriate position on a fin monitor switch (not shown).

An alternative method of generating the required stabilization signal for ship stabilization apparatus has been evolved. The requires only a roll angle input signal into an operational amplifier computing network. The new control system can also incorporate additional features such as automatic gain compensation, automatic fin limiting, natural list compensation and forced roll facilities.

I claim:

1. An anti-roll stabilization system for ships of the type in which a fin, in operation, protrudes from the ship below the water-line and is angularly displaced in response to a fin control signal comprising:

means for detecting the ship roll angle and producing an electrical roll angle signal which varies as a function of roll angle,

circuit means for receiving said roll angle signal and having a second order lead/lag transfer function for producing an electrical fin control signal,

means for detecting ship speed and producing an electrical ship speed signal which varies as a function of the inverse square of the ship speed and

means for receiving and multiplying said fin control and ship speed signals to produce a further control signal.

2. An anti-roll stabilization system according to claim **1** in which the gain of the fin control signal is varied inversely as the square of the speed of the ship.

3. An anti-roll stabilization system according to claim **2** in which a signal inversely proportional to the square of the speed of the ship is produced in a configuration of operational amplifiers and is then fed into a multiplier together with the fin control signal wherein the two signals are multiplied together.

4. An anti-roll stabilization system according to claim **3** in which, in place of the signal inversely proportional to the square of the speed of the ship, a signal is derived from one or more preset potentiometers the voltage across each of which is adjusted to give a signal corresponding to a range of ships' speed.

5. An anti-roll stabilization system according to claim **3** wherein the input stage of the configuration of operational amplifiers is designed to saturate when the primary signal exceeds some specified amplitude.

6. An anti-roll stabilization system according to claim **5** wherein the output voltage of some at least of the operational amplifiers is limited by using pairs of diodes in the feedback path.

7. An anti-roll stabilization system according to claim **3** in which compensation is made for the natural list of the ship about its roll axis by subtracting within a configuration of operational amplifiers from the roll angle

signal produced therein a signal produced by averaging the roll angle signal in an operational amplifier having a time constant which is large compared with the natural period of the ship.

8. An anti-roll stabilization system according to claim 3 in which the operating mode of the operational amplifiers normally forming the lead/lag network in the configuration of operational amplifiers may be switched to form a sine wave generator thereby producing a fin control signal producing forced rolling of the ship.

* * * * *