"CONSTANTIN BRÂNCUSI" UNIVERSITY – ENGINEERING FACULTY
UNIVERSITY'S DAY
8 th INTERNATIONAL CONFERENCE
Târgu Jiu, May 24-26, 2002
Târgu Jiu, Geneva Street, nr.3, 1400, Gorj, România,Tel.+4053215848, Fax+4053214462, www.utgjiu.ro

STABILISERS AND STABILISING SYSTEMS ON SHIPS

Gheorghe SAMOILESCU, Asso. prof. ph. eng.*
Serghei RADU, eng.(marine first electric engineer)*

Naval Academy "Mircea cel Batran", Constantza

ABSTRACT: Over the past twenty-five years, the stabilizer has become increasingly popular as a standard fitment for ships, especially on passenger/ vehicle carrying ships and on certain classes of warships. Attempts to reduce the rolling motion of a ship date back more than a century but not until 1936 was fully practical solution to the problem achieved when Brown Bros of Edinburgh and William Denny and Bros of Dumbarton successfully installed fin stabilizers on the steamer "Isle of Sark". Following this, the design rapidly gained favor over the clumsier, bulkier and less practical devices of earlier years. During the 1939-45 War, for instance, over one hundred ships in the Royal Navy were fitted with stabilizers to improve gunnery. After 1950, stabilizers were installed in increasing numbers on merchant ships.

1. Introduction. A ship at sea has six degrees of freedom, i.e. rolls, heave pitch, yaw, sway and surge. Of these, only roll can effectively be reduced in practice by fitting bilge keels, anti-rolling tanks or fin stabilizers. A combination of fins and tanks has potential advantages in prime costs and effective stabilization at both high and low speeds. Since a ship is a damped mass elastic system, it has a natural rolling period and large rolling motions may be induced by resonance with relatively small wave forces. Large resonant rolls can be avoided by generating forces equal and opposite to the impressed sea force.

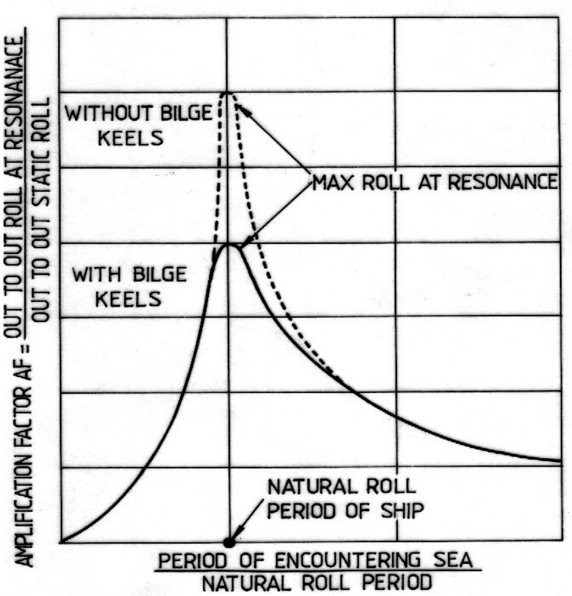

Figure 1. Amplification factor

Fig.1 shows that the roll amplitude at resonance is much greater than that at long wave periods. The ratio of these amplitudes is the dynamic amplification factor, which is limited by the inherent damping of the ship, i.e. viscous damping and the action of bilge keels.[1]
The control system for the fin stabilizer can be classified as electro-hydraulic. On the electrical side, it includes heavy electrical gear (motors, starters, solenoid valves, etc.), very sensitive electromechanical sensors and sophisticated electronic circuitry.

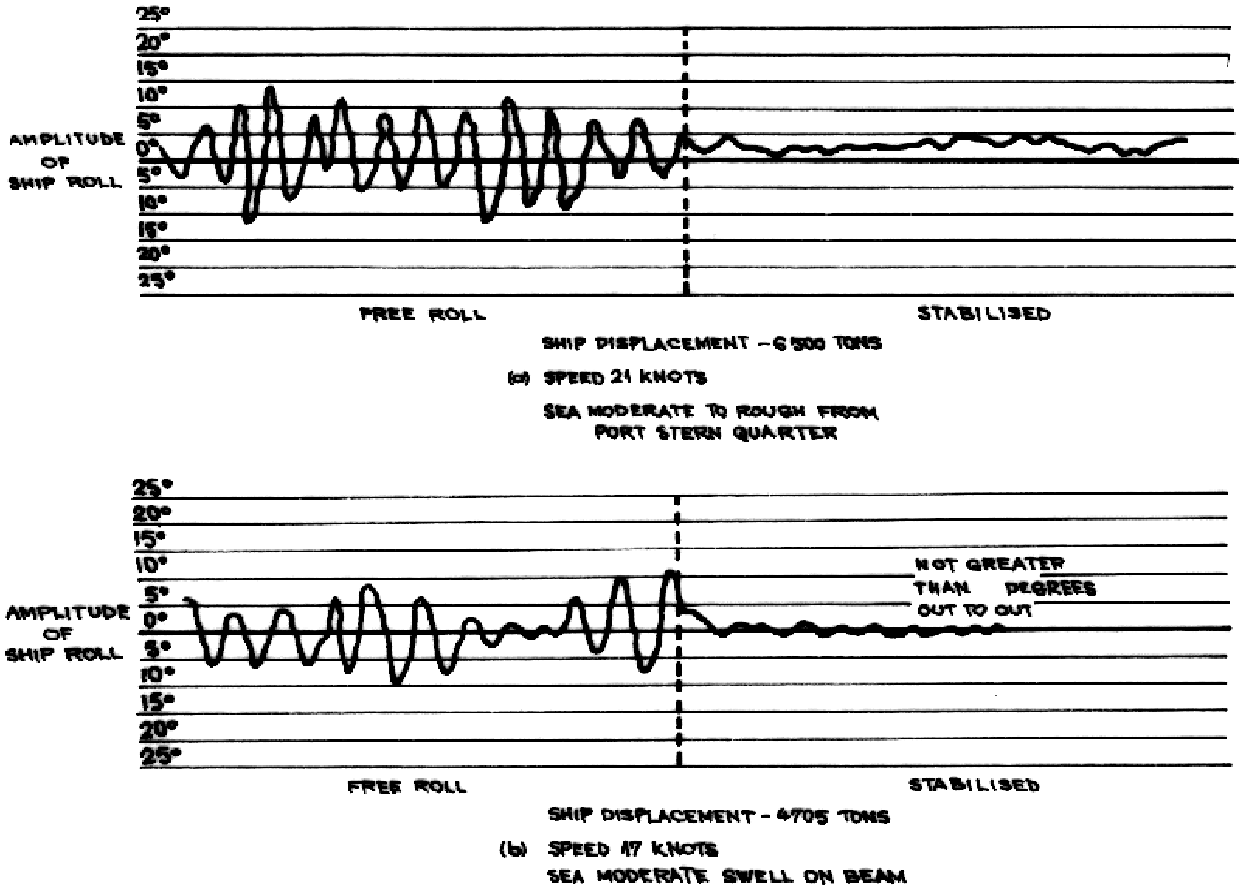

Figure 2. Roll and roll damping curves

Fig.2 shows roll and roll damping curves for two ships in various sea conditions, and obtained results with stabilizers.[2]

2. Beam sea/Following sea control. Early stabilizer control systems were designed on assumption that rolling is the result of one of two distinct types of the sea state, ”Beam Sea” or “Following sea. Under “Beam Sea”, the tendency is for the ship to roll heavily at its own natural period especially if the natural period of the waves matches that of the ship. Stabilization action in this case amounts to true damping of the periodic motion, i.e. fin position should be such as to oppose roll motion. In practice, some roll angle (actually about – 10%) is added to roll velocity to effect a phase advance of the velocity signal and thus make up for the time lag between the initiation of a control movement of the fins and their actual movement.
Fig.3 (a) shows the curves used for “Beam Sea” control, i.e. actual roll, a 10% inverted roll, and roll velocity (the latter to a slightly reduced scale).
In the “Following Sea” conditions, the ship has a tendency, in addition to its own period of roll, to lie over on the contour of the waves in an irregular manner. Stabilization here must include action to restore the ship to an upright position in addition to damping out of the

periodic motion. Roll velocity is combined with a percentage of the non-inverted roll angle signal to produce a control signal which lags behind the pure damping (i.e. velocity) signal. The amount of lag is adjusted by varying the percentage of roll used. Fig.3 (b) shows the curves when 63% roll angle is combined with roll velocity.

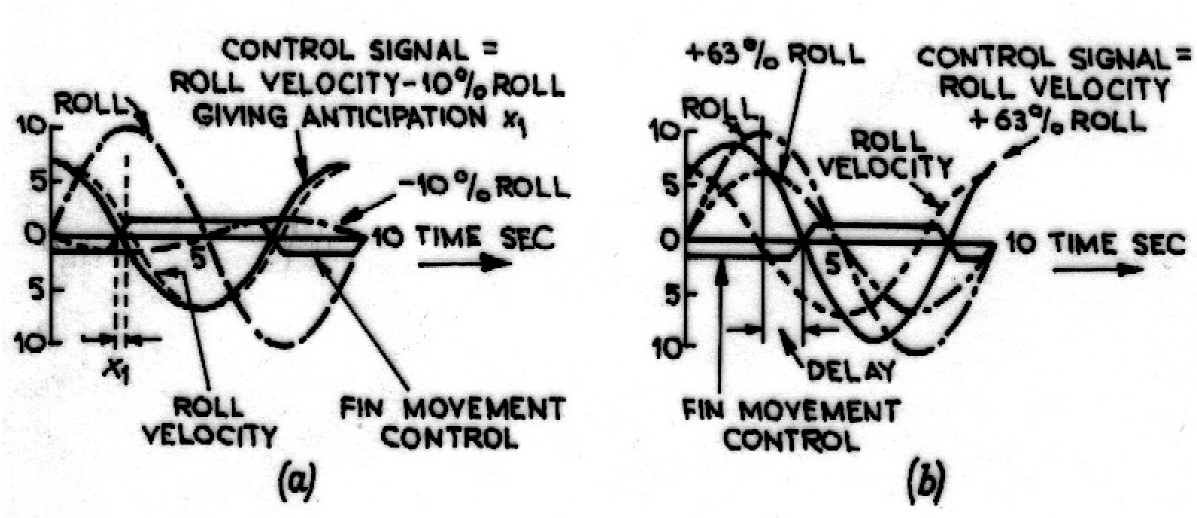

Figure 3. Basis for (a) beam sea control and (b) following

On occasions when sea conditions were neither entirely “Beam” nor “Following” the choice of which type of control mode to put into operation was left to the navigator.

The sensing elements of the Beam / Following Sea control system are two 150mm diameter gyroscopes, one a vertical keeping gyro and other a velocity sensitive gyro (Fig.4).

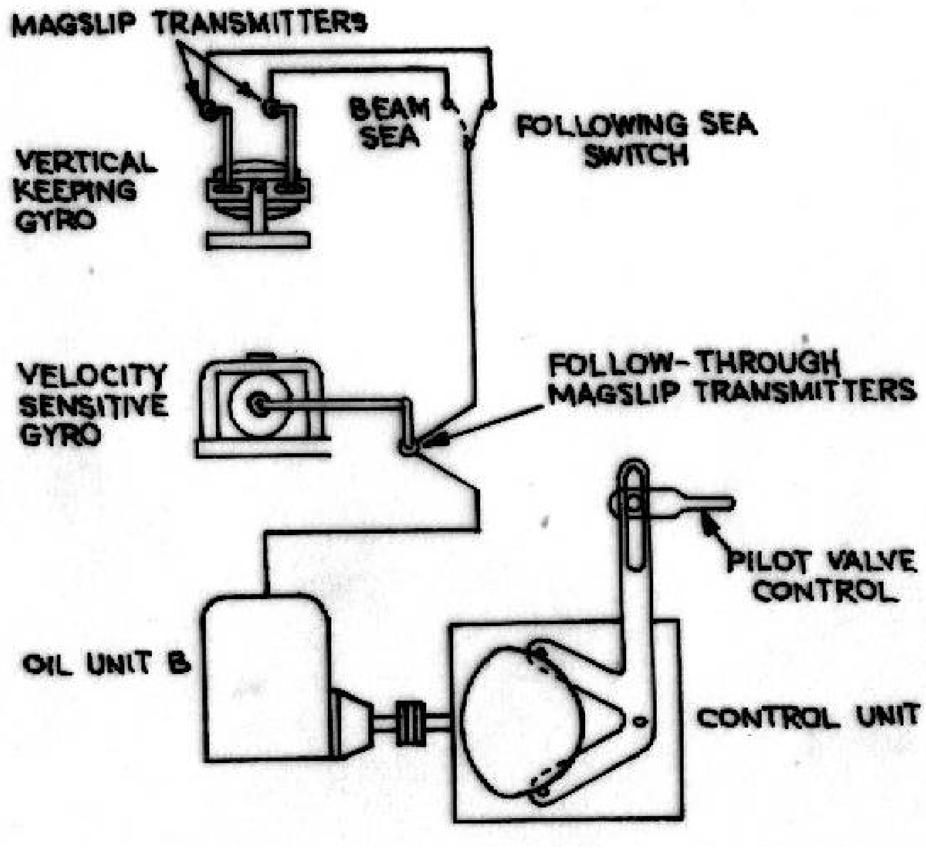

Figure 4. Original control

The former is a pendulous wheel, which is provided with automatic means for keeping it vertical when, upset by ship acceleration, ship turning, etc. The velocity sensitive gyro has its spin axis against centralizing springs, the deflection of the springs being proportional to the angular velocity of roll. Magslip transmitters convert the motions of each gyro unit into electrical signals. These are then summed by a follow-through transmitter magslip and applied to an ARL Type B hydraulic unit. Two magslip transmitters are provided for the vertical keeping gyro so that the different roll angle signals required for Beam and Following Sea can be selected as appropriate.
The hydraulic unit acts as an amplifier, converting the low power electrical signals into hydraulic power sufficient to actuate the hydraulic pumps operating the fins.

3.Fin stabilizers The stabilizing power of fins is generated by the "lift" on "airfoil" sections which may be all-moveable, with or without flaps or partly fixed, partly moveable. These fins are tilted, usually hydraulically, in phase with the roll at long wave periods, 90° out of phase at resonance and in phase with roll acceleration at short periods.[3]
Non-retractable fins are commonly used where space within the hull is limited. They are usually fitted at the round of the bilge and do not project beyond the vertical line from the ship's side or the keel line, to minimize the risk of contact with a quay wall or the sea bottom. The fin shaft, to which the fin is rigidly attached, passes through a sea gland in a mounting plate welded or bolted to the hull and is supported by two substantial bearings. A double-ended lever keyed to the inner end of the fin shaft is actuated by two hydraulic rams supplied from an electrically driven pump.
Control of fin movement is automatic and is usually derived from gyroscopic sensing gear which, in its simplest form, Velocity Control, is based on one small, electrically driven gyroscope mounted horizontally with its axis athwart-ships. The angular velocity of roll of the ship causes the gyroscope to process against centralizing springs to an amount proportional to the velocity and generates a small force which is hydraulically amplified by a hydraulic relay unit to provide power sufficient to operate the controls of the variable delivery pump via suitable linkage. Part of the linkage is coupled to the fin-shaft to transmit a canceling signal to the pump control and to bring the fin to rest at the angle of tilt demanded by the sensing unit. This type of control is often fitted in small installations, usually for economic reasons, and is most effective against resonant rolling.
Ships seldom roll in a purely resonant mode: the sea state is often highly confused. More elaborate, and more expensive, control systems are required to deal with suddenly applied roll, rolling at periods off resonance and rolling in conditions arising from the combination of several wave frequencies. A sensing unit based on a vertical-keeping gyroscope coupled into differentiating and summation units enables fin movement to be controlled by a composite function derived from roll angle roll velocity and roll acceleration. By adding a "natural list" unit, stabilization is achieved about the mean point of roll and so reduces both propulsion and stabilizing power demand. This is known as a compensated control system, (Fig.5), and is generally used in large installations.

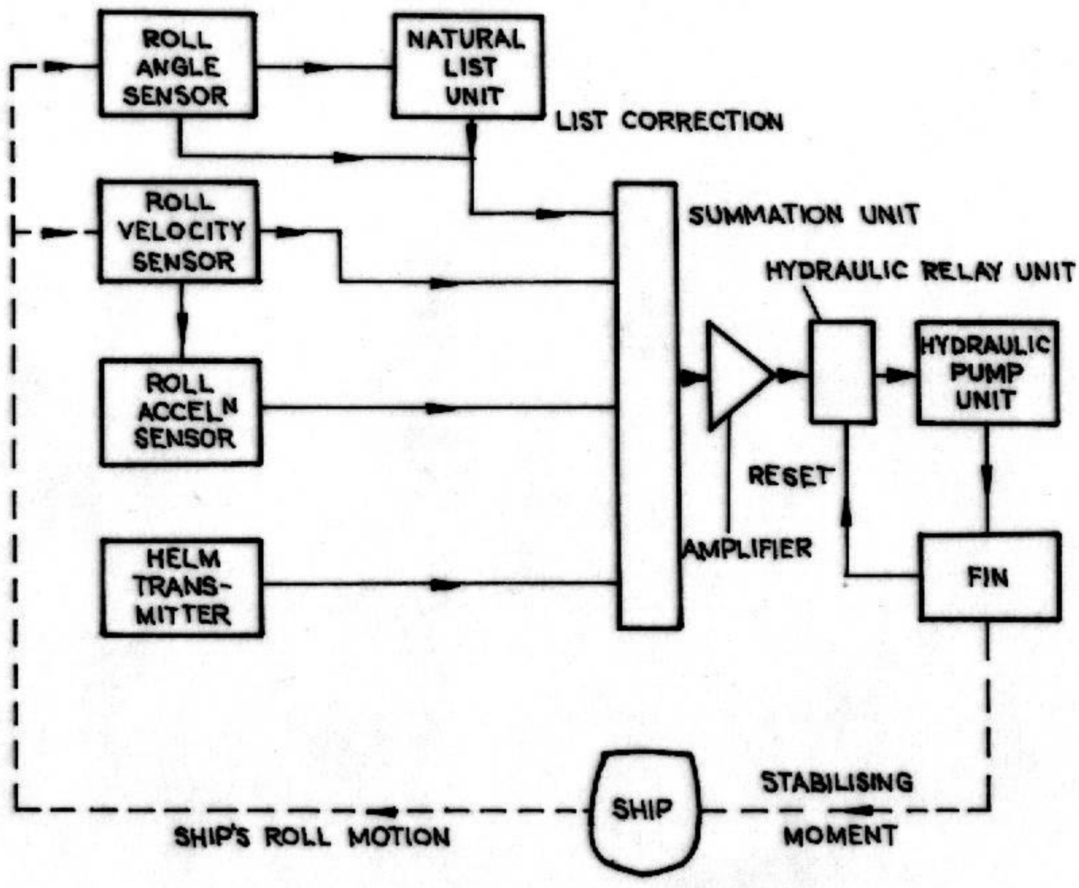

Figure 5. Principles of Multra control system

4. Multra Control System by Muirhead In the Multra Control Systems, fin movement is a function of:

1. Roll angle.
2. Roll velocity.
3. Roll acceleration.
4. Natural list.
5. Ship speed, if a speed control unit is employed.

Roll acceleration this control function opposes the commencement of any rolling motion. It is particularly effective in “confused sea” conditions or when the ship is acted upon by large irregular waves. The control signal is derived from the velocity gyro by measuring the angular velocity at which the velocity gyro precesses about the vertical axis. Position sensor **P1** provides the input to a simple position servo, the position driver being servomotor **M** and feedback loop via sensor **P2**. The output of tacho generator **T** is proportional to the angular velocity of **P1**, which, of course, is roll acceleration. (Fig.6)

Natural list this control function allows the vessel to stabilize around a listed position (to avoid propulsive power being wasted using the stabilizers to correct for list). This control signal is obtained by applying the roll angle signal to a position servo with a long time constant and using the steady list output to modify the roll angle signal (Fig.7).

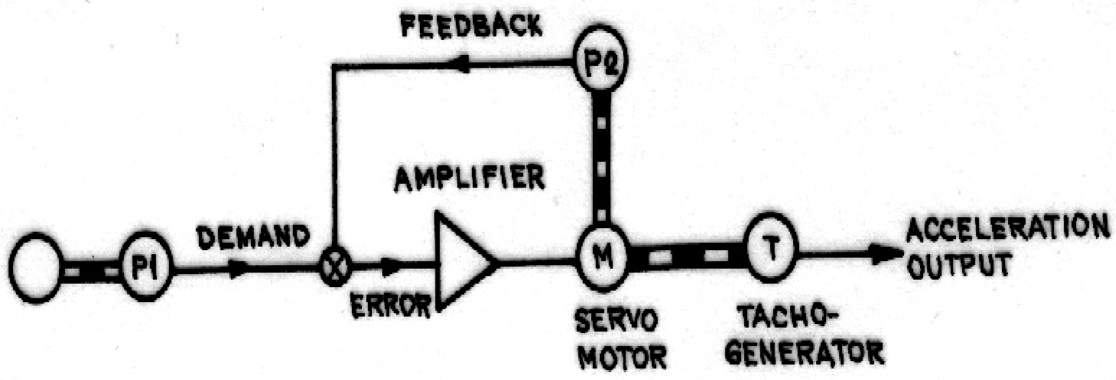

Figure 6. Roll acceleration

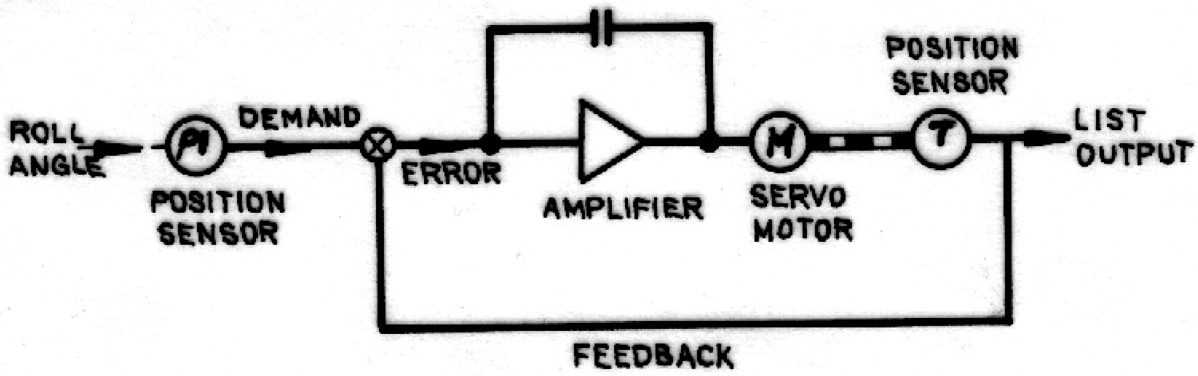

Figure 7. Natural list

Ship’s speed control (fin angle reduction) to a first approximation, the hydrodynamic forces on the fin are proportional to the square of the forward velocity of the ship, hence at higher speeds the generation of a given restoring couple requires a smaller fin tilt angle. In some ships, to avoid over-correction and unacceptable cyclic stressing of the fin shaft as the fin oscillates; a fin angle/speed control system is necessary. This automatically reduces the angle to which the fin is tilted as the ship’s speed increases. The reduction is so arranged that the lift generated by the fins remains constant and the speed at which reduction starts is known therefore as the “design” speed.

The ship’s log signal is used as an input to control the necessary reduction in output from the gyro unit when operating above the “design” speed. A fail-safe facility brings maximum fin angle reduction into operation if the ship'' log should fall below a certain level. This will come into operation if the ship'' log fails (or if the ship is travelling too slowly for the fins to be of use anyway).

Hydraulic relay unit. Several stages of improvement have been made to the hydraulic relay unit since the type B unit of the Beam/Following Sea control system (which had the disadvantage of providing rather harsh control of the main pumps).

The unit is a sensitive, two-stage hydraulic amplifier, which produces sufficient power to operate the tilt mechanism of the VSG pump. Two noteworthy refinements of the unit are a dither drive (to eliminate static friction), and a hydraulic accumulator (to reduce the size of the driving motor and pump yet still obtain a rapid step function response).

Roll reduction in excess of 90%, typically 30° out to out reduced to less than 3° out to out, can be achieved at resonance and low residual rolls can be maintained over a wide range of frequencies. However, since the stabilizing power varies as the square of the ship's speed, fins are least effective at low or zero speed where they function only as additional bilge keels.
Retractable fins fall into two classes, those that extend and stow athwart-ships and those that hinge into a fore-and-aft stowed position.
In the athwart-ship-retracting type, the fin-shaft has a tapered outboard end to which the fin is keyed. The parallel inboard end passes through a sea gland on the inboard face of the fin box and is supported by two bearings. One, close to the inboard end of the fin, is carried in a heavy crosshead, arranged to slide in top and bottom guides with the fin box and the other in a crosshead slideably mounted on the extension guides, within the hull. The hollow bore of the parallel section of the fin-shaft houses a double-acting piston to act as housing and extending gear. Tilting of the fin is by two or four hydraulic cylinders, which may be of the simple oscillating type or arranged on the Rapson-slide principle as used for steering gears. Power units, control and sensing equipment are as for non-retractable fins.
In hinged or folding type, the fin-shaft is rigidly fixed into the crux, which has two heavy trunnions disposed vertically and housed in bearings top and bottom to the fin box. The fin is free to oscillate on the fin-shaft and a vane type motor the stator of which is secured to the crux provides the tilting force and the rotor keyed to the fin through a flexible coupling. The van motor is housed in an oil-tight casing secured to the fin and is provided with a sea gland bearing on a sleeve fitted to the crux. The whole of the casing and the fin is full of oil under pressure to prevent the ingress of seawater.
A double acting-oscillating cylinder connected to the upper trunnion achieves housing and extending the fin. Power units, control and sensing equipment are generally similar to the other types of stabilizers except that feedback of fin angle is accomplished electrically by synchros.
The fin and fin-shaft are integral structures supported on taper roller bearings, which are carried in the fin housing. Movement of the fin-shaft to tilt the fin is effected by means of a cylinder tilting mechanism with a double acting piston. The fins are rigged out for operation from the stowed position by rotation of the fin housing about the rigging axis, in upper and lower bearings in the fin box.[3], [4].
The Muirhead New-Multra systems comprise their own attitude sensors. Fin movement is a function of the same control parameters used in the system previously described, with the exception of helm correction, the desirability for which was considered marginal. Ship's speed control is included as part of the new system. The principal change in the system is the control unit. This has been redesigned and simplified for greater reliability by using electronic analogue computer techniques. The vertical gyro has been dispensed with, roll and roll acceleration being produced by electronically integrating and differentiating the roll velocity signal. Only two synchros for picking up the roll velocity signal from the rate gyro. The output from the unit is a modulated 60 Hz carrier signal suitable for driving a hydraulic relay unit, or fin control unit for operating an electro-hydraulic servo-valve. Where possible, it is preferable to use the electro-hydraulic servo valve because one time delay in the system is eliminated. However, not every installation is adaptable to the direct use of an electro-hydraulic servo-valve, particularly where a mechanical input is required, and there the hydraulic relay unit is used. A feature of the system is that it operates from one power supply only, single phase. No supplies at other frequencies or d. c. are necessary. Because the control unit no longer utilizes a vertical gyro, stabilization is about the mean or natural list position. List correction is available, if it is required to operate the ship stabilizing with respect to the vertical. This is provided from a heavily damped pendulum system in the control unit with a synchro picking off the angle between the pendulum and the ship's structure. This signal can be switched to the summation unit within the controller to appropriately modify the roll angle.

A switch is provided to enable the vessel to be force rolled. The method of doing this in the original system was by no means of a linear variometer in series with the fin control signal acting as an induction regulator and rotated mechanically by a cam lever system driven by a servo system controlled from the ship's log output signal. In the new system a linear variometer (i. e. a device giving an out put voltage directly proportional to roll angle when coupled to a gyro) is used in the ship's log to provide the speed signal. The speed attenuation is obtained in an electronic potential divider. Speed parameters in the circuit are adjusted on test so that the attenuation commences at the design speed and provides the correct output voltage over the specified speed range. To make up the gain lost in the potential divider, an amplifying stage employing an operational amplifier is incorporated. A "fail safe" feature is included in the circuit to prevent overloading of the fins in the event of failure of the log signal. As an alternative to the hydraulic relay unit which provides a mechanical output for operating the pilot valve of the main fin hydraulic machinery, a fin control unit, may be used which will drive an electro-hydraulic servo valve directly. The unit takes the fin control signal from the control unit and the fin angle signal from the fin transmitter box to derive an error signal, which is phase sensitively demodulated and amplified to give a voltage suitable for operating the electro-hydraulic servo valve.[5], [6]
For small vessels only roll velocity is used as a control signal which can still provide good stabilization, especially at, or near, the ship's period so the control unit essentially contains a velocity gyro unit with synchro coupled to it giving a signal suitable for feeding on to either a hydraulic relay unit or a fin control unit. Speed compensation is again available if required.

5. Denny Brown Stabilizers Control unit (**Fig.8**) is based on the use of an angular accelerometer rather than a gyro as the sensing device for roll motion. The accelerometer output, which is proportional to the roll acceleration of the ship, is integrated once to obtain roll velocity then a second time to obtain roll angle. The three signals, roll acceleration, roll velocity and roll angle, provide all the information about the ship's rolling motion necessary to obtain optimum roll reduction.

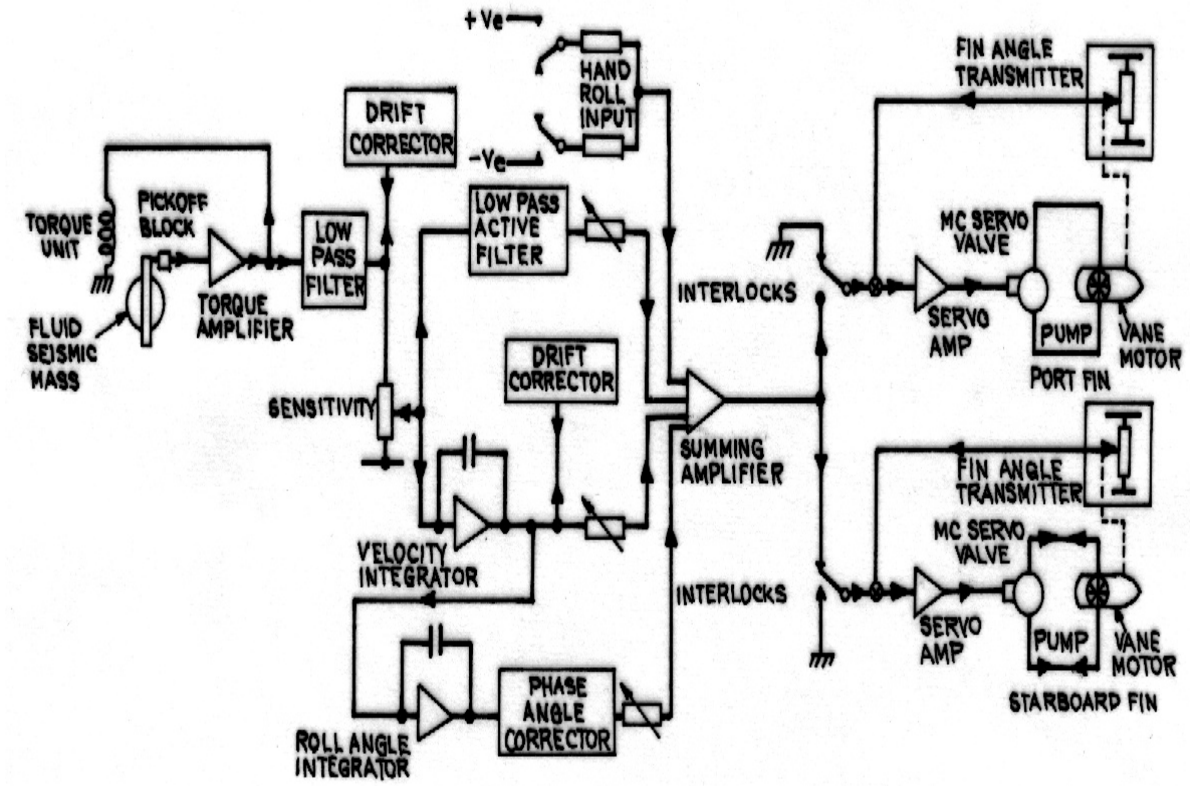

Figure 8. Block diagram of the Denny Brown stabilizer control system

The low range angular accelerometer incorporates an annular tube or toroid filled with a sensing medium of silicone fluid for use as the seismic mass. A small “paddle” block the tube and an inductive type of pick off senses the positions of the “paddle” as it is pushed by the inertial mass when the accelerometer rotates. This pick off signal is fed to a servo amplifier which, in turn, drives a torque coil forcing the paddle back to its central position and thus exactly countering the force applied to the “paddle” by the fluid.

Since the torque is servo controlled, an electrical signal output is generated which is exactly proportional to the acting angular acceleration.

Conventional integrating circuits, employing high gain operational amplifiers, produce first velocity then roll angle signals. Each of the basic roll motion signals (i. e. acceleration, velocity and angle) is routed through a sensitivity switch before being combined with the other signals in a summing amplifier. Each sensitivity switch has 12 positions so that a precise “mix” can be arranged between the three signals to suit the characteristics of a particular ship.

An interesting feature is the incorporation of drift corrector circuits on the acceleration and velocity output lines. Since both the average angular acceleration and average angular velocity of the ship must equal zero, drift correctors, which are constantly monitoring signal outputs, produce an output such that the average acceleration and average velocity is zero.

The use of a three-term controller (acceleration, velocity and angle) ensures automatically that the amplitude and phasing of the fin angle demand signal is optimized over the whole frequency band. At low frequencies, the angle term predominates; at the resonant frequency, the angle and acceleration terms cancel and the velocity term predominates; and at high frequencies, the acceleration term predominates.

A separate servo amplifier is provided for each fin system. Current from the servo amplifier energizes the actuating coils of the pump servo valves. Fin angle reduction circuitry is included in the system although the facility is not used on all ships.

Improvements to the control system resulted from the introduction of the MC (moving coil) servo valve. Amplification was eliminated and, as a result, the number of components in the pump servo system was greatly reduced. The system response was also improved. Current in the coils of the torque motor causes rotational movement of the rotor of the servo valve away from its neutral position. Balance is achieved when the torque of the feed back and centering springs match that produced by the torque motor. The new position taken up by the rotor allows hydraulic fluid to be admitted to one of the tilting cylinders of the main pump and away from the other.

The direction and magnitude of tilt (and hence the stroking of, and sense of fluid flow of, the main pump) is determined by the direction and magnitude of current in the torque motor coils. As the pump tilt shaft rotates to the demanded position, torque is applied to the servo valve rotor via the feedback spring which equals the torque exerted by the torque motor and the centering spring returns the servo valve rotor to the neutral position. Pump output is thus directly related to the current input.

Torque to counter roll is generated by the combination of the ship’s forward speed and the tilting of fins projecting laterally from each side of the ship’s hull. The angle of tilt of the fins relative to their direction of motion through the water is determined by the control system (previously described) which produces appropriate control signals. Direction of tilt is such as to exert a moment on the hull opposing the incipient roll. For example, if a roll to starboard were to develop the port fin would be tilted nose down and the starboard fin would be tilted nose up.

Rapid reversal of the attitude of the fins is essential and this is provided for in the mechanical equipment. The total period of double roll may vary from ten seconds for a ship such as the *QUEEN ELIZABETH* and only a small part of this period can be allotted to the reversal of fins at the end of each roll in order that the righting moment may be retained effectively as long as possible. In practice the reversal time ranges from one second up to three and a half

seconds. During this period each fin may have to be rotated through an angle of 40°. As a point of interest this may be contrasted with the thirty seconds usually required to move a rudder through 70°.
The fin tail-flap is gear driven from a fixed rack so that, as the fin tilt angle increases from zero in either direction, so the tail-flap angle changes in the same sense but at a higher rate. For a given fin area and ship speed, the hydrodynamic loading on the fin (and the consequent anti-roll couple exerted on the hull) is increased by use of such a tail-flap.

6. Tank stabilizers Tank stabilizers are virtually independent of the forward speed of the vessel: they generate anti rolling forces by phased flow of appropriate masses of fluid (water or reserve fuel, etc) in transverse tanks installed at suitable heights and distances from the ship's center line. Fluid transfer may be by open flume or from and to wing tanks connected by cross ducts. The tank/fluid combination constitutes a damped mass elastic system having its own natural period and capable of developing forces at resonance with the impressed wave motion. [5], [6].
Since the fluid can only flow downhill and has inertia, it cannot start to move until the ship has rolled a few degrees. The natural restoring forces limit the maximum roll angle and initiate a roll in the opposite sense. In the mean time the fluid continues to flow downhill, piles up on the still low side and provides a moment opposing the ship motion. As the ship returns and passes its upright position, fluid again flows downhill to repeat the process.
The fluid flow tends to lag quarter of a cycle behind the ship motion, a phase lag of approximately 90°, to generate a continuing stabilizing moment. This is due, mainly, to transfer of the center of gravity of the fluid mass away from the centerline of the ship. The transverse acceleration of the fluid generates an inertia force and thereby a moment, about the roll center, which reduces the gravity moment when the tanks are below the roll center and increases it when they are above. In practice, tanks may be placed 20% of the beam below the roll center without serious loss of performance. Above the roll center, other factors associated with the phase of fluid motion prevent augmentation of the gravity stabilizing power being realized. The phase lag may be increased, within limits, by placing obstructions, e. g. orifice plates, grilles, etc. in the fluid flow path to increase the damping.
In the wing tank system the mode of operation is similar to the simple flume but the tank geometry combined with the dynamic amplification of the flow tends to make fluid pile up to a greater height at a greater distance from the ship's center line to give more effective stabilization. The wing tanks must be of sufficient depth to accommodate the maximum rise of the fluid without completely filling them. For purely passive action the tank tops are vented to atmosphere but in a controlled passive system, such as the Muirhead-Brown, they are connected by an air duct fitted with valves, controlled by a roll sensing device, which regulate the differential air pressure in the tanks to modify the natural fluid flow rate. This system will generate its full stabilizing power from a residual roll at about 7° out-to-out at resonance, due to the fact that dynamic amplification of the fluid motion may be from twice to six times the long period effect. The natural period of the fluid is a function of tank geometry and the volume of fluid contained; it is arranged to be equal to or slightly less than the lowest natural roll frequency of the ship. Provided the system has little damping, maximum roll reduction is achieved at resonance and the roll amplitude/roll period characteristic is virtually a straight line at about the optimum residual roll characteristic. (fig.9)

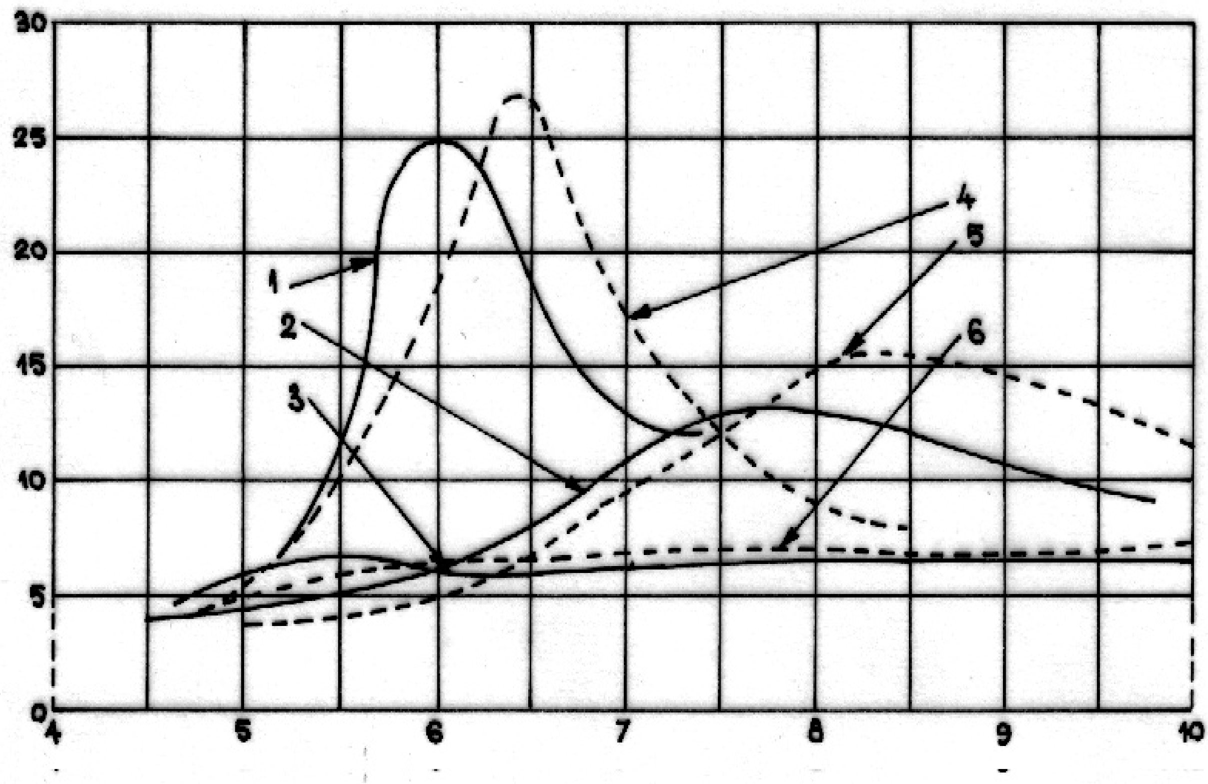

Figure 9. Typical performance curves for Muirhad-Brown tank stabilizer

7. Bibliography:

1. D.W.SMITH, Marine Auxiliary Machinery, Butterworths, (sixth edition), London, UK, 1985

2. G.O.WATSON, Marine Electrical Practice, Butterworths (fifth edition) London, UK, 1995

3. J.A. Hint, Automation in merchant ships, LTD, London, (fourth edition),1991

4. V. Maier, Mecanica si constructia navei, Editura Tehnica, 1989;

5. V. Maier, Solicitari generale in arhitectura navala moderna, Editura Tehnica, 1997;

6. *** News Ships, Marine engineering development, International Shipbuilding, 2001