H.M.S. 'CHALLENGER' SEABED OPERATIONS VESSEL ELECTRICAL SYSTEMS

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PART II—STEERING AND SPEED-CONTROL SYSTEM

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Introduction

The previous article in this issue of the *J.N.E.* dealt with the 3·3 kV system in the SOV. This article concerns the steering and speed-control systems that interface with the HV system. Steering and speed is controlled by adjustment of the propeller pitch on Voith Schneider propellers and Lips bow thrusters; the ship is not fitted with rudders. The principles and equipment involved are of interest to mechanical and to electrical engineers.

A brief description of the ship was given in Part I. This article starts with an explanation of the operation of the Voith Schneider propellers and Lips bow thrusters, and goes on to discuss the operation of the overall propulsion control system. Descriptions of the quartermaster's console, the system pitch controllers, and the electrohydraulic systems are given.

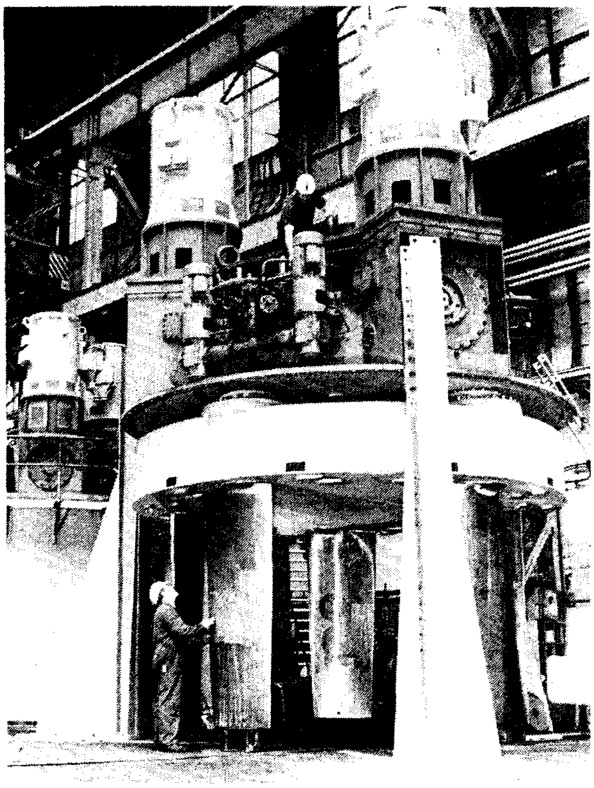

FIG. 1—A VOITH-SCHNEIDER PROPELLER

Voith Schneider Propellers

FIG. 1 shows a typical Voith Schneider propeller. The SOV has two, positioned side by side at the stern, and each unit is driven by two double-wound induction motors. The motors are each capable of producing 1·25 MW at 1185 rev/min or 0·5 MW at 890 rev/min (separate windings) when connected to the 3·3 kV 3-phase 60 Hz supply. To give some idea of their size, the motors weigh 10 tons. The five propeller blades are 7 feet in length, and the maximum diameter of the VS unit is 15½ feet. The whole unit plus oil weighs approximately 100 tons and each VS propeller can produce over 3000 hp.

FIG. 2 shows the construction of the propeller. The drive

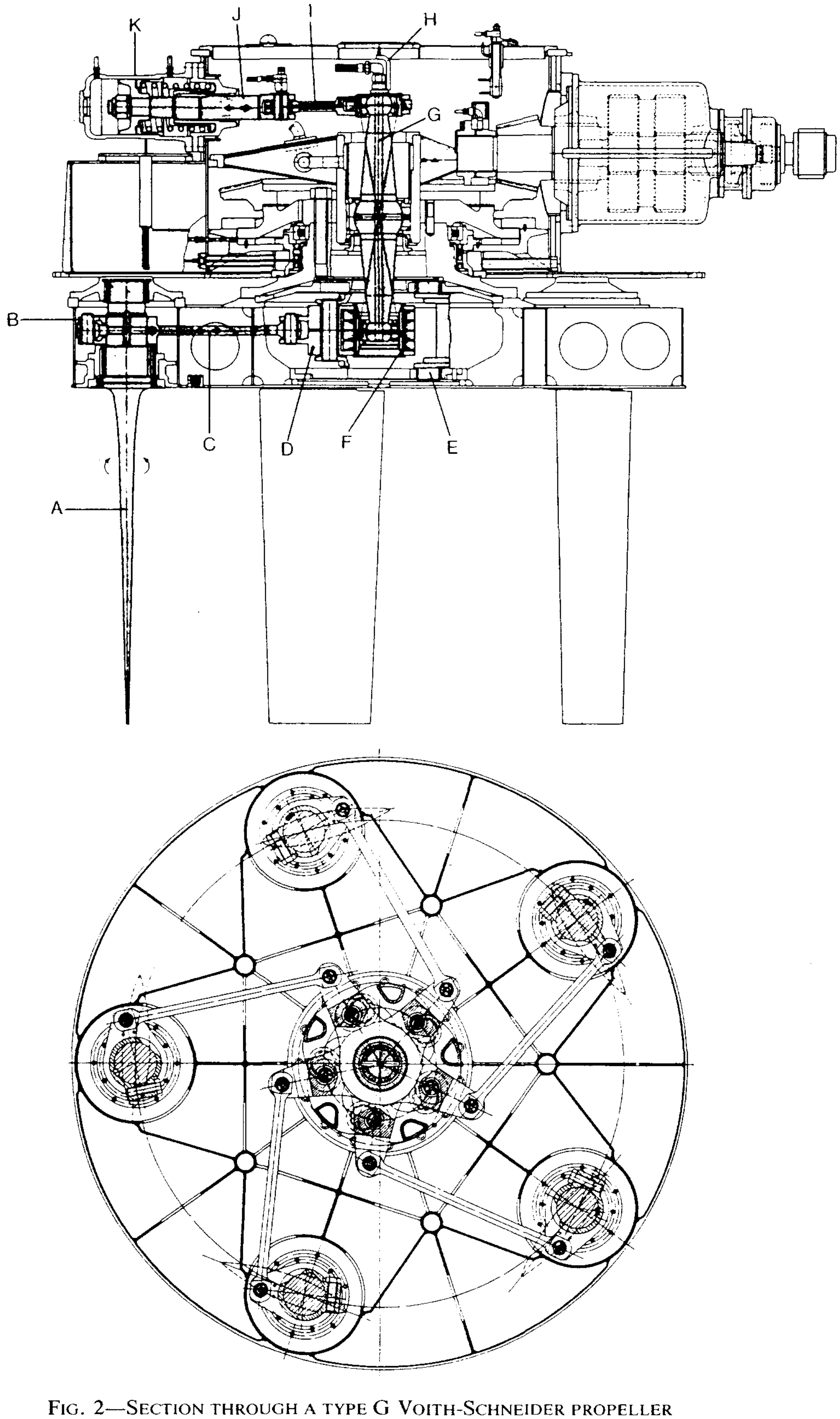

FIG. 2—SECTION THROUGH A TYPE G VOITH-SCHNEIDER PROPELLER

Key:

A	Blade	E	Rocking arm	I	Push rod
B	Actuating lever	F	Coupler sleeve	J	Inner piston
C	Connecting rod	G	Control rod	K	Servomotor cylinder
D	Coupler	H	Pitch indicator		

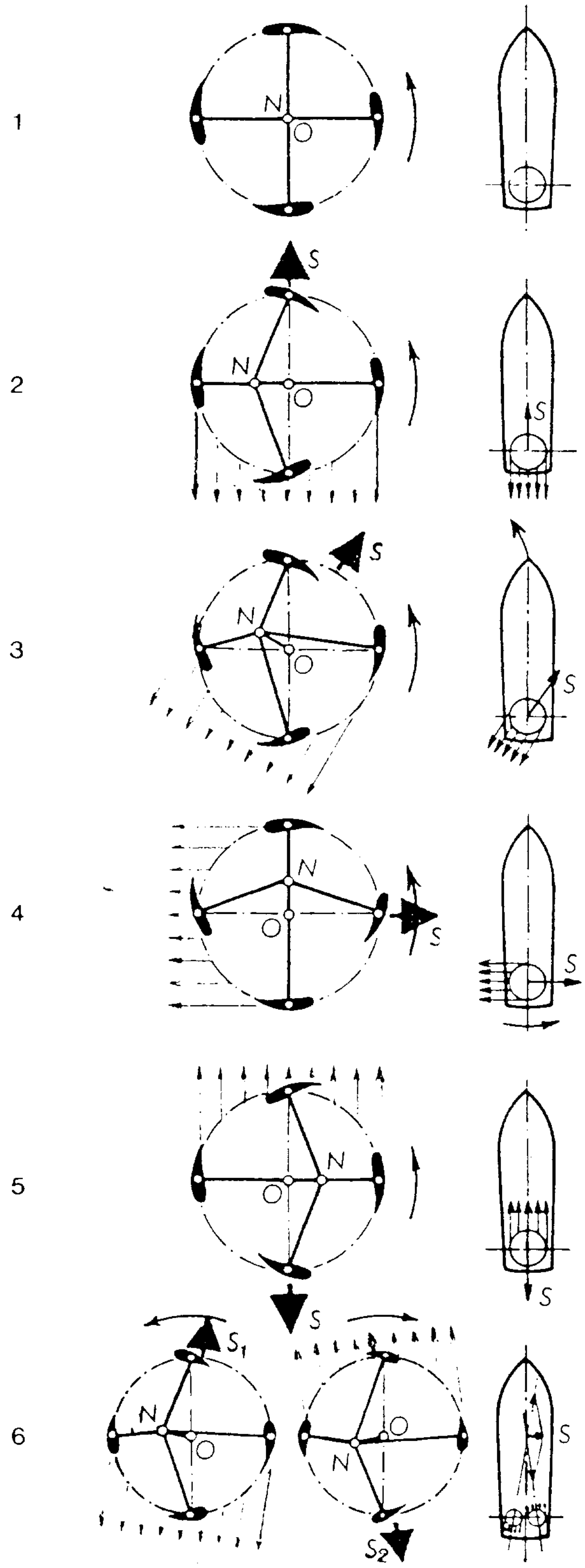

FIG. 3—OPERATION OF THE VOITH-SCHNEIDER PROPELLER

Key: O Propeller centre
N Steering centre
S, S_1, S_2 Thrust

motors of the VS unit fitted in the SOV are vertical and drive through fluid couplings on to the reduction gearing which turns the rotor casing and blades. Two hydraulic servo motors operate at right angles upon the top end of the control rod thus moving the 'steering centre' at the bottom end of the rod, and applying fore-and-aft and athwartships pitch.

The operation of the VS propeller is explained in FIG. 3. When the steering centre N is moved from the centre O of the circle, the blades perform an oscillating movement about their axes as the rotor rotates and a propeller jet is produced with a thrust acting in the opposite direction.

In Sketch 1, the steering centre N is located in the centre O of the circle. While rotating, the blades remain tangential and no thrust is developed. The propeller is 'idling'.

In Sketch 2, the steering centre N is shifted to port, and the blades are so controlled that the verticals to the chords of the blade profile intersect in the steering centre N. Each blade then performs an oscillating movement about its axis. The leading edge of the blade is directed outwards in the forward half circle and inwards in the rear half circle. Thus, in the forward half, water is thrown into the blade orbit, and, in the rear half, away from the orbit, though in the same direction. In this way, a water jet astern is produced and, as reaction, thrust S, which provides forward propulsion and the ship moves forward.

The thrust is at right angles to the line O–N, and its magnitude is proportional to the distance O–N. Because of the rotational symmetry about the axis of the propeller, similar considerations apply to any other location of the steering centre N.

In Sketch 3, the steering centre is shifted to port and simultaneously forward. Propeller jet and thrust S are again at right angles to the line O–N. In addition to a longitudinal component, the thrust includes an athwartship component, or in other words, the propeller provides a steering force and the ship turns to port.

In Sketch 4, the steering centre is moved forward as shown, a pure thrust athwartships to starboard is produced and the ship turns on the spot.

In Sketch 5, the steering centre is moved to starboard which results in conditions opposed to those shown in Sketch 2. The thrust is directed astern and the ship moves astern.

In Sketch 6, in a ship equipped with two Voith Schneider propellers, if one propeller is given a forward oblique thrust and the other an astern oblique thrust with both thrusts directed to the same side then the resultant of the thrusts S_1 and S_2 is a transverse thrust S which acts about amidship and moves the ship sideways.

Therefore, by operation of the servomotors the oscillating movement of the blades is adjusted to provide the desired ship speed and direction of travel. The method of controlling the servomotors from the bridge or the DP computers is explained later.

Lips Bow Thrusters

FIG. 4 shows a Lips bow thruster. Each of the three bow thrusters is driven

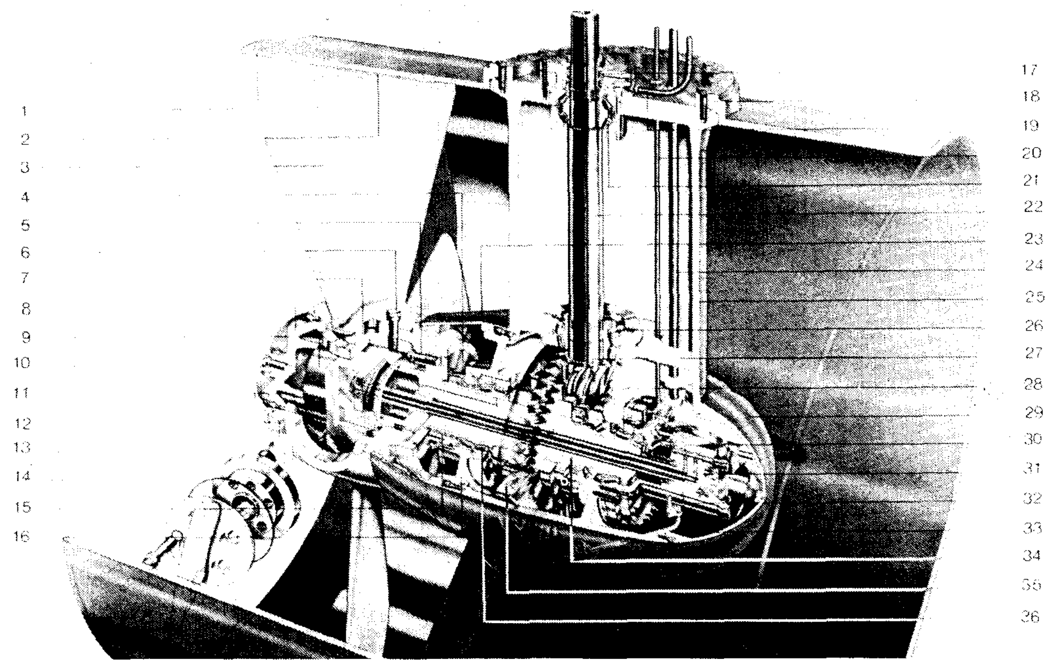

FIG. 4—LIPS TRANSVERSE TUNNEL THRUSTER TYPE CT

Key:

1	Tunnel section	13	Crank pin	25	Gear pod
2	Stainless steel liner	14	Blade seal	26	Lower pinion shaft bearing
3	Propeller blade	15	Propeller shaft seal	27	Spiral bevel pinion
4	Flange protection ring	16	Gear pod cover	28	Thrust bearing assembly
5	Shaft-flange bolt	17	Pinion shaft seal	29	Gear pod cap
6	Blade bolt	18	Mounting ring	30	Oil distribution valve
7	Blade carrier	19	Lub oil return pipe	31	Piping insert
8	Hub cover	20	Hydraulic pressure oil-pipe	32	Hydraulic control unit
9	Moving cylinder-yoke	21	Upper pinion shaft bearing	33	Head oil-pipe
10	Cap	22	Pinion shaft	34	Propeller shaft
11	Hub body	23	Fairing cone	35	Spiral bevel wheel
12	Sliding block	24	Pitch control rod	36	Propeller shaft bearing

by a Laurence Scott induction motor capable of delivering 1·5 MW at 710 rev/min on a 3·3 kV, 3-phase, 60 Hz supply. The thrusters are single-speed 218 rev/min Lips variable-pitch tunnel thrusters with propellers about 8·5 ft in diameter. Note the pitch control rod (24) and hydraulic pitch servo system inside the propeller casing. It is the turning of the control rod that decides the pitch of the propeller.

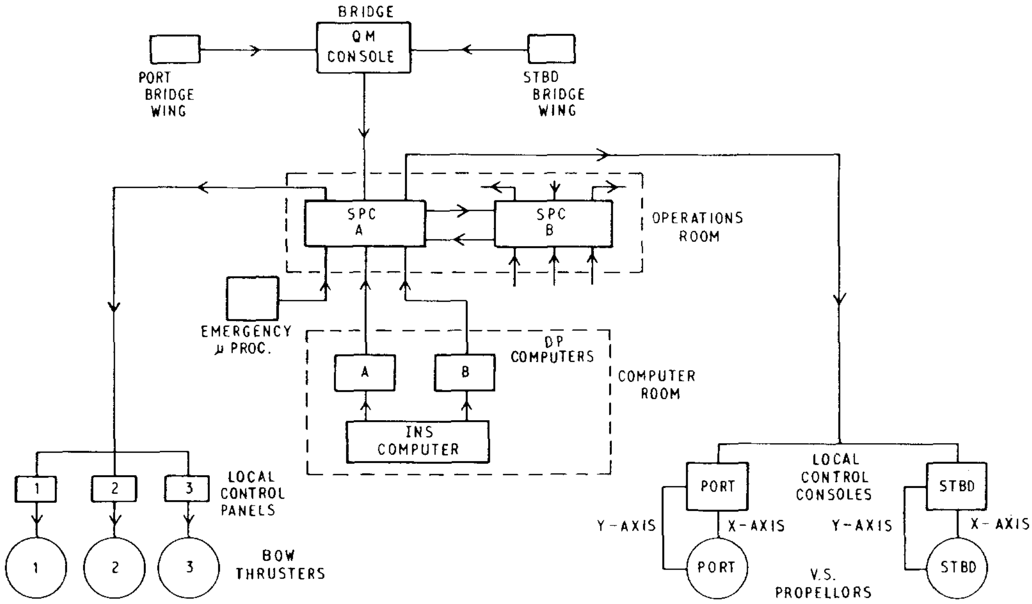

FIG. 5—PROPULSION SYSTEM CONTROLS

Propulsion Control System

A block diagram of the propulsion control and dynamic positioning systems is shown in FIG. 5. The DP system will be described in Part III of this series of articles in the next issue of this *Journal.* The propulsion control system functions by the operation of controls on the quartermaster's console which produce d.c. demand voltages, and these are applied to the system pitch controllers (SPCs). The SPCs process and distribute the demand signals to electrohydraulic sub-servos that in turn operate the VS servomotors and bow-thruster control rods. The movements of the sub-servos provide electrical position signals that are compared with the demand signals, resulting in the required positioning of servomotors and control rods.

Two SPCs are used for reliability. The DP computers operate via the SPCs when in DP mode of operation and control is transferred from the bridge to the operations room.

Quartermaster's Console

The quartermaster's console is designed and manufactured by Vosper Products Ltd., Cosham and a view of the console is shown in FIG. 6. There are four modes of operation obtained by using the steering mode select switch and these are: Passage, Manoeuvring, Autopilot, and Remote Autopilot.

Passage Mode

Whilst the ship is on passage the console is used to provide pitch demand signals for control of the Voith Schneider propellers. An ahead or astern pitch signal is required for each VS propeller to control the VS servomotor which moves the VS control rod along the 'X' axis to control ship speed as previously

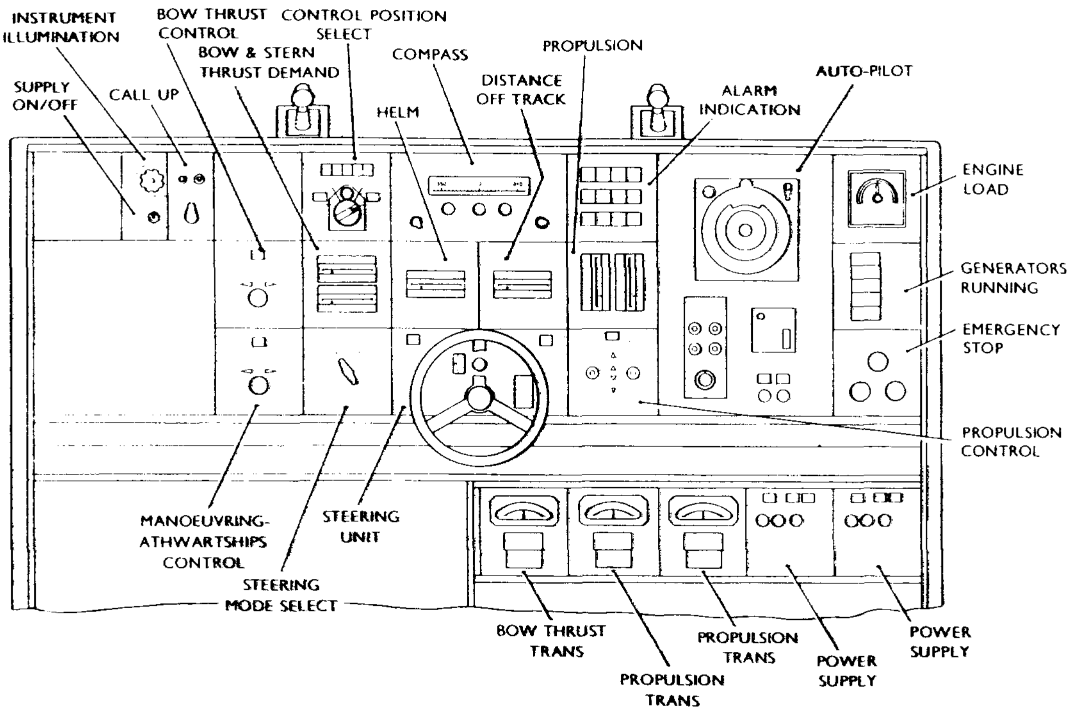

FIG. 6—THE QUARTERMASTER'S CONSOLE

described. Similarly, an athwartship pitch demand signal is provided for each VS propeller to control the VS servomotor which moves the control rod along the 'Y' axis and thus controls steering of the ship.

The ahead or astern pitch is applied by operation of the throttle switches, one per propeller, positioned on the propulsion control unit. The pitch demanded is then shown on the port and starboard indicators on the propulsion unit above. Each switch operates a small d.c. motor in either direction. The motor is coupled to three potentiometers, two of which provide identical voltages in the range 10–0–10 volts, supplying ahead/astern demand signals to system pitch controllers 'A' and 'B'. The third potentiometer output is fed to a propulsion indicator. The port and starboard VS propellers can be controlled independently by operation of the throttle switches. The athwartship pitch control is achieved by turning the steering wheel shown in FIG. 6. The helm demanded is shown on the helm indicator. The circuitry here is similar to that for ahead/astern control but in this instance the wheel is directly coupled to the potentiometer wiper blades and only one demand signal controls athwartship thrust on both VS propellers. There are four potentiometers of which, two provide athwartship thrust demand signals to system pitch controllers 'A' and 'B', one

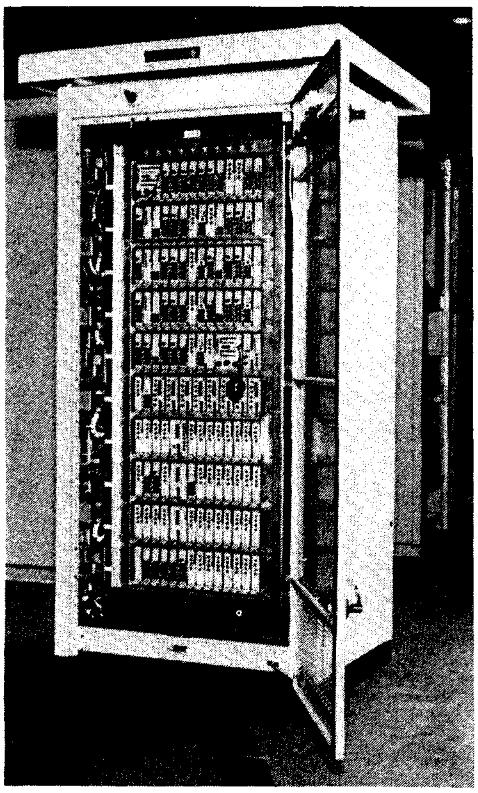

FIG. 7—SYSTEM PITCH CONTROLLER

provides an output to the autopilot, whilst the last operates the helm indicator. In the passage mode, the athwartship thrust is limited to a third of full athwartship thrust by circuitry in the SPC to prevent the application of excessive steering pitch signals. Also, the bow thrusters are available during passage mode although they will not normally be used.

Manoeuvring Mode

When manoeuvring the ship, the ahead and astern pitch is controlled as in the passage mode. The Voith Schneider athwartship pitch control this time is achieved by one throttle switch on the manoeuvring athwartship control unit. The steering wheel in this mode is meanwhile disconnected by means of an electromagnetic clutch. The throttle switch operates a small motor that is mechanically coupled to the four potentiometers described above. In this mode the helm signal is disconnected from the helm indicator and connected to the stern thrust demand indicator.

The athwartship control of bow thrusters is obtained by the use of one throttle switch positioned on the bow thrust control unit. The thrust demand is then shown on the bow thrust demand indicator. This one switch operates a small motor and potentiometers in a manner similar to the VS athwartship control and controls one, two, or three bow thrusters.

Autopilot

For autopilot control, the athwartship control from steering wheel and throttle switch are disconnected and the autopilot controls the small motor and potentiometers to provide the necessary athwartship pitch control signals to the system pitch controllers.

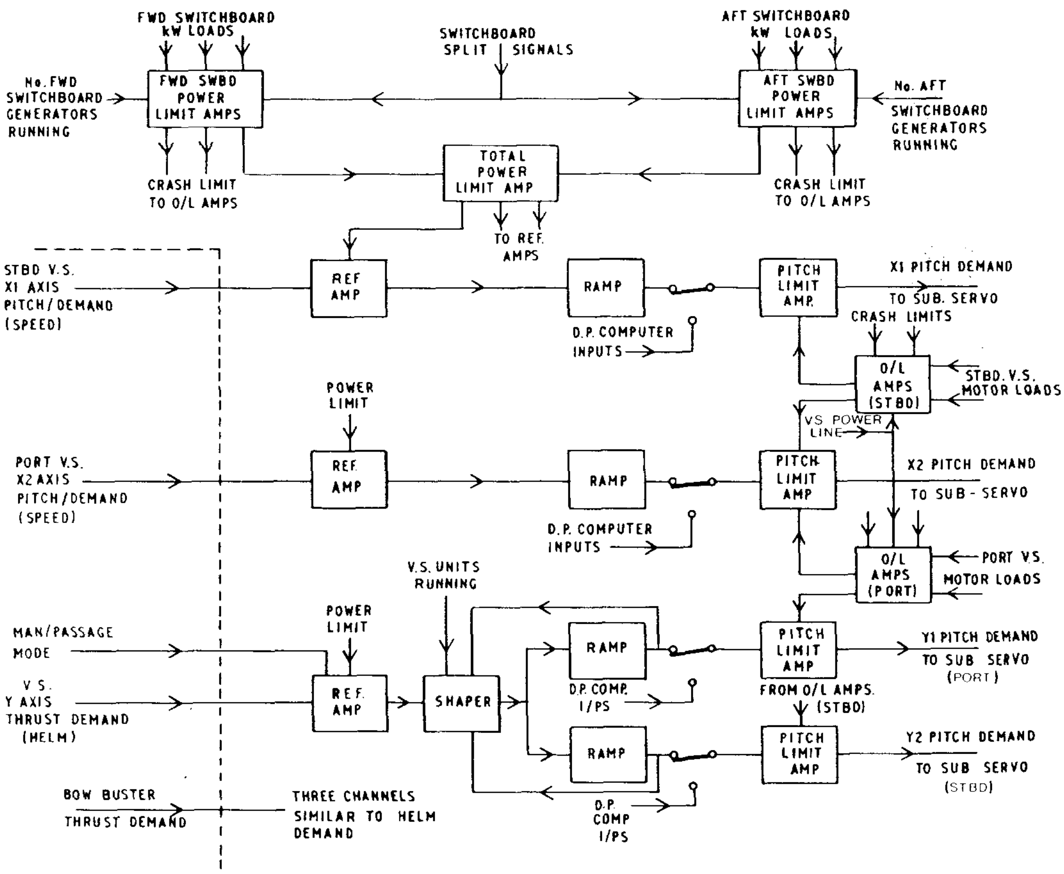

FIG. 8—SYSTEM PITCH CONTROLLER—PITCH CONTROL CHANNELS

System Pitch Controllers

The system pitch controllers, positioned in the operations room, are designed and supplied by General Electric Company (Electrical Projects), Rugby and FIG. 7 shows a view of one system pitch controller. There are two SPCs (channels 'A' and 'B') but only one is used at any time. The second is a standby ready for use if required. This arrangement is designed to achieve the reliability required for this important system.

The SPCs have several functions as follows:

(*a*) Pitch reference control (PRC)
(*b*) Available power control (APC)
(*c*) Command signal selection
(*d*) Channel fault detection
(*e*) Control logic
(*f*) Monitoring and testing

The first two functions only, being the most important, are described here.

Pitch Reference Control

A simplified block diagram of the pitch control and available power control circuits is shown in FIG. 8. GEC have used Unistat Analogue Electronics generally to form the seven channels:

(*a*) Two channels for ahead/astern control of the two VS propellers (X1 and X2 Axes). These channels are housed in the PCBs shown in second from top row in FIG. 7.
(*b*) Two channels for combined athwartship thrust control of the two VS propellers ('Y' Axis). These channels are housed in the PCBs shown in third from top row in FIG. 7.
(*c*) Three channels for combined athwartship thrust control of the three bow thrusters (T1, T2, and T3). These channels are housed in the PCBs shown in fourth and fifth rows from the top in FIG. 7.

The four input signals derived from potentiometers in the QM console are shown on the left side of FIG. 8 and identical signals are passed to system pitch controllers 'A' and 'B'. Each group of channels is now discussed in turn:

Ahead/Astern Speed Control: These controls give pitch proportional to QM pitch demand. Since the thrust is roughly proportional to pitch squared and the drag of the ship is proportional to the ship speed squared, it follows that the speed attained by the ship will be roughly proportional to the pitch demand. Reference to FIG. 8 shows that X1 and X2 pitch demand inputs are amplified in a reference amplifier and passed to a varying-rate ramp circuit. This ramp reduces the rate of change of the output of the ramp as the output ramp rises from 0 to full scale. When the pitch reference signal falls, however, the rate is increased. This has the effect of:

(*a*) enabling the drive to attain low-pitch values quicker;
(*b*) reducing the rate of change of power load applied to the system;
(*c*) enabling the pitch to be removed quicker during a crash manoeuvre.

From the ramp, the pitch signal passes into a pitch limit amplifier which provides normal operating limits on the pitch but in addition it has a variable control. The overload amplifiers operate with the pitch limit amplifiers to reduce pitch under overload conditions; this will be explained later. The pitch demand outputs X1 and X2 are then passed to Regulator Europa ahead/astern sub-servo units.

Athwartship Thrust Control of VS Propeller: For the ahead/astern control, dissimilar thrust may be required, for instance to aid turning. The athwartship control, however, must produce similar outputs to enable the two VS propellers to thrust in the same direction. Any other arrangement would be self-defeating. Therefore, only one 'Y' axis athwartship demand signal is required to provide outputs to both port and starboard VS propeller. Note that operation of the selector switch in the QM console to passage mode makes contacts which limit the reference to ⅓ thrust.

The thrust reference voltage after multiplication in the reference amplifier is taken to circuitry in the shaper which predicts the pitch needed by any number of thrusters to produce the demanded thrust. The shaper circuit receives information concerning the number of thrusters running to do this calculation. The ramp and pitch limit amplifiers carry out similar functions as previously described.

Furthermore, this arrangement maintains the relationship between wheel/lever demand and total thrust for any number of drives provided the capability of the VS units is not exceeded. The pitch demand outputs Y1 and Y2 are then passed to Regulator Europa athwartship sub-servo units.

Bow Thrust Control: This is a similar control to the athwartship thrust control which is extended for use on the three bow thrusters. The pitch demand outputs T1, T2, and T3 are passed to Lips bow thruster sub-servo units.

Available Power Control

FIG. 8 shows how, for each switchboard, the generator capacity available is monitored against generator load. When the load reaches a predetermined limit, a pitch-limit circuit operates to reduce the pitch of all running units and thus reduce load. This can be achieved if the switchboards are running as separate units or if the system is run as a whole. There are two stages of power limiting:

(*a*) *For Light Overloads:* when the power limit has just been exceeded, the

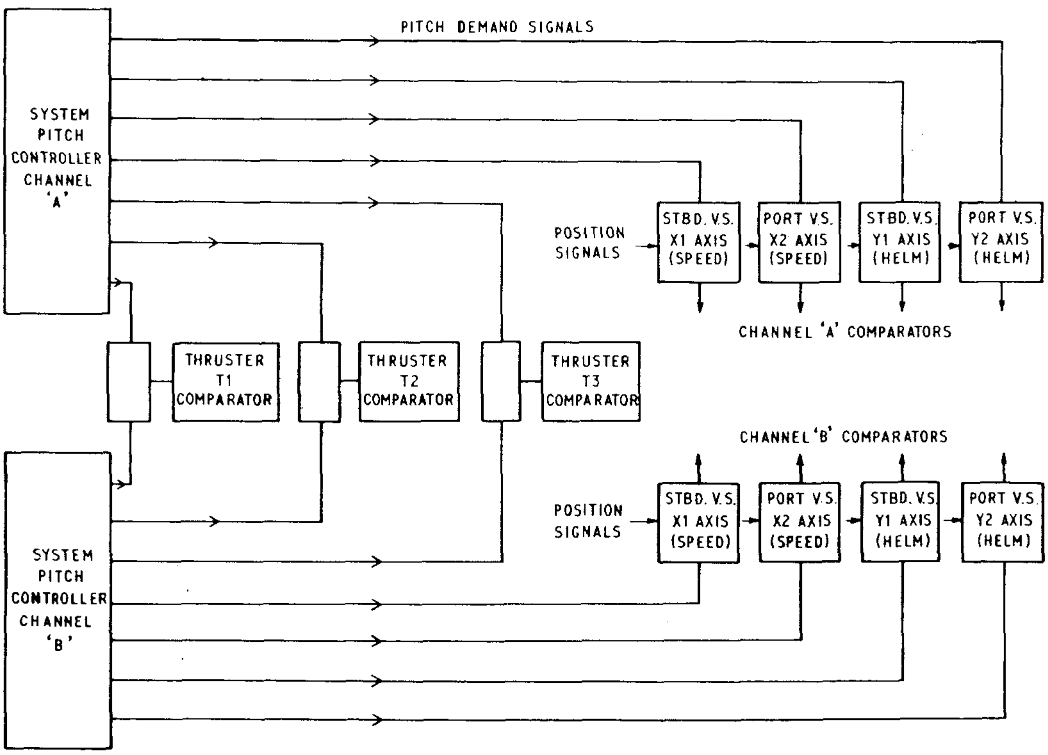

FIG. 9—DUPLICATION OF SIGNAL SYSTEM TO ENSURE DIVER SAFETY

total power limit amplifier operates upon all the reference amplifiers reducing the output voltage and then causing a small reduction in pitch on all running units. This is sufficient to reduce the load as required.

(*b*) *For Larger Overloads:* when these occur, the overload amplifiers operate reducing the limits in the pitch limit amplifiers, quickly reducing the pitch demand and the drive.

All this is to protect the generators during overloads caused by suddenly worsening conditions or equipment failure.

The drive motors on the Voith Schneiders and the bow thrusters are also protected against overloads by using the overload amplifiers and pitch limit amplifiers to detect the motor load and reduce pitch sufficiently to remove any overload. Each unit is individually protected.

The foregoing is confined to essential details because the SPCs are quite complex units. FIG. 9 is included to emphasize the duality of the signal system, everything being duplicated to ensure diver safety.

The pitch demand signals from the SPCs are fed to the VS and BT electro-hydraulic sub-servos which apply propeller pitch. The Lips bow thruster sub-servo is less complicated than the dual Regulator Europa sub-servos used with the Voith Schneider propellers and therefore provides the better starting point.

Bow Thruster Electrohydraulic Control System

FIG. 10 shows a simplified version of the way that pitch is applied in proportion to the magnitude of the demand signal. The demand signal is compared with the position signal and the resulting error signal is amplified and applied to the directional valve. The polarity of the comparator output decides which directional valve solenoid is operated and hence the direction of flow of hydraulic fluid to the control cylinder. The cylinder piston is moved to the left or right thus turning the pitch actuation rod through appropriate gearing. At the same time the feedback potentiometer wiper blade is turned increasing the feedback (position) voltage until the error is reduced to zero. At this time the directional valve returns to the central position cutting off flow of hydraulic fluid and leaving the control cylinder piston in the demanded position. Meanwhile the movement of the pitch actuation rod has moved the directional valve which forms part of the hydraulic pitch servo system inside the propeller hub. This movement of the valve spindle allows the main flow of hydraulic fluid in the appropriate direction inside the propeller hub to push against the propeller pitch operating piston and adjust the pitch on the propeller. The movement of the piston also moves the piston rod and valve sleeve in the same direction as the valve spindle thereby bringing them back into alignment, i.e. with the spindle in the central position cutting off flow of

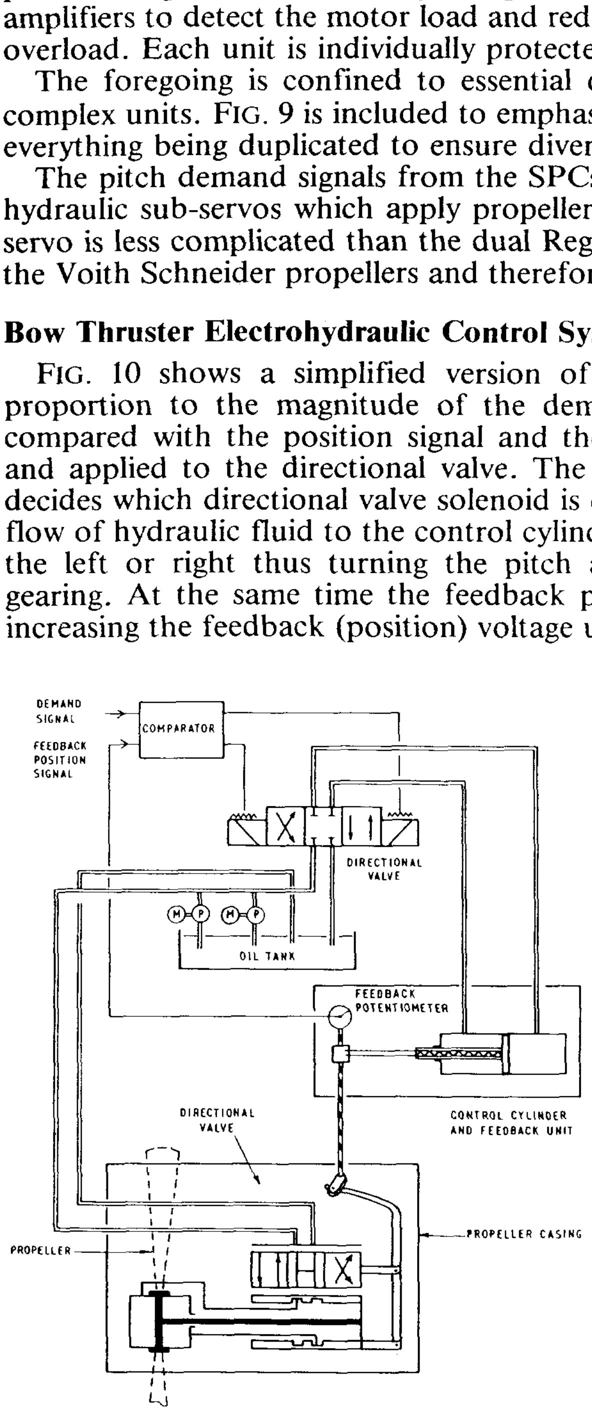

FIG. 10—BOW THRUSTER SUB-SERVO SYSTEM

hydraulic fluid. The piston then stops with the required propeller pitch applied. Any subsequent adjustment of the demand signal will cause the propeller pitch to take up the required new position.

Voith Schneider Electrohydraulic Control System

FIG. 11 shows one of four identical electrohydraulic control units used with the Voith Schneider propellers. Assuming that this unit is controlling the ahead/astern (X axis movement via a servomotor) on the port Voith Schneider propeller, then the other three units are controlling the 'Y' axis movement on the port Voith Schneider propeller, and 'X' axis and 'Y' axis movement on the starboard Voith Schneider propeller (see FIG. 9).

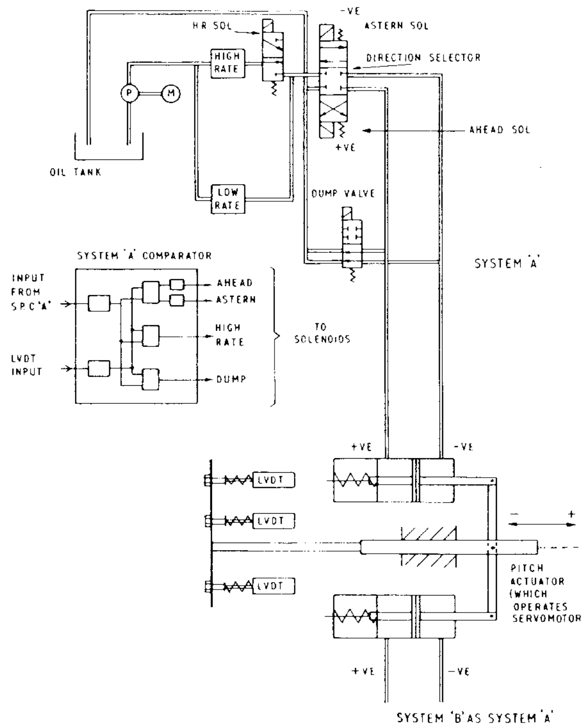

FIG. 11—VOITH-SCHNEIDER ELECTROHYDRAULIC CONTROL SYSTEM

Considering System 'A' in FIG. 11, the demand signal is received from SPC 'A' and is compared with the position signal received from the linear variable differential transducer (LVDT). The error (or difference) signal (+ve or −ve) is amplified in the comparator unit and ahead or astern signals passed to the direction selector valve. The valve operates allowing flow of hydraulic fluid in the required direction thus moving the control cylinder piston to left or right. This movement of the piston also moves the LVDTs which increases the position signal until demand and position signals are balanced and the ahead or astern signal is reduced to zero. The direction selector valve then returns to a central position, flow of hydraulic fluid is cut off, and the piston remains in its new demanded position.

The pitch actuator has moved to the left or right dependent upon whether ahead or astern has been demanded. This movement is applied through linkages to the speed (X axis) servomotor shown in FIG. 12. The point 'h' is moved thus sliding the control pin 'd' allowing hydraulic fluid to flow to either side of the servomotor piston. The piston and push-rod 'b' then moves the top 'a' of the control rod. This movement continues until the control pin is reset by the linkage shown, thus cutting off flow of fluid and leaving the top of control rod in the demanded position. Reference to FIG. 2 shows how pitch is applied to the blades. Considering system 'B' in FIG. 11 the demand signal is received from SPC 'B' and compared with another LVDT output to achieve the same movement of pitch actuator and propeller pitch. Hence we have an alternative channel for control of the propeller pitch to improve reliability of the system. (Only channel A or channel B operate at any one time—the standby channel being held in the neutral position).

FIG. 12 shows the steering servomotor which is used to move the control rod and propeller pitch to achieve athwartship (Y axis) steering adjustment. Another control system as shown in FIG. 11 is used with this servomotor.

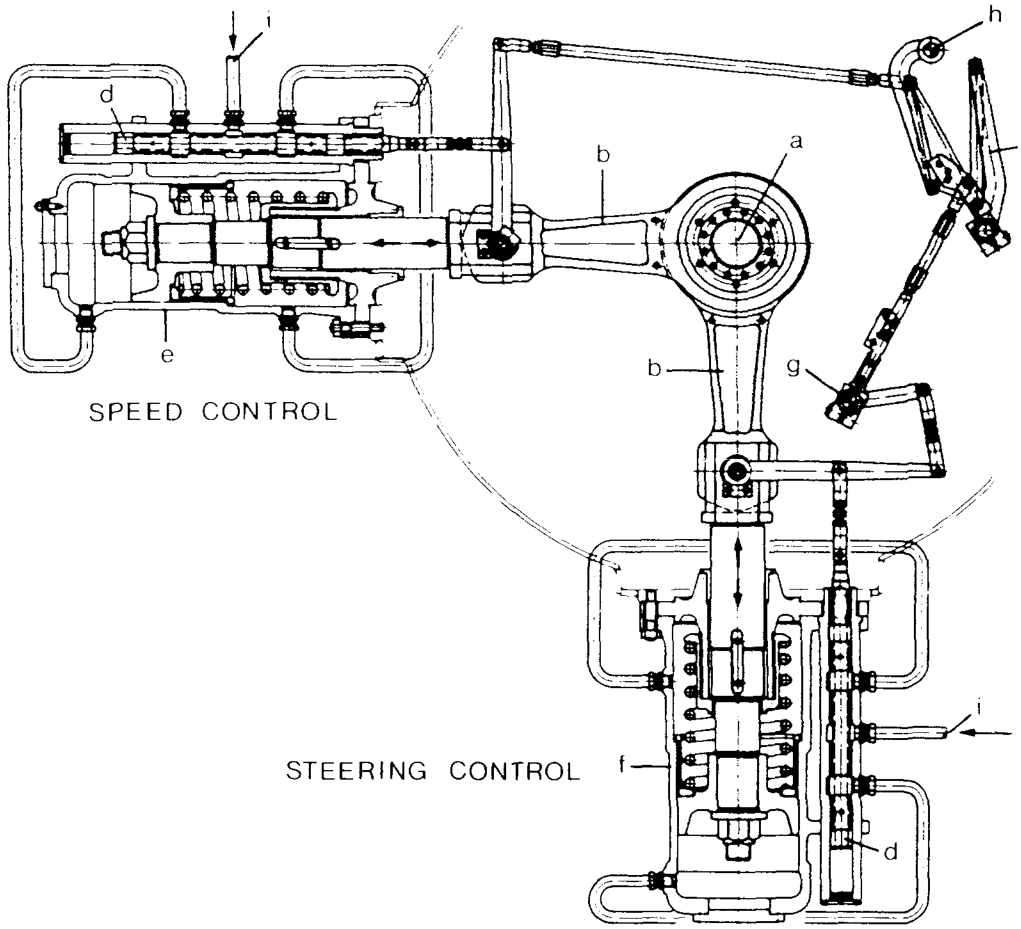

FIG. 12—SERVOMOTORS AND SPEED REDUCING LINKAGE

Key:

(a) Control rod
(b) Push-rod
(c) Speed-reducing linkage
(d) Control pin
(e) Speed servomotor (servomotor for longitudinal component)
(f) Steering servomotor (servomotor for athwartship component)
(g) Control shaft for steering adjustment (athwartship component)
(h) Control shaft for speed adjustment (longitudinal component)
(i) Servo valve oil supply

It is also interesting to note that two rotary variable differential transformers are positioned inside each VS unit. One is connected to X axis control linkage to measure speed pitch achieved and the other is connected to the Y axis control linkage to measure steering pitch achieved. These indications are then displayed on the MCR console.

Summary

When considering the SOV machinery, it is easy to overlook the complexity of the steering and speed control arrangements in comparison with the more publicized high voltage and dynamic positioning systems. Consequently, considerable detail is included here to emphasize the importance of this third link in the chain. It is hoped that this information will be helpful to users and maintainers alike.

The next issue of the *J.N.E.* will include Part III of this series, the Dynamic Positioning system, explaining how the GEC computers Type 4070 interface with the SPCs to position the ship with the desired heading.

The number of manufacturers involved in the systems is high, as are also the interfaces, and technical, contractual, costing and programme matters associated with such large systems generally. Even in these days of design and build by the shipbuilder, there is a great deal of in-house expertise required to allow the MOD to act as a sensible customer.

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