# WEAPON HANDLING AND LAUNCH SYSTEM FOR 'UPHOLDER' CLASS

BY

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## Introduction

Following the decision to replace the OBERON Class of diesel electric submarines, the Naval Staff Requirement (NSR) for the Type 2400 UPHOLDER Class[1,2] Weapon Handling and Launch System (WHLS) was issued in 1981. This can be summarized as follows:

(*a*) Weapon handling to be as mechanized as possible, using chains for transportation.

(*b*) The weapons to be individually shock protected.

(*c*) Discharge, using slide valve and air turbine pump combinations, to be a safe and fully automatic (processor-controlled) self-regulating process with a remote control (from the control room) facility capable of firing any weapon in the correct manner in salvo or single shot mode within the time limits stated in the agreed characteristics.

(*d*) The flood and drain system to be as automated as possible, and both it and the discharge system to be fully interlocked to prevent incorrect operation.

(*e*) All equipment to be designed to suit its environment, operate with the minimum of maintenance between refits and facilitate an 'Upkeep by Exchange' policy.

These requirements and the constraints involved in accommodating the system in a relatively small submarine meant that the design solution had to be radically different from that previously undertaken for nuclear submarines.

Strachan & Henshaw have had a greater involvement in this project than previous weapon handling and launch system designs and commenced their preliminary studies in 1978. Under the design and development contract they became the system design contractor, and in 1986 were made the design authority. However, the development of the system has been in close co-operation with the MOD and has been carried out against a background of paring down to get within space and weight constraints. This will help to explain the evolution of development and the choice of final design.

## DESIGN AND DEVELOPMENT EVOLUTION

As with most projects, the original design has undergone considerable refinement since its inception early in 1978, as size and cost constraints have demanded more unified solutions. To assist with the formulation of design, mathematical modelling and the building of prototypes have been extensively employed to investigate and prove performance of the main equipments, particularly where they depart from concepts used in previous classes of submarine. Some of the principle innovations requiring particular attention are described below.

## Weapon Handling

The traditional single deck weapon stowage compartment (WSC) layout was employed using short beams cantilevered from the hull frames to support an upper tier of two weapons, port and starboard. The lower tier of weapons was carried on the deck of the compartment. A preference to support and handle weapons from beneath rather than suspend them was decided early in the project, and this, coupled with the Staff Requirement to shock protect each weapon independently, determined the particular characteristic of the Type 2400 handling system. Each stowage cradle became too heavy to be man-handled and, by combining them to form a stowage tray or palette for each weapon, the whole assembly could be mechanically handled in a single operation. With this method, the time to prepare to receive weapons from the embarkation equipment was reduced and it was accomplished with minimum crew.

Post-shock alignment between the stowage and torpedo tube was also much simplified in the Type 2400 using this stowage tray system.

Because a submarine is at risk while weapons are being embarked, great emphasis has been placed on the need to minimize the equipment that has to be removed in order to allow the embarkation hatch to be closed. By having the embarkation ramming equipment and the rails permanently fixed in the boat, with only a short removable section which passes through the hatch as soon as the weapon is clear, the hatch can be closed promptly.

## Weapon Launch

Although the Type 2400 is only a little over a third the size of a nuclear powered submarine, its weapon fit has not been affected, and in many respects it is superior to most R.N. submarines. Initially two alternative launch systems were considered: water ram discharge, as fitted in all U.K. nuclear submarines, and the air turbine pump (ATP). The former is relatively heavy, and difficult to install and maintain. Although both systems utilize the same water transfer driven by pneumatic power, the ATP offered a more flexible performance, was very compact and thus was more suitable for a small submarine. For operational reasons also this was the preferred option; however, the ability to accommodate a fall-back water ram was allowed for.

The main elements of the launch system are represented in FIG. 1 and are described on pp. 285–291. They comprise three groups of equipment:

(*a*) Tube and discharge equipment.

(*b*) Fore end control equipment.

(*c*) Fire control equipment including the weapon data bus. The latter is integrated with the boat's command system and is not discussed here.

### *Torpedo Tubes and Forward Dome*

The torpedo tubes are situated on the upper deck and penetrate the upper section of the dome. This section of the dome bulkhead has nine major penetrations, all with complex curved sections which made it difficult to assess the stress distribution and strength (both static and under shock). The design of the dome was only finalized after extensive scale model testing. Finite element analysis was used and a full scale shock test was carried out on the air turbine pump mounted, as it would be, in the dome. Shock inputs from this work and evaluations made by ARE Dunfermline were used to design the torpedo tubes and, combined with assessments of the cost-effectiveness of manufacturing techniques, it was decided to manufacture the greater part of the tube from Q1N steel forgings, with closed die forging for the smaller and more complex shapes and open die forgings for the tube sections themselves.

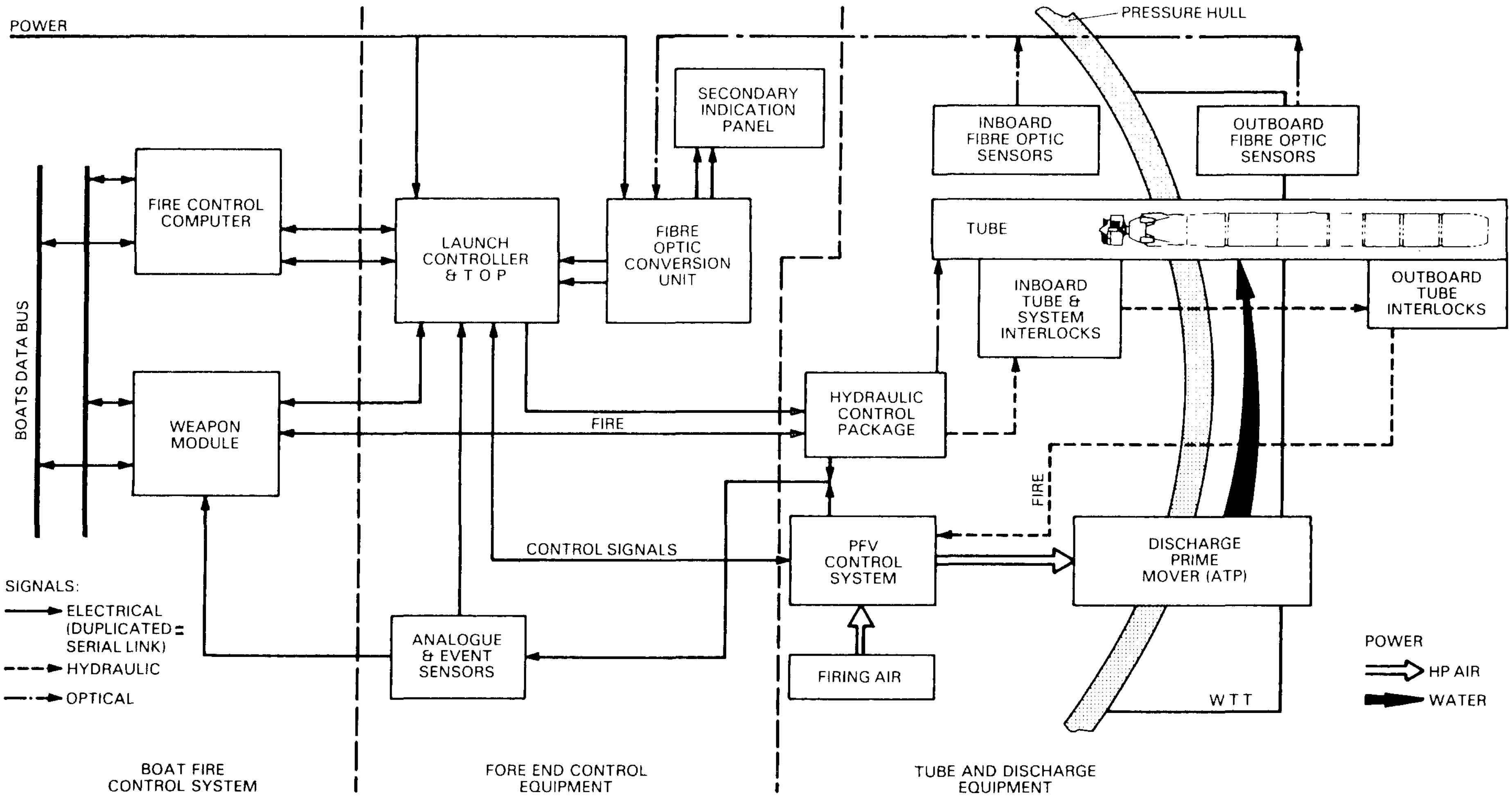


FIG. 1—LAUNCH CONTROL SYSTEM

ATP: air turbine pump
PFV: programmable firing valve
TOP: torpedo operator's panel
WTT: water transfer tank (or impulse tank)

Other than in the method of manufacture, the torpedo tubes are very similar to those of other classes, with the exception of the slide valve. This new valve (FIG. 2) allows impulse water from the ATP into the tube and forces the weapon out. The outer sleeve of the valve allows inlet ports to be cut all round the tube, giving an even distribution of flow which assists weapon dispensers (which pay out the wire of wire-guided weapons) and also reduces the hydrodynamic loss of the system.

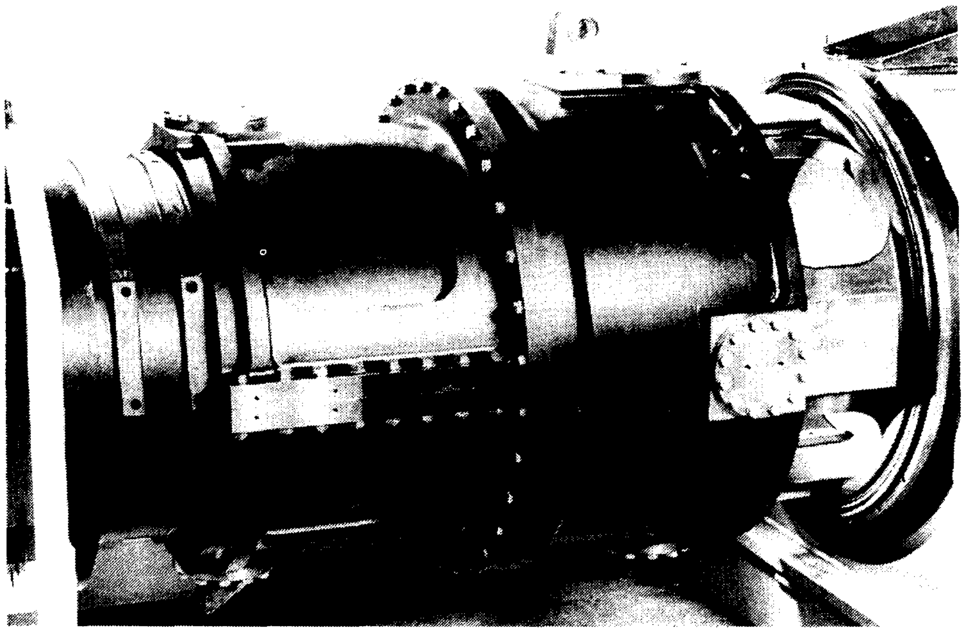

FIG. 2—TORPEDO TUBE SLIDE VALVE ASSEMBLY IN OPEN POSITION

*Tube Indication System*

When considering options for a torpedo tube indication system the problem of the environment encountered by external sensors has a major influence on the choice of system. The unreliability of electrical sensing equipment fitted outside the hull on existing submarines led the project to explore the possibilities offered by fibre optic technology. Advantages include cable weight saving, being not susceptible to signal interference, suitability for use in the weapon stowage compartment (which is classed as a magazine), and the fact that the design could be made positively fail safe (as light is required for a signal). Commercial equipment was not directly available, but the cable was, and by adapting termination techniques and developing a sensor a system was put together. A prototype was built and fitted in H.M.S. *Osiris* where it remained operational for two years without a single failure.

*Tube Control and Interlock System*

Mechanical operating linkage through the dome for tube openings was not possible because of lack of space in the upper dome. Hydraulic operation and control was employed.

From the initial proposal submitted to meet the broad characteristics of the Naval Staff Requirement, the design chosen differed only slightly. The principle deletions were:

(*a*) Automatic flood and drain packages interlocking the rear doors to the flooding and draining system.

(*b*) Torpedo tube lip vents to reduce the number of penetrations through the dome bulkhead.

(*c*) Interlocking between equalizing valves and the firing system. These valves were found to have no significant effect on firing efficiency.

(*d*) Hydraulic interlocking together of the slide valves, for which many proposals were submitted, but because of space constraints they could not be accommodated. For this reason selection was interlocked by mechanical means for manual operation and electrically for automatic mode.

Further simplification of the circuit was effected by the use of pressure biasing, centring and differential piloting techniques. These allowed a significant reduction in the number of valves, reduced piping and, in the case of lightly loaded actuators and valves, assured high integrity when subjected to shock. It should be noted that valve centring and offset springs are rarely effective at shock levels above 30 g.

To minimize the number of penetrations through the dome, regenerative control was adopted for the slide valve and bow cap actuation. The number of penetrations was reduced from 94 to 72 by supplying together all those external assemblies requiring biasing. This, together with the other advantages listed on p. 000, was considered far more important than the one drawback of possible loss of fluid outboard, which has been catered for by providing line break and leakage detection equipment.

The system's most important feature is that hydraulic and mechanical interlocking remain paramount and there can be no response to invalid commands.

*Prime Mover and Control System*

The weapon launch prime mover chosen was the air turbine pump, the advantages of which have been described. Considerable development work has been completed with a prototype unit built in a weapon firing discharge rig at ARE Portland. Early research carried out by AUWE (as it was then) on a computer-controllable firing valve was further developed by Strachan & Henshaw and, combined with the development of the slide valve, produced a firing system which was very economical in energy terms.

The optimum weapon exit velocity using the minimum air is achieved by monitoring certain system parameters, matching them with a particular firing valve opening profile, and then controlling the valve to that profile. The generation of the opening profile is referred to as 'precalc', which was a series of algorithms and factors that have been developed and thoroughly tested. The parameters read by the launch controller are:

- Reservoir air pressure.
- Main air connection.
- Tube number.
- Weapon type.
- Boat speed.
- Overall launch factor.

By controlling the firing valve in this way a large number of different discharge characteristics can be available for the fire control system to deploy weapons to the best effect.

The design process was never static, and the natural desire to squeeze as much as possible into the design was curbed by the introduction of a design 'freeze' once the production contracts were placed. Changes invariably incur additional design costs, generally add weight to the submarine, and can cause programme dislocation.

## DESIGN DESCRIPTION

The system to be described has been designed to meet the Naval Staff Requirement mentioned earlier, and so is capable of handling and discharging a variety of weapons including mines. The discharge system can be controlled automatically from the control room or manually from the weapon stowage compartment

### Weapon Handling Equipment

The integrated handling system allows the functions of weapon embarkation, hoisting, traversing, stowage and loading to be carried out with weapons securely held at all times.

*Embarkation*

The embarkation system guides and supports the weapon during passage from the dockside into the weapon stowage compartment. It features a shallow angled pair of embarkation rails and a power operated system which will transmit the weapon along the rails independent of a shore crane. Inside the WSC a two wire hoist is used to lower the weapon to the appropriate stowage tier. (FIGS. 3 to 6).

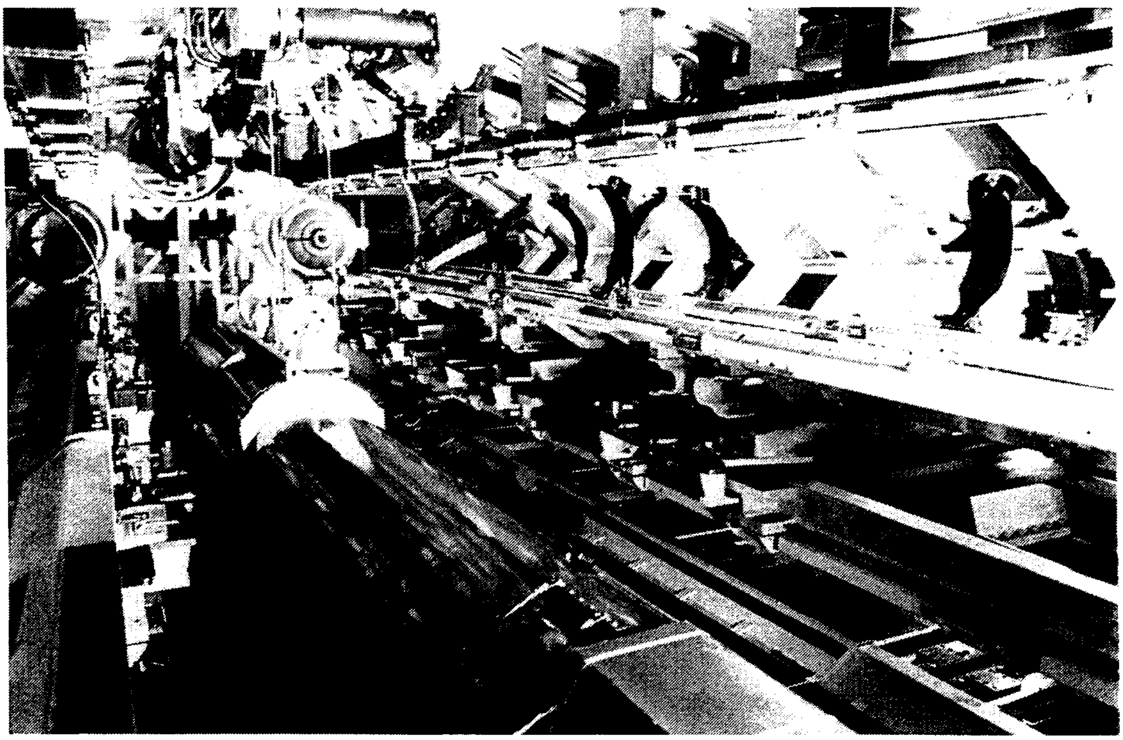

FIG. 3—EMBARKING HARPOON

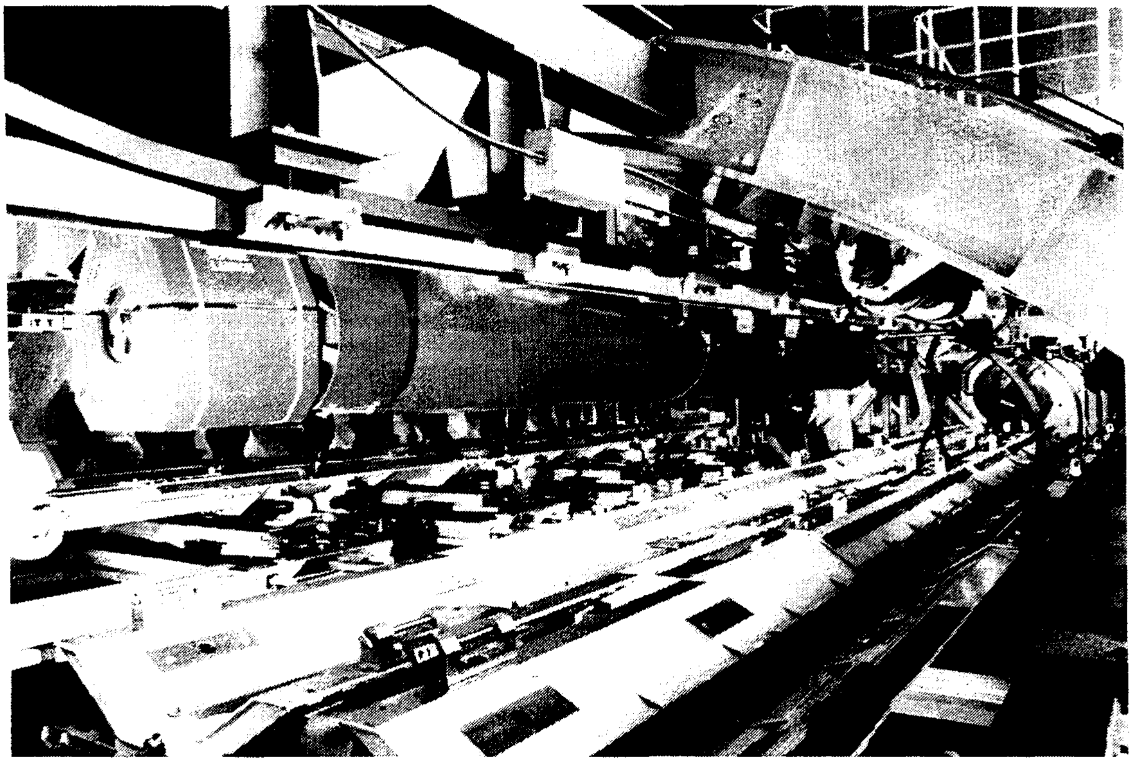

FIG. 4—EMBARKING HARPOON

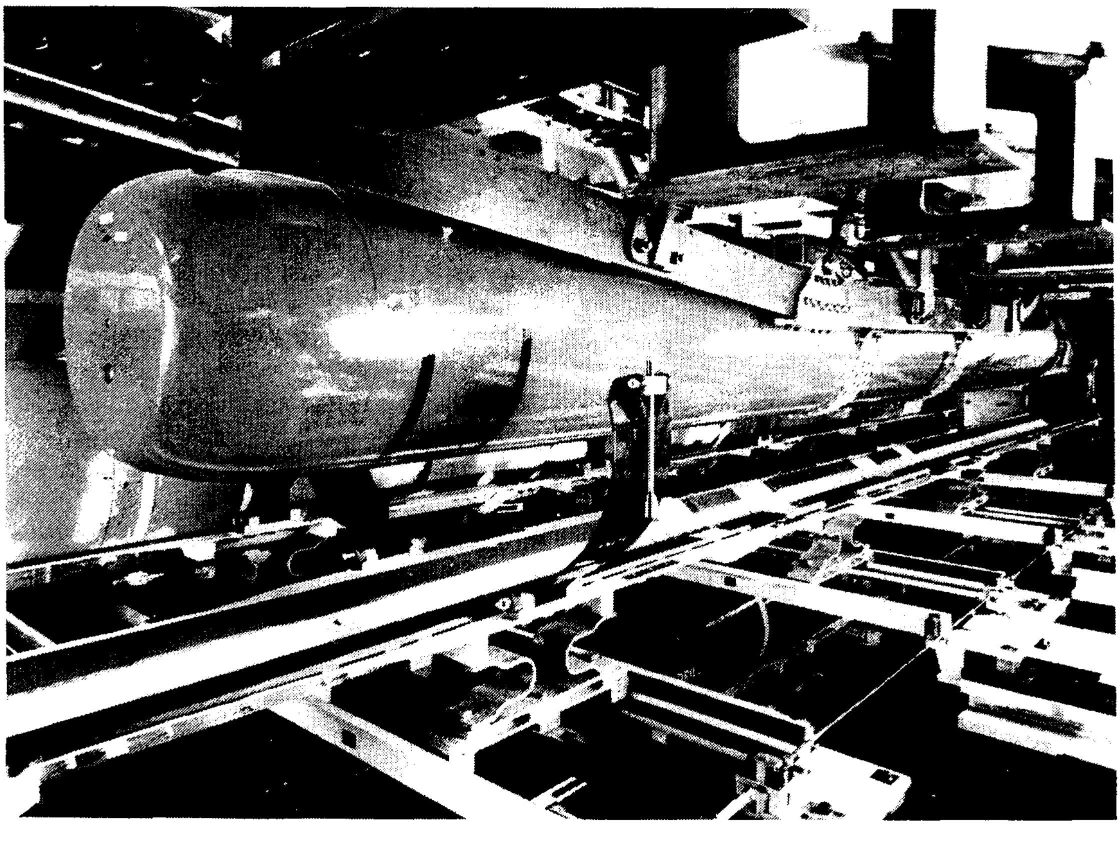

FIG. 5—HARPOON BEING EMBARKED ON TO THE UPPER TIER

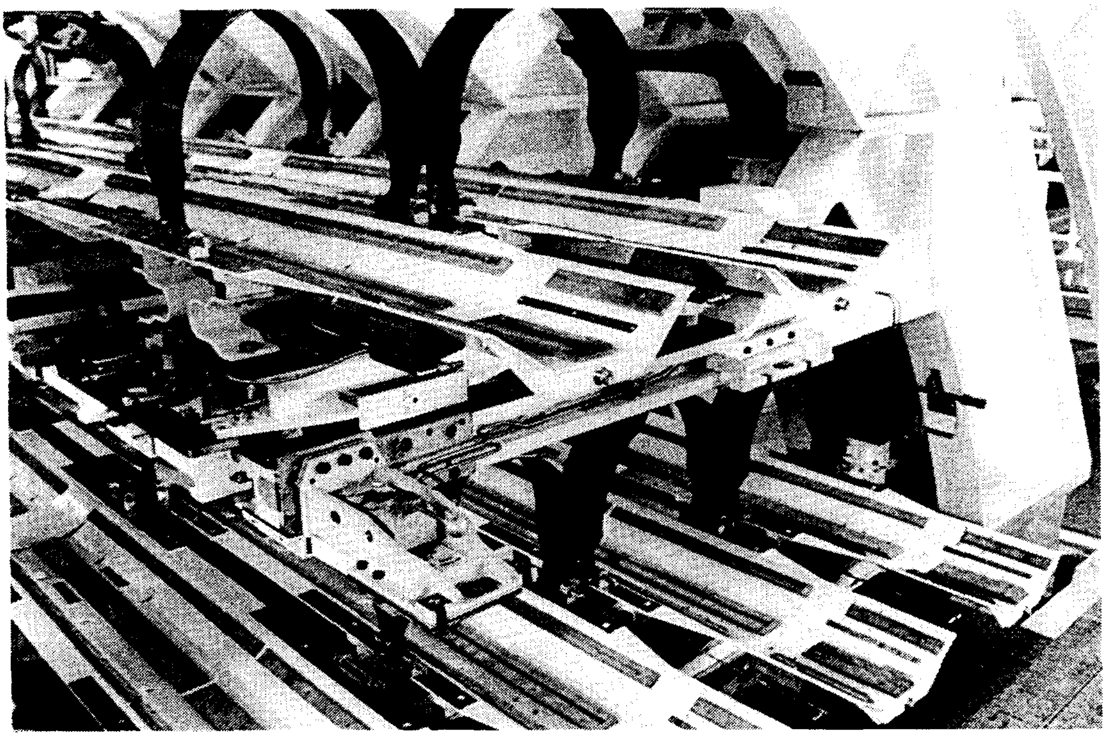

FIG. 6—TORPEDO STOWAGE TRAYS

The embarkation system consists of:

- Rails and support structure.
- Trolley and straps.
- Drive unit.
- Slot guide.
- Internal hoist.

The whole length of the embarkation rails, with the exception of the short length necessary to allow the closure at the embarkation hatch, is permanently attached to the boat's structure in order to minimize preparation time. These rails locate the wheels of the trolley and contain the embarkation rammer chains.

The drive unit consists of a hydraulic motor, an epicyclic gearbox, and a brake unit driving a torsion tube on each end of which is a sprocket box which transfers the driving force to the chains.

*Stowage*

Each weapon is supported on an independently shock mounted stowage which can deploy securing straps to match the weapon hard point positions. Dispensers (FIG. 7) will be stowed together with the weapons and provision has been made for spare units to be stowed independently aft of the stowages. The twelve identical stowage assemblies each comprise a weapon stowage tray, a number of securing straps and five traversing trolleys. The weapon stowage tray (FIG. 6) supports the weapon and dispenser over their complete length. The stowage trays are secured to the traversing trolleys via 'J' type shock mounts. At each corner of the trolley is a wheel which allows it to be removed athwartships along the trolley path.

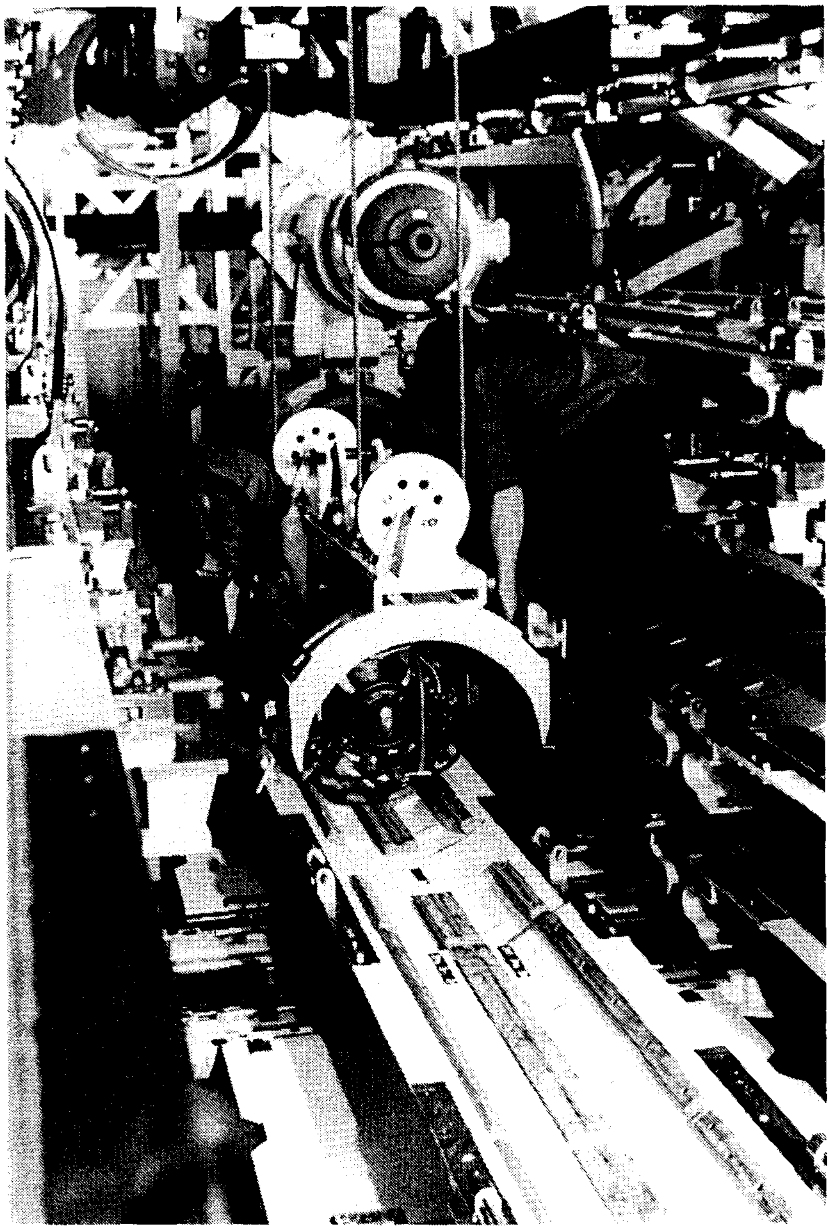

FIG. 7—EMBARKING WEAPON DISPENSER

*Traversing*

The traversing system allows a weapon to be moved from its stowage position to the ship's centre line from embarkation or to a load line for tube loading. The equipment consists of a set of trolley paths with integral stowage latches and a traversing drive system.

The traversing trolleys run athwartships on five trolley path plates which are secured to the upper faces of cantilever beams on the upper tier and to the traverse deck beams on the lower tier. The four forward plates contain stowage latches mounted on each loadline to retain the trolleys under athwartship shock loading. The first and fourth trolley plates are known as 'driven' plates and extend outboard to connect with traversing drive sprocket boxes.

The drive system comprises a hydraulic motor and brake unit driving a chain via a worm and wheel gearbox, line shafting and the pair of sprocket boxes all mounted outboard of the weapon stowage.

Portable paths are provided to bridge the space between the cantilever beams to enable traversing of weapons to and from the centre line.

*Loading*

An independent set of loading equipment is provided for each torpedo tube.

Each loading system consists of a hydraulic motor, epicyclic gearbox and brake unit mounted on the partial bulkhead aft of the weapon stowages, and it drives a chain rammer via a sprocket box. The duplex rammer chain runs in a steel guide which is permanently mounted above each loadline weapon. For the lower tubes the gap between the forward cantilever beam and the tube rear door is bridged with a chain rammer track extension piece which is manually rigged and stowed when not in use.

*Hydraulic System*

All weapon movement and control functions are powered by hydraulics alone. The functions are divided into port and starboard systems and controlled by two independent but similar hydraulic circuits. At the heart of the system is the rotary selector control valve that enables a single operator to control all weapon handling functions.

**Weapon Tube Equipment**

The weapon tube equipment embraces the tube structure and its associated operating and indication systems.

*Tube Structure*

The tube structure comprises rear door, inboard length, shipbuilder's length, slide valve, outboard lengths and bow cap.

The rear door and inboard length assembly are fitted to the after end of the shipbuilder's tube. The rear door (FIG. 8) is operated manually and is

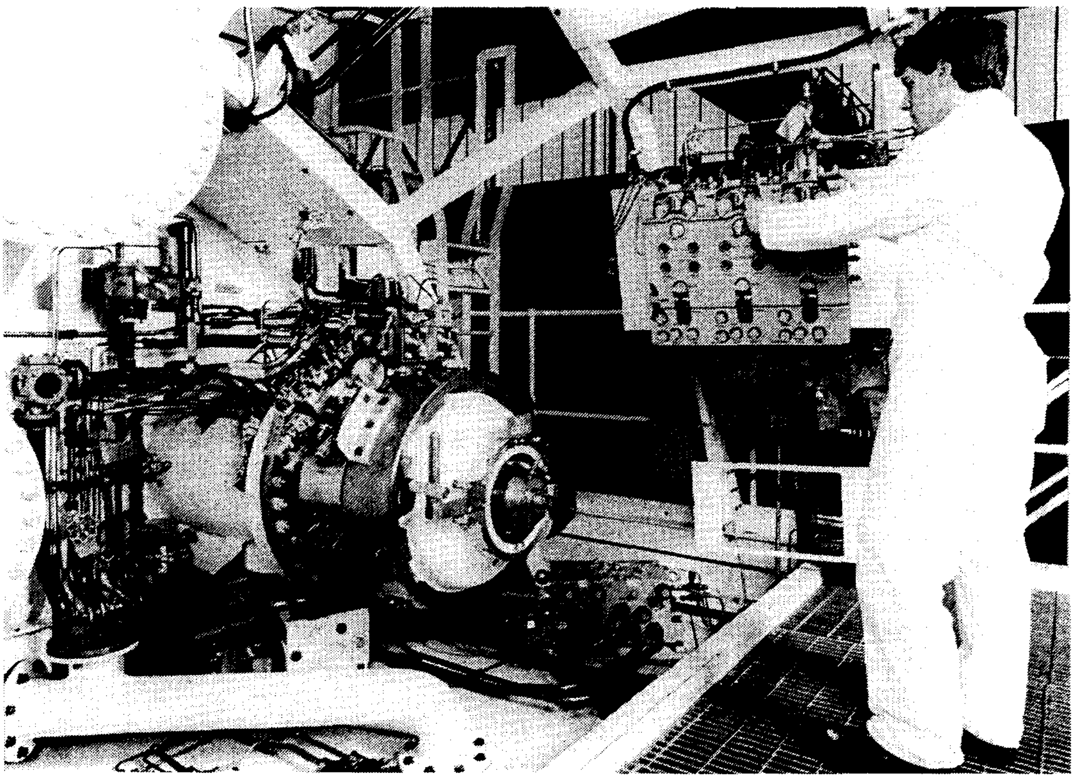

FIG. 8—REAR DOOR ASSEMBLY, WITH HYDRAULIC CONTROL, ON SYSTEMS TEST RIG

interlocked mechanically so that a check can be made to ensure that the tube is drained of water. It is also interlocked hydraulically by means of a lock bolt so that it cannot be opened unless the bow cap and slide valve are shut. Mounted in the inboard length are the weapon guide strips.

The slide valve body is fitted between the forward flange of the shipbuilder's tube and the after flange of the outboard length. Valve ports are machined into the body, on which are also mounted slides. The valve outer sleeve incorporates bearing pads which run on the slides. The slide valve is operated by its own hydraulic actuator.

The outboard length comprises two major sections of tube, each about two metres long. The aft section is welded into the impulse tank or water transfer tank (WTT) forward bulkhead and supports the top stop and rear catch which is hydraulically actuated. The forward section is welded to the main ballast tank forward bulkhead and supports the bow cap length and actuating mechanism. Both outboard length sections have weapon guide strips and sacrificial zinc anodes mounted to the tube bore.

The bow cap length is spigoted and bolted to the forward end of the outboard length. The bow cap is operated by its own hydraulic actuator and is independent of the bow shutter.

*Tube Indication System*

This system utilizes fibre optic technology and comprises sensors, cables, bulkhead penetration, hull glands and a light transmitting/receiving interface unit. The sensors are mounted on the tube structure and they monitor tube openings by the passage of light along the optical fibres. Sensors are designed to pass light when they are in the 'safe' condition. Signals are passed to the launch controller which displays them on the tube operator's panel (TOP).

## Weapon Launch Equipment

The Launch System consists of four sub-systems (FIG.1):

*External Sea Water Circuit*

Water is drawn from the sea to pressurize the water transfer tank. The water passes from the tank via a slide valve into the torpedo tube where it propels the weapon through the tube and the shutter aperture into the sea.

*Air Turbine Pump*

The ATP is the prime mover, drawing the water from the sea.

*Internal Air System*

High pressure air provides the energy source for the ATP and consists of a reducing station, an air reservoir, a programmable firing valve (PFV) and a flexible hose assembly. The reservoir is fed from the boat's main air supply through the high flow reducer and can be isolated from the rest of the system, storing a volume of air dedicated to discharge. The PFV is mounted on the reservoir exhaust port and controls the power delivered. The valve is of the sleeve type which can be precisely controlled hydraulically. A launch controller controls the position of the sleeve via the hydraulic control pack, by means of a servo valve and a linear variable displacement transducer, to deliver the required firing pulse to the turbine. Air is directed from the PFV to the turbine via the flexible hose which isolates any relative movement between the turbine and the rest of the equipment. The hydraulic control package also contains a timing circuit and a servo position control circuit to ensure fail safe and emergency facilities.

*Launch Control System*

The control system is required to provide a man machine interface for the operation of the weapon tubes. It also provides a controlling signal to operate the air turbine pump in such a way that the discharge is shaped to suit the weapon being launched, and ensure that a rapid, automatic salvo can be attained. At the centre of this system is a micro-processor incorporated within the launch controller and providing the necessary variability of control.

The launch controller (FIG. 1) interfaces with the command fire control computer via the weapon system data bus and displays a summary of the weapon tube and discharge system status on a Torpedo Operator's Panel. The controller incorporates safety checks that are independent of the hardware interlocks and correlates all system alarms including tube overpressure. Facilities for fault diagnosis and discharge instrumentation are also provided.

The controller consists of a processor card set and associated memories mounted on an internal bus together with interface cards which are able to communicate with the following system peripherals:

- Submarine weapon system.
- Torpedo operator's panel.
- Hydraulic control packages.
- Discharge equipment.
- Fibre optic conversion units via a private serial link.
- Discharge instrumentation recorder (in the launch controller).

Remote control of the unmanned fore-end is possible, providing the tube is flooded and the tube test/safe/fire switch on the TOP is set to Fire.

The fire control computer issues the fire command to both the weapon module and the launch controller by data bus, but the actual launch signal of 24 V d.c. is generated by the weapon module. This signal is switched through the launch controller, providing all system software interlocks are satisfactory, to the hydraulic firing solenoid (in the hydraulic control package). The hydraulic signal will pass through the tube hydraulic interlocks, providing they are correct, to the programmable firing valve. Air is then discharged, in a controlled manner, to the air turbine pump, which discharges the weapon.

Should the data bus or launch controller be inoperable for any reason, it is still possible to fire from the weapon module, assuming weapon and discharge system hydraulic interlocks are correct.

## Weapon Tube and Discharge Control System

The system has to operate the mechanical components of the weapon tube. It is necessary that the tube openings are operated safely, quietly and at a speed compatible with weapon requirements. The compact hydraulic system utilized also provides power to operate the flood and drain system valves. The system is depicted in FIG. 9 and consists of a number of separate assemblies:

(*a*) Control package. This contains solenoid-operated pilot valves controlling the operation of higher flow directional control valves.

(*b*) Actuator Control Valve package. This directs the main hydraulic fluid to the actuators. It also contains flow regulating and non-return valves.

(*c*) Flow Fuse packages, which protect the power source in the event of a major pipe failure downstream.

(*d*) Accumulators. These provide adequate flow during peak demand and also give a fall-back capability in the event of a power source failure.

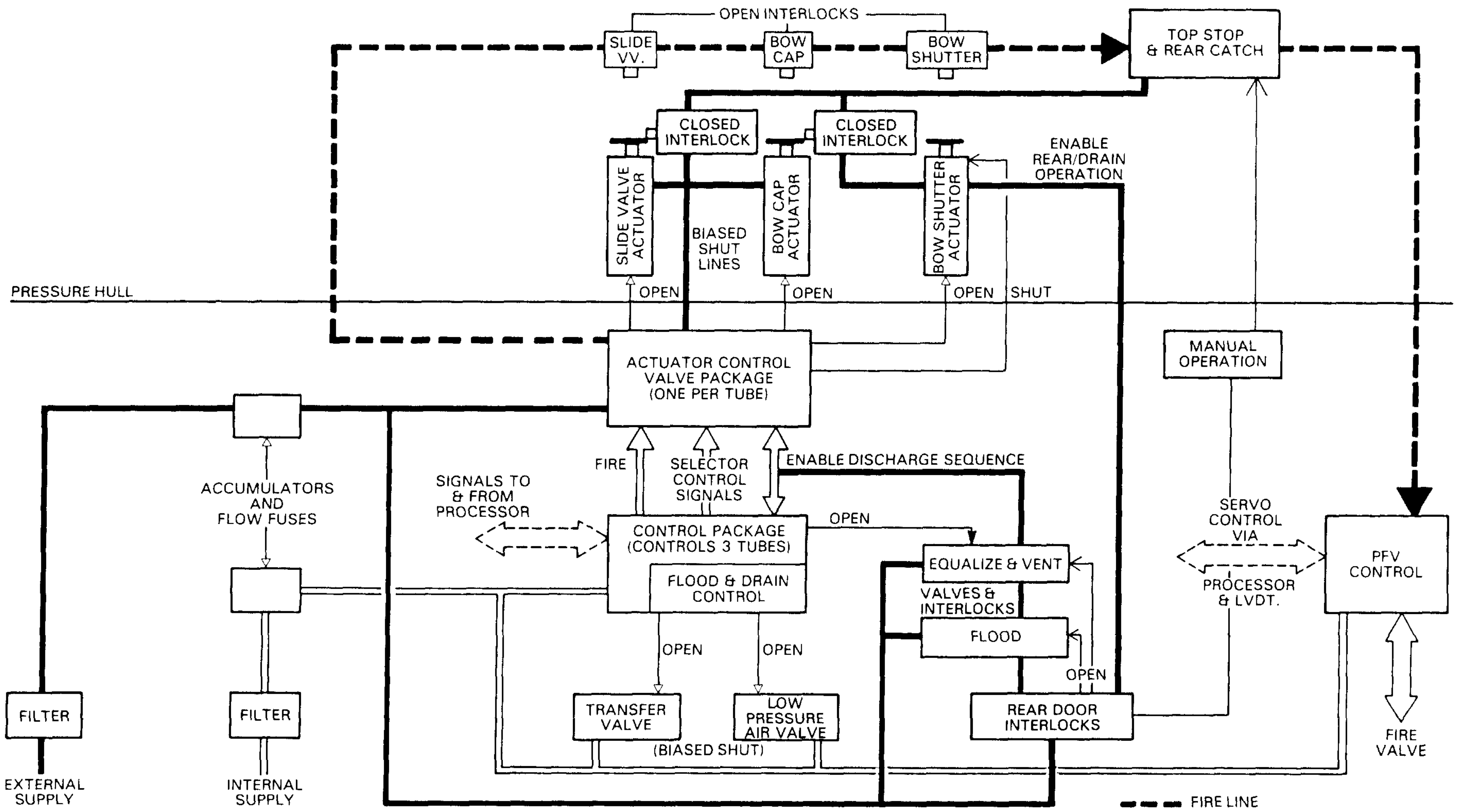


FIG. 9—HYDRAULIC DISCHARGE CONTROL SYSTEM FOR SINGLE TUBE
PFV: PROGRAMMABLE FIRING VALVE

(*e*) Actuators to operate the system hardware.
(*f*) Interlock valves to maintain hull integrity.
(*g*) Filters.
(*h*) Flood and drain system valves.

Each of these has been constructed using integrated circuit techniques employing cartridge valves and inserts in order to afford:

(*a*) Space and weight saving.
(*b*) Simplification of associated pipework and support bracketry.
(*c*) Minimization of toroidal sealing ring losses.
(*d*) Ease of maintenance.
(*e*) Higher system integrity.

All assemblies have, wherever possible, been designed to use common parts and either are constructed in corrosion resistant materials or have been suitably protected against corrosion by plating or other techniques, depending upon their location.

*Boat Supplies*

The system uses both the external and main (internal) hydraulic ring main supplies. The external main is used to serve all those assemblies which may come into contact with sea water, whereas the internal one caters for those in which salt water contamination of the fluid (OX-30) is unlikely.

*Pressure Level & Flow Demands*

The normal supply pressure range is between 138 and 240 bar, with a flow demand of up to 39 litres/minute which is limited using a flow controller sited in the filter packs. Return line pressure is maintained at not less than 5 bar to minimize the risk of cavitation.

*Filtration and Strainers*

The operating cleanliness level lies between R.N. Class 2000 and R.N. Class 6300 with reflushing at the upper limit. To this end, filters are fitted with 6 micron absolute elements together with 15 bar bypass valves and electrical and mechanical indicators set at 5 bar.

Further protection is afforded by disposable strainers in the inlets to all major assemblies.

*Accumulators/Flow Fuses*

External hydraulic fluid is supplied to each tube set via a dedicated accumulator of 20 litres capacity to enable a complete discharge sequence without replenishment. Control packages are supplied with fluid via a single accumulator for emergency piloting. The PFV control packages contain an accumulator large enough to permit a full salvo routine without replenishment.

Flow fuses and turbine flowmeters are fitted for line break protection and fluid loss indication.

*Operation—General*

All port or starboard slide valves, bow caps, bow shutters, equalizing valves, transfer valves and LP air valves are operated from either the port or starboard hydraulic control packages via pilot selector valves which can be either manually or electrically operated.

Flooding or draining of a particular tube, and rear door lock bolt withdrawal, are selected from pilot selectors contained within each tube rear door interlock package. All pilot selector manual overrides are positive and latch into detents in either open or closed positions. The tube interlocks are operated by the various doors themselves when at their extremes of travel.

Discharge profiles are controlled automatically at the port and starboard PFV control packages, but in the event of a failure within the control system, will switch automatically to fixed mode to ensure a complete discharge.

*Operation of Slide Valves and Bow Caps*

Slide valve and bow cap control circuitry is regenerative, i.e. actuator head ends are pressurized continuously to:

(*a*) Enable the use of smaller accumulators.
(*b*) Prevent the entry of sea water via actuator glands.
(*c*) Admit smoother operation on start-up.
(*d*) Enable the use of larger control orifices for speed regulation.
(*e*) Minimize the number of hull penetrations by providing a common source outside the pressure hull.
(*f*) Enable simplification of slide valve control circuitry.

Both slide valve and bow cap operating speeds are regulated using pressure compensated flow controllers to provide consistent operating times and ensure against the possibility of blockage. All service lines are protected against shock induced pressures and flows by high speed automatic reset shunt relief valves.

*Operation of Bow Shutters*

All bow shutter control circuitry is conventional, to cater for the loading imposed upon the shutter by the operating situation of the submarine. Shutter control circuits, like slide valves and bow caps, use pressure compensated flow controllers and high speed relief valves for speed regulation and shock protection respectively. In addition load control (over-centre) valves are fitted to cater for load reversal and counter-balancing.

*Interlock Arrangements*

The system has been designed to stand alone. That is to say that discharging can be safely effected even in the event of a total failure of its co-operating instrumentation system:

(*a*) Bow caps and slide valves are retained shut to enable flooding, draining or unlocking of rear doors.
(*b*) Flood and drain valves must be shut and rear door lock bolts engaged before equalization and opening of slide valves, bow caps or bow shutters.
(*c*) In the event of an abnormal disruption to either of the above then the system will—without operator intervention—return itself to a safe state.

Other Safety Interlocks ensure that:

(*a*) Vent valves must be selected to open before lock bolts can be disengaged to enable an additional check on outboard sealing integrity before freeing rear doors.
(*b*) Rear door lock bolts must be withdrawn before a weapon can be freed for withdrawal or manual shake-up of outboard top stop and rear catch lugs.

Firing Interlocks ensure that:

(*a*) To preserve firing efficiency, only one slide valve per side can be opened; opening of more than one is prevented by mechanical means in manual mode of operation, and by electrical interlocking by the fire control computer in automatic mode.

(*b*) Slide valves, bow caps and bow shutters must be fully open to enable firing to commence.

(*c*) A weapon cannot be freed for discharge until the firing pulse has passed through the slide valve, bow cap and bow shutter interlocks to gain access to and raise the relevant top stop and rear catch lugs.

(*d*) Firing pulses cannot be processed at the PFV packs until top stop and rear catch lugs have been raised and the firing line terminus cleared by selection of 'clear firing lines' by either automatic or manual means at the hydraulic control package.

(*e*) Once firing pulses have been received at the PFV control pack the active discharge phase will be completed regardless of failure of the control system.

*Control of the Programmable Firing Valve*

On the fire command the launch controller generates the opening profile and, once the hydraulic firing signal reaches the PFV control package, it opens the PFV. The position of the valve is sensed by its linear velocity displacement transducer which feeds back to the controller to complete the firing to the selected profile.

## Conclusion

The logical requirements to be satisfied by any weapon handling and launch system do not vary greatly from one class of vessel to another. As a result of this, it has been possible to produce a highly versatile system which is readily adaptable to meet most requirements—particularly the discharge operation and control system, which is independent of the location of the slide (or flap) valve, bow cap and shutter actuators and interlock valves. Different prime movers and their method of control or alternatively swim out weapons can readily be accommodated to give a range of discharge characteristics and levels of automation. The evolution of the design has been a long, complex and carefully considered process. Experience gained from the design of previous nuclear submarines and the wealth of research carried out of MOD(N) and others has been used to produce a technically advanced weapon handling and launch system.

*References*

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