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TRANSACTIONS (TM)

MACHINERY SYSTEM DESIGN FOR A PLATFORM EMERGENCY AND SUPPORT VESSEL

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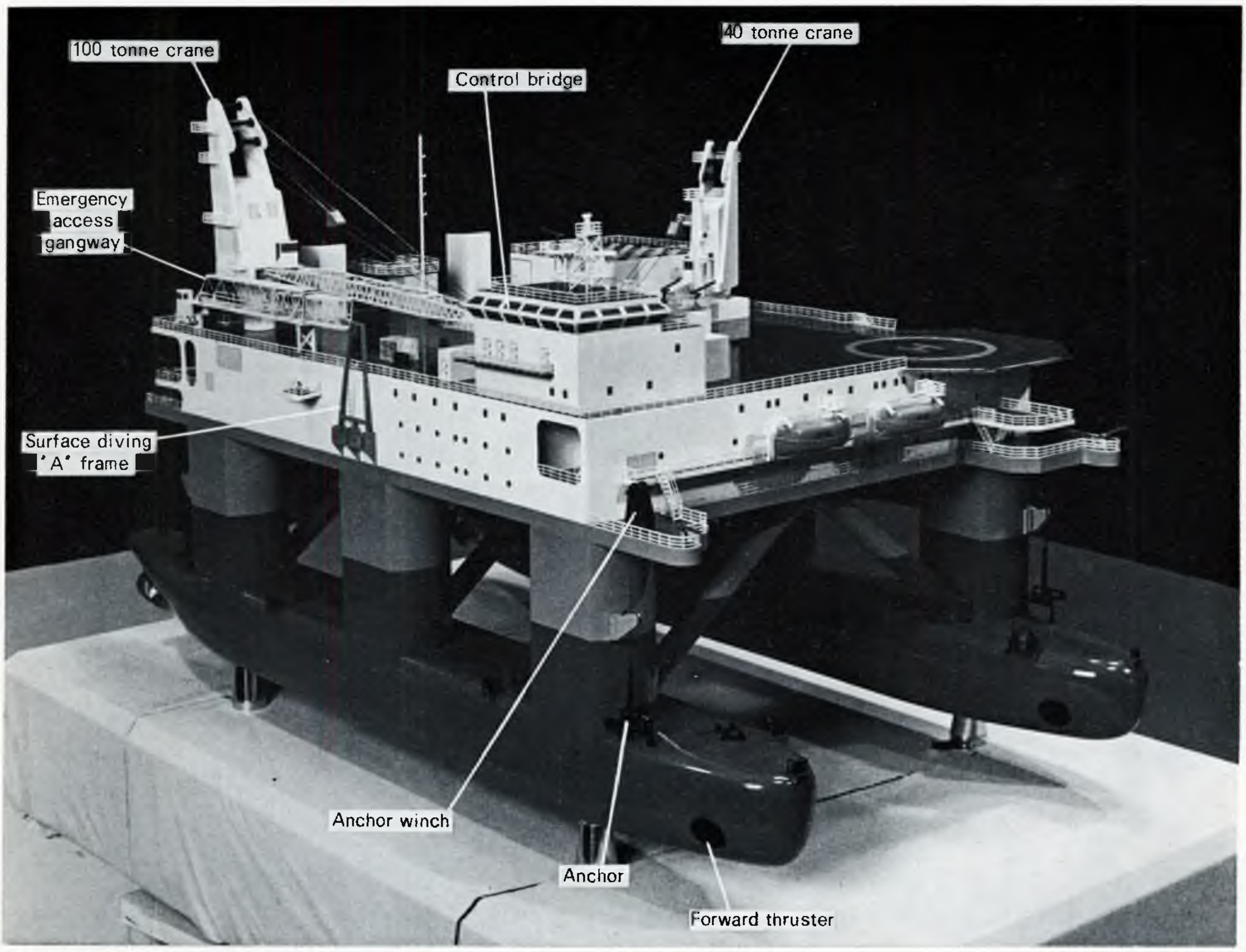

FIG. 1a. View on a forward starboard quarter of vessel model

SYNOPSIS

An Emergency and Support Vessel, the ESV, for British Petroleum and British National Oil Corporation is under construction by the Scott Lithgow Group to the preliminary design and detailed specification of BP Tanker Company. The vessel is intended for the day to day support of offshore oilfield operations and will have the most advanced facilities yet available to the offshore operators for dealing with emergencies arising on their installations. The paper gives a brief description of the vessel and its intended modes of operation, and deals with the philosophy and novel features of the design of the machinery systems.

INTRODUCTION

The ESV has been designed to the requirements of BP Petroleum Development Limited to fulfil an emergency and support function for the installations of the Forties offshore oilfield in particular, and also to those of BNOC for the Thistle oilfield. The design philosophy is such that this vessel will also be well suited to providing similar support to other oilfield installations in the area off the North West European Continental Shelf.

A joint Working Party of the field operators and the vessel designers was set up to evaluate the requirements for this type of vessel. Advice was also received from Consultants specializing in the control of oilfield emergencies and the design has progressed accordingly over four years as new requirements have been identified.

Many features of the vessel are novel and little guidance was available at the time from Classification Societies and Statutory Authorities. Therefore, it was necessary to produce a very detailed and comprehensive specification for the vessel to enable shipyards to quote realistically for the contract.

The Specification was completed in May 1977 and updated in April 1978 to take account of the Working Party views on operation in an emergency role, which were based on available experience of oilfield incidents, with particular recognition of the potential existence of a hazardous gaseous environment. The basic technical specification remained unchanged. The contract for construction of the vessel was placed in January 1979 and delivery is scheduled for mid-1981.

This paper discusses the principal machinery systems of the ESV. It has not been possible within the scope of a single paper to discuss all the systems, or any system in great detail, but an insight is given into the operational requirements of the vessel and the design philosophy adopted to meet those requirements with expectation of high vessel availability in the emergency and various supportive roles.

rm Emergency and Support Vessel

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ctively, BP Tanker Company Limited

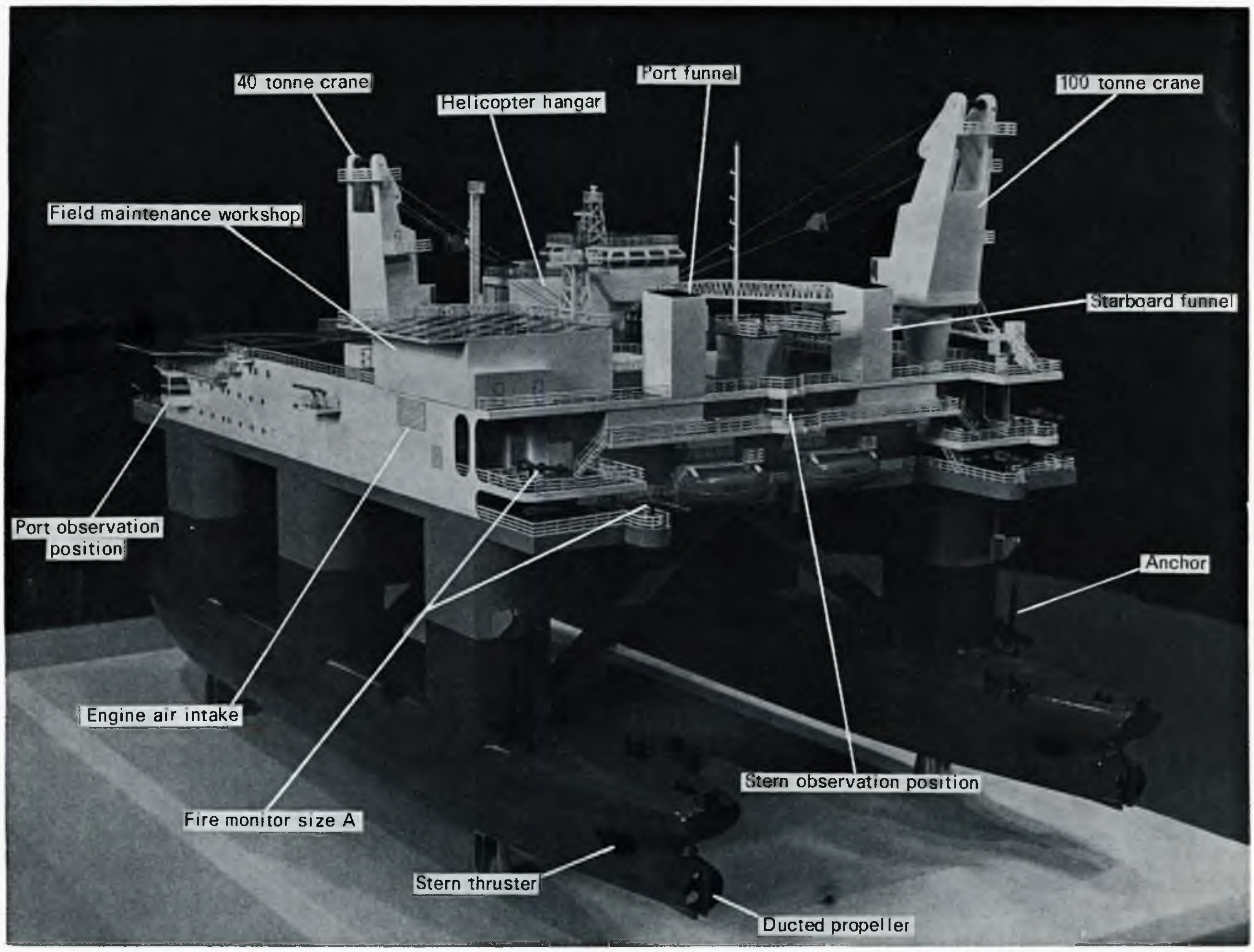


FIG. 1b. View on after port quarter of vessel model

OPERATIONAL REQUIREMENTS

The operational requirements of the vessel, in order of priority, have been identified to be as follows.

1. Emergency role

1.1 Provide a rescue and lifesaving facility to a stricken offshore installation by enabling direct evacuation of personnel (if possible), recovery of survivors from the sea, and to give succour and medical aid on board.

1.2 Act as a forward operations and communications centre in the event of a blow-out or fire on an installation.

1.3 Provide water drenching for cooling the main structure of the installation from a stand-off position, or at close quarters as necessary, and to conduct well kill operations to effect initial recovery of the installation.

1.4 Be capable of safely withdrawing from a hazardous gas concentration.

2. Support role

2.1 Provide accommodation for transient personnel.

2.2 Provide helicopter handling facilities, including hangar and maintenance capability for a field helicopter.

2.3 Provide a mobile and stable base for inspection and routine maintenance of the structure of an installation both above and below the waterline, and of pipelines in the general area of the oilfield; to deploy divers under saturation conditions to achieve this.

2.4 Perform urgent maintenance of structures and pipelines.

2.5 Perform salvage operations.

3. Additional design requirements

3.1 To have the ability to remain on station for extended periods, and to bunker sufficient fuel to enable fire fighting operations employing dynamic positioning of the vessel to continue for at least three weeks.

3.2 A transit draught speed in calm water of about 12 knots.

3.3 To have maximum, secure station keeping ability in the vicinity of an oilfield installation in poor weather conditions, without recourse to mooring, in order to maximize diving time.

3.4 To have a deck load capability of at least 500 tonnes, in order to carry portable equipment and materials required during emergency and routine support operations over and above the full complement, ship stores, fuel, fresh water, and stored mud powder.

3.5 To have dimensions suitable for entering drydock in North West Europe, and a transit draught suitable for entering harbour.

CLASSIFICATION

The vessel is designed for Classification by Lloyd's Register of Shipping for service in the area of the North Sea and up to the North West European Continental Shelf. The full Classification Notation for the vessel will be as follows.

✠OU 100A1 Support Vessel, ✠LMS, UMS, with descriptive notations: "Semi-submersible, self—propelled, dynamically positioned, firefighting ship 2 (10,200 cubic metres/hour) with water spray".

No detailed regulations for this type of vessel are yet in existence. For this reason, extensive discussions between the designers and the Department of Trade took place during the various design stages. Subsequent to these discussions, the DOT ruled that the ESV would need to comply with some of the requirements of the Merchant Shipping (Life Saving Appliances) Rules 1965 as applicable to both Class VII and Class VIIIA. In respect of damage stability the vessel would need to comply with the IMCO Code for Mobile Offshore Drilling Units.

GENERAL DESCRIPTION OF THE VESSEL

The vessel is of semi-submersible design, having twin pontoons with six vertical columns supporting the platform superstructure. A model of the vessel is illustrated in Fig. 1.

Each pontoon contains two motor rooms, two pump rooms, a steering gear compartment, fuel bunker tanks, fresh water tanks and water ballast tanks. Bulk mud powder is stored in four silos located in the base of each fore and aft column.

The platform contains two segregated engine rooms and associated spaces, a standby generator room, an emergency generator room, mud mixing and pumping plant, high tension transformer and switchboard spaces, a saturation diving complex, a hospital complete with operating theatre, and accommodation and associated service spaces for 220 personnel, of whom 120 are transient.

On the upper deck, at the starboard forward quarter, the control bridge and helicopter hangar and reception facilities form one block, a maintenance workshop and fire fighting platform are situated at the opposite quarter of the vessel, with a helicopter landing pad and parking for an additional machine between them. Two electro-hydraulic cranes are provided, a store crane of 40 tonnes and the main crane of 100 tonnes (25 tonnes at 53 m radius), together with a hydraulically operated emergency access gangway. A moonpool is provided in the centre of the platform and is capable of being plumbed by both cranes. Additionally, strong points are provided in the moonpool to allow the vessel to lift 500 tonnes about 3 m off the sea bed by adjustment of its own displacement.

The vessel is equipped with two electrically-driven main propulsion controllable pitch propellers in steerable nozzles, one in each pontoon. Lateral thrust is provided by four electrically-driven, transverse controllable pitch thrusters, situated in tunnels at the forward and after ends of the pontoons.

Dynamic positioning will be achieved by the two main propellers, the four lateral thrusters and the steering nozzles working together under the control of a computer.

As an alternative to, or as a support for, the dynamic positioning system, a four point anchoring system has been provided and the control system will recognize any combination of anchors. Under normal circumstances, the vessel will be able to deploy and recover its own anchors.

POWER SYSTEM SECURITY FOR DYNAMIC POSITIONING

Of all the operating requirements of the vessel, that which has the most far reaching effect on the design philosophy of the machinery systems is the capability of dynamically positioning close alongside a fixed installation, with or without anchor assistance, especially in adverse weather conditions. This enables diving to take place or provides help to deal with a well blow-out or other emergency in a potentially hazardous atmosphere. In the former case, any system failure may cause the diving bell to become entangled in the installation structure, with possible loss of life. Failure in either case may result in damage to the vessel and installation.

System reliability has been an overriding consideration in the selection of equipment and in the design of the auxiliary systems and controls. Material specifications have been written with a view to plant and system reliability, and to prolong intervals between major overhauls.

Operating limits for dynamic positioning (DP) operation have to be determined, initially from computer simulation, but finally from vessel trials. These limits have to be tested for a comprehensive series of possible mechanical, electrical and control failures. The final, accepted capability of the vessel to dynamically-position and deploy divers under saturation must reflect the most serious effect of component failure in the required vessel heading and in stated sea conditions. The system adopted significantly raises the standard for diving support vessels presently employed in the North Sea.

To enhance the safety of the vessel and of divers operating from the vessel, the following have been provided:

1) duplicated thrusters in fixed direction;
2) duplicated, and segregated, engine rooms and associated machinery spaces;
3) duplicated system components, with electrical supplies taken from different sources;
4) split switchboards in separate spaces;
5) main transformers in separate spaces;
6) alternative control stations, with manual control override of all automatic systems;
7) secure power generation system with back-up pitch limitation and preference tripping of non-essential load;
8) duplicated DP computers, position reference and sensing systems;
9) siting of DP control console alongside the main manoeuvring console, both having unobstructed views of overside working areas.
10) full machinery monitoring system and warning of incipient faults and power shortfalls.

As a part of the design process, two major computer dynamic simulations have been performed. One was to assess the dynamic positioning capability of the vessel, and the effect of major component failures on that capability. The other covered an analysis of fault protection and power plant stability. In the latter case, a computer program has been developed to assist the shipbuilder in checking the final selection of equipment parameters to ensure safe and stable operation of the entire plant during switching, during start-up and shutdown operations, and during various fault conditions.

CONSTRAINTS ON MACHINERY SYSTEM DESIGN AND EQUIPMENT SELECTION

A number of constraints on the design have had far-reaching consequences.

Increase in weight of platform and contents reduces the vessel stability, and the deckload capability at the operating draught, as well as increasing the transit draught. Since the main power plant is situated in the platform superstructure, weight of equipment has had to be carefully controlled. This has had a large influence on equipment selection.

To minimize the water services in the motor rooms and to avoid too many penetrations of the bulkheads between motor rooms and pump rooms, all pumping services are concentrated in the latter areas which are situated below the fore and aft columns. The congestion in the pump rooms has caused much work for the shipbuilder in obtaining a workable arrangement. The situation is not helped by the mud storage silos protruding into the pump rooms from the columns, since the silos have had to be installed as low as possible.

The specification requires the noise level on deck not to exceed 70 dB(A). To achieve this figure requires the provision of very large silencers on main engine exhausts. Little can be achieved to reduce the noise in the engine rooms with three engines operating at high loads, but flexible mounting of the diesel generator sets and their exhaust systems will reduce structure transmitted noise and vibration to the diving habitat chambers and to the accommodation.

Establishing watertight integrity between pontoon spaces has posed limitations on machinery arrangements in motor rooms and pump rooms. All watertight doors between these spaces are to be closed normally, and the size of door opening available poses access problems for machinery. The integrity of watertight bulkheads in the event of collision, or other damage resulting in flooding, has also posed problems in routing ventilation ducts and pipework. The requirements for damage control are being developed with the Classification Society and Statutory Authority as the design is progressed.

In order to achieve high utilization of the vessel and ensure that it can perform its roles for extended periods with high reliability and system security, equipment had to be very carefully selected against stringent specification requirements. Not only are component materials specified to a high standard, but all control equipment and machinery systems are specified in detail to ensure maximum reliability. Many proposals offered by manufacturers have not stood up to scrutiny for adequate reliability and fail safe facilities, and the authors can only assume that such manufacturers are not aware of the high standard required for vessels which dynamically position close to fixed structures.

MACHINERY ARRANGEMENT AND SYSTEMS

The machinery spaces are arranged, where possible, in a symmetrical manner about the fore and aft centre-line of the vessel. The machinery arrangement in each space is a "mirror-image" of the appropriate space on the opposite side of the vessel, except for handed machinery and controls. The natural fire barriers inherent in the construction of the vessel are used, as far as possible, to achieve security of machinery systems. To this end, the electrical switchgear and distribution system is designed to have equivalent security divisions as for the machinery systems. Fig. 2 shows the locations of machinery spaces.

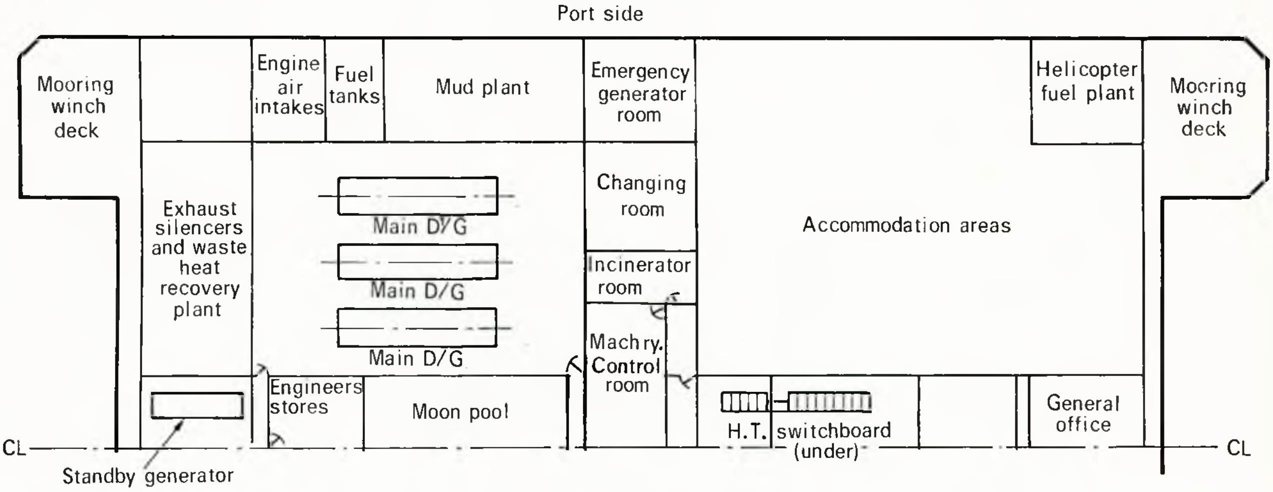
The machinery is arranged such that the port engine room is supplied by the necessary auxiliaries and storage tanks in that space and in the port pontoon. Similarly, the starboard machinery spaces are self-sufficient. Cross connections of important services for use in emergency are arranged in a fire-proof security zone between the two engine rooms.

The main generating machinery consists of six flexibly mounted, four stroke, diesel generator sets each running at 1000 rev/min and rated at 3.4 MW (E) at 6.6 kV and 50 Hz. Three sets are housed in each of the two separated engine rooms in the platform structure and are capable of connection in any combination to the main HT switchboard.

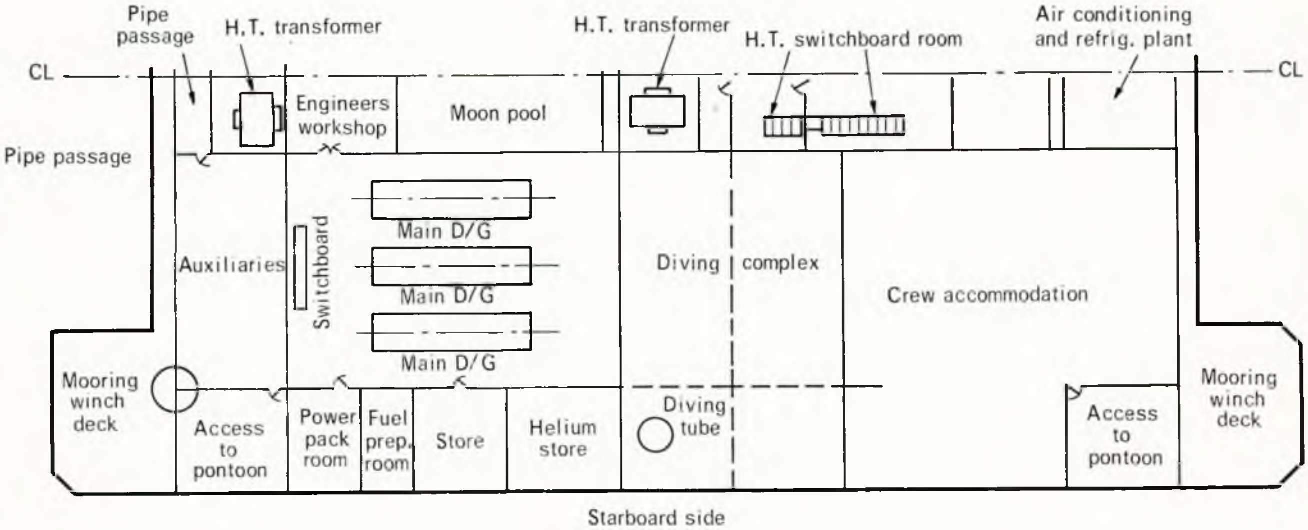
A radiator cooled standby diesel generator and a radiator cooled emergency diesel generator are provided, each in a separate compartment and with associated medium tension switchboards. The former unit is rated at 800 kW (E) and is to be used for start up of main engines, supplying mud plant loads, and for supplying essential services in the event of failure of the medium tension electrical system. The emergency generator is rated at 250 kW (E) since it must maintain essential supplies to the diving complex life support systems, as well as the usual emergency switchboard supplies, in the unlikely event of failure of the other generating systems. Both engines are entirely independent of services from either of the main machinery spaces, and initial start of either engine is achieved by use of an emergency hand started diesel driven compressor. The emergency diesel generator can additionally be started by hydraulic means.

Each controllable pitch main propeller is driven through a reduction gearbox at 220 rev/min, via clutch couplings, from either one or two propulsion motors. Each motor, rated at 2.24 MW (E), 6.6 kV, 50 Hz, is a squirrel-cage induction motor having a nominal speed of 1500 rev/min, and one motor per shaft is capable of driving a monitor fire pump via a clutch coupling as an alternative to propeller drive. Two similar motors are situated one in each forward pontoon motor room to drive the fire and drenching pumps through variable speed fluid couplings.

Each of the four thrusters is driven by a similar motor to the propulsion/fire pump motors but rated at 1.5 MW (E) at a nominal



2a) 'A' deck 29.7 m AB (Stbd. side is opposite hand.)



2b) Lower deck 24.5 m AB (Port side is opposite hend.)

FIG. 2. Arrangement of machinery spaces at lower deck level

peed of 1000 rev/min. Fig. 3 shows the power system scheme for the vessel.

The diesel engines operate on gas oil, this being the present North Sea standard. However, provision has been made in the design to facilitate any future conversion of the main engines to burn fuel oil.

Engine and auxiliary machinery cooling is achieved by integrated high temperature and low temperature freshwater cooling systems, thus reducing sea water systems on the vessel to the minimum necessary.

Waste heat from the main diesel generator exhaust systems is recovered in hot water boilers for production of potable water and for vessel and service heating. No steam is employed on the vessel. Electrode boilers are provided to maintain the heating load when engine output is too low for adequate waste heat recovery.

Four freshwater generators are installed, three of which will provide the maximum daily requirements of the vessel. A mean daily consumption of 60 tonnes of potable water has been estimated.

Compressed air is produced for engine starting at 30 bar g and is reduced in pressure and dried for control air. General service air is supplied at 8 bar g and 1020 m^3/h free air delivery (FAD) is available to the diving complex for aeration of the diving tube air/water interface during bell recovery. Other compressors supply motive air for the transport of mud powder and agitation of the mud storage silos.

A large number of hydraulic systems exists on the vessel, the main ones being for operating remote valves, watertight doors, fire monitors, anchor and mooring winches, the emergency access gangway, taut wire winch, diving service winches, and deck crane drives. Rationalization of the different hydraulic systems has been a design criterion in order to reduce the number of power packs and system components. However, in practice, the wide range of operating pressures required by the various systems has prevented rationalization being taken to an optimum level.

POWER GENERATION

A load analysis was performed in detail for each operating mode of the vessel, and a maximum load of about 20 MW (E) was calculated, but only required when operating in the emergency mode in severe weather conditions. Table I gives a summary of the anticipated maximum loads for each operating role of the vessel. Additionally, an assessment of the environmental conditions for the Forties and Thistle Fields was made to establish the possible operating limitations of the vessel, and the periods when maximum plant availability would be required. This enabled an assessment of available maintenance time for the prime movers to be established. A wave height exceedance diagram is presented in Fig. 4 for an area of the North Sea including the Thistle Field.

A full technical and economic assessment of the available types of power plant was made. Emphasis was placed on engine availability and on the power/weight ratio, governing and transient performance, part load performance and waste heat availability, running costs, fuel bunker requirements to meet the stated endurance of the vessel and maintenance requirements. This assessment led to the clear-cut decision in favour of the selected central power generation system. The alternative options, employing direct-drive gas turbines, direct drive diesels, gas turbine electric, "father and son" arrangements, and a combination of gas turbines and diesel engines, were found to be less suitable

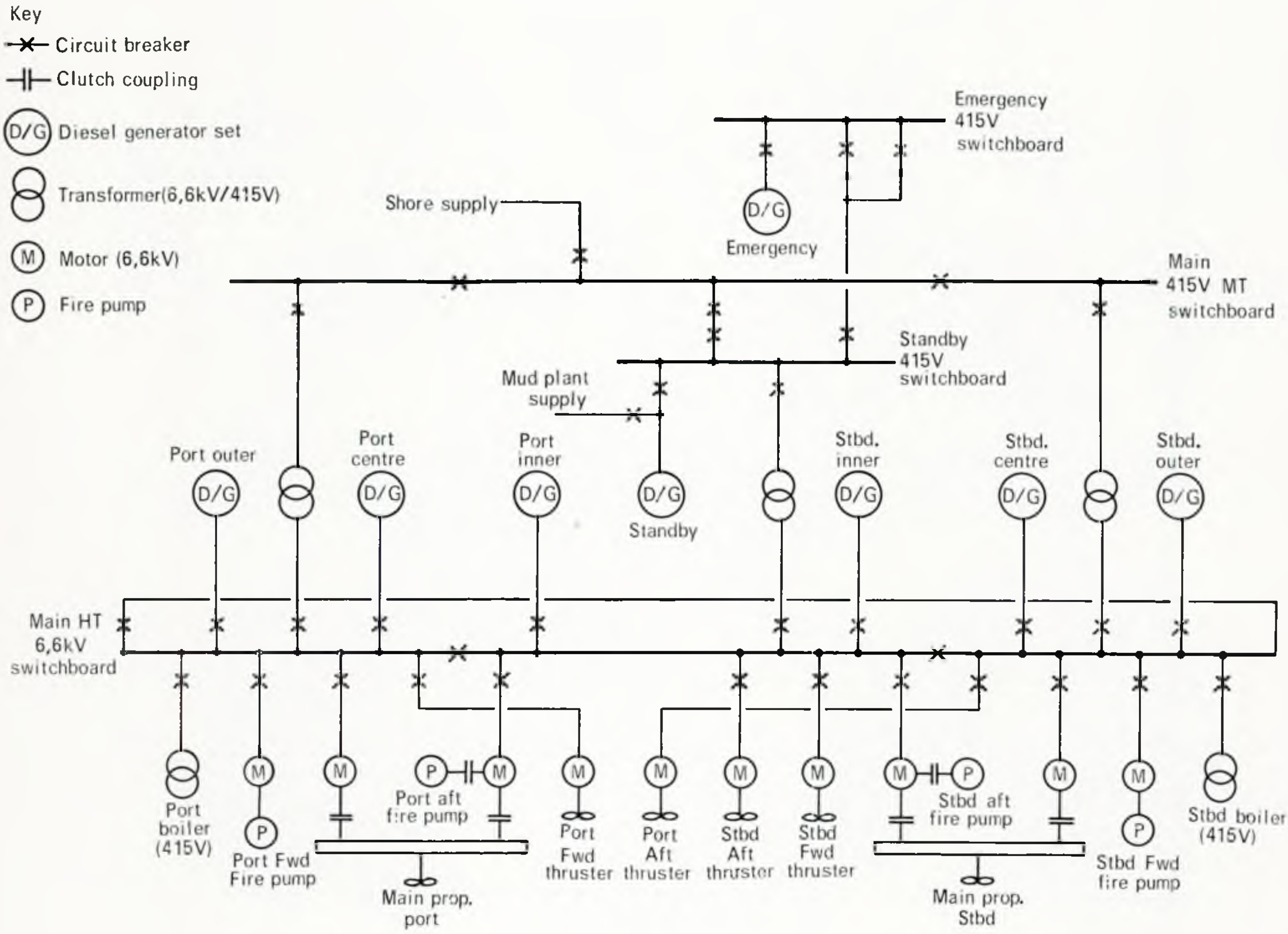


FIG. 3. Power system arrangement

TABLE I. Load Analysis Summary for Vessel

	CONDITION	VESSEL AVAILABILITY DAYS/YEAR		NUMBER OF HT MOTORS			ELECTRIC LOAD 27°C AMBIENT (HEATING: 1184 kW (M))				ELECTRIC LOAD —3°C AMBIENT (HEATING: 3000 kW (M))			
		Forties	Thistle	Thrusters	Propulsion	Fire Pump	Total Boiler MW	Total Mean MW	Total Peak MW	No. engines for security	Total Boiler MW	Total Mean MW	Total Peak MW	No. engines for security
1	Anchor	363	359	0	0	0	0.4		2.77	2	1.68		4.05	3
2	Free running	—	—	0	2	0	—		6.14	3	0.9		7.04	3
3	Free running	—	—	0	4	0	—		10.78	4	0.5		11.28	4
4	D.P., diving and anchor	363	359	2	2	0	—	8.57	10.12	4	0.6	9.17	10.72	4
5	D.P. and diving	356	346	4	2	0	—	10.47	12.64	5	—	10.47	12.64	5
6	D.P., diving and crane	256	230	4	2	0	—	10.7	12.87	5	—	10.7	12.87	5
7	Full D.P.	356	346	4	2	0	—	10.27	12.44	5	—	10.27	12.44	5
8	Close in emergency (D.P. and anchors)	256+	230+	2	2	3	—	14.71	16.26	6	—	14.71	16.26	6
9	Evacuation/land emergency team/stand off and pump	356	346	4	2	3	—	16.18	18.35	6	—	16.18	18.35	6
10	Stand off cooling (max)	356+	346+	4	2	4	—	18.05	20.22	6*	—	18.05	20.22	6*

Notes:

1. *No security in event of one engine trip. 2. In items 4 to 10, electrical loading assumes maximum thruster power allocation is being utilized to maintain station in limiting weather and sea state conditions.

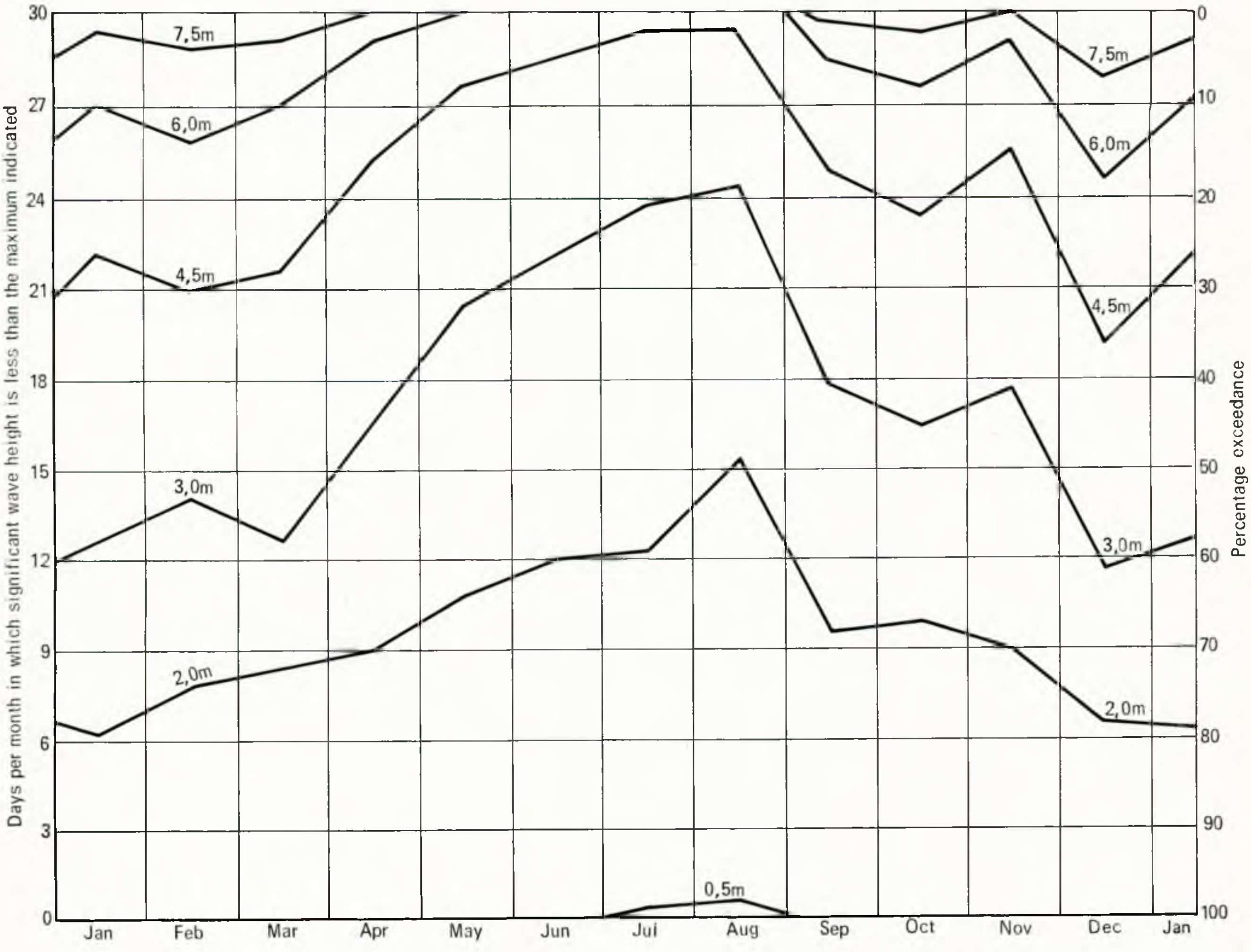


FIG. 4. Significant wave height occurrence—days/year for Thistle Field. (Forties Field similar)

DIESEL GENERATOR CONTROL PHILOSOPHY

The diesel generator control philosophy is that power failure cannot be tolerated. Hence, the loading on running engines will not exceed a value when in automatic control so that, should one generator trip off the busbars, the load on the remaining engines will not exceed 110% of rated engine load.

When a diesel generator set circuit breaker trips:

1) Pitch will automatically be reduced on the propellers and thrusters by the dynamic positioning computer, when load on other engines is in excess of 100%.
2) Similarly, pitch will be reduced by the pitch control systems should the load on any engine reach 110%.
3) Preferential tripping of non-essential load will occur in steps.

Under these circumstances, the diesel generators will only have to sustain 110% load for a few seconds after one of the running sets has tripped; which is well within the Classification and Specification requirements.

To prevent unnecessary starting and stopping of engines, the engines selected for Autostart are arranged with a shutdown switch which operates if the load falls below, and remains below, the shutdown point for 15 minutes.

During diving operations, and when dynamically positioning, a power failure could cause loss of life and serious damage to the vessel and any adjacent fixed installation. When free-running (except when in a congested seaway), at anchor, in harbour, and when no diving is taking place, a power failure is unlikely to result in a serious consequential accident.

A standby main diesel generator will be armed for start on selected alarms initiated by main diesel generator system faults. On one (or more) main diesel generator trip, the selected standby engine(s) should have already started automatically and should be ready to share load soon after the first engine tripped.

On main HT or MT power failure, the standby diesel generator will start automatically and energize the MT busbars. Fig. 5 shows the start-up and shut-down sequence envisaged and the maximum anticipated loads for each vessel role.

The governing and transient performance of the engines was examined critically. Fast response to large load changes is considered desirable for this type of vessel.

Electronic droop governing will be provided for each main diesel generator set. Hydraulic droop governing will be applied to the standby diesel generator which will only have to run in parallel with main diesel generators for limited periods, particularly during start-up of the main sets. Isochronous electronic governing was considered for the main sets but it became apparent that certain failure modes of this system can introduce major instabilities into the power system. Failure on the "paralleling lines", for example, could result in load swinging between two groups of diesel generators resulting in a blackout.

PROPULSION DRIVES

Fig. 6 shows the propulsion, thruster and fire pump drive arrangements. The stern gear arrangement will allow examination and maintenance of the stern bearing and shaft seal from inside the vessel.

Each propulsion gearbox is a unidirectional, single reduction, twin input, single output unit, with integral thrust bearing and fitted with a shaft brake. The gearing is specified to be capable of accepting the loadings imposed when:

i) the first motor, having been clutched into the stationary shafting and with the propeller at zero pitch, is direct-on-line started;
ii) when the second motor at rated no load speed is clutched to the gearing when the first motor is developing full load;
iii) when the propeller is absorbing full power from both motors and one clutch disengages or one motor trips.

The shaft brake is provided to facilitate re-engagement of the drive as soon as possible after the clutches or driving motors have tripped, and also to make inspection and maintenance possible on a propulsion line when the other propulsion line is in operation. The brake control is automatic, with manual override, and has interlocks to prevent the brake being applied unless both propulsion clutches are disengaged; and, when the brake is engaged, to prevent first motor start when clutched into, or clutch engagement to a running motor.

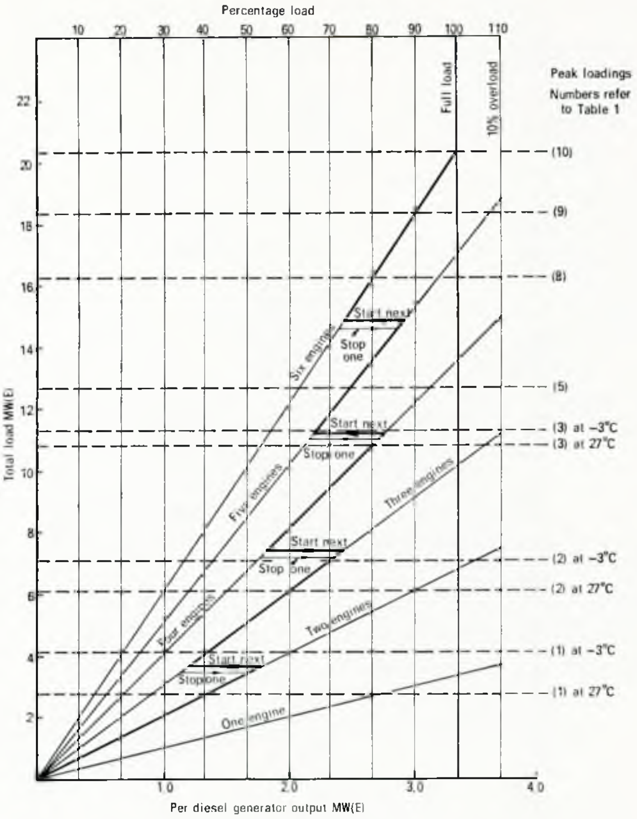


FIG. 5. Diesel generator start and stop sequence

The clutch couplings provided between the gearbox and motors, and motor and fire pump, are air operated and are rated to be capable of accepting slip for short periods, particularly when the second motor is clutched in at full speed to an already driving gearbox.

When two motors are driving the propeller at high loads up to full power and one motor trips or one clutch disengages, the remaining motor and clutch must accept twice full load torque during the time taken for propeller pitch to be automatically reduced. The clutches are arranged for automatic disengagement when slip persists for longer than a few seconds. Suitable alarms are provided.

The pitch control systems of the main propellers and thrusters are required to operate continuously over small pitch changes when in the dynamic positioning mode, and account must be taken in the design of components to prevent unequal wear over the length of travel of these components causing unstable pitch control. In event of pitch control system failure, the main propeller pitch is arranged to remain "as is", and the thruster pitch is arranged to return to zero.

Main propeller pitch is arranged to be automatically reduced to an acceptable level within two seconds on clutch slip, on clutch disengagement, or, on failure of one motor when two propulsion motors are driving the propeller. The pitch control system for thrusters and main propellers will reduce pitch to an acceptable level on driving motor overload and on an individual generator load reaching 110%; and pitch will be restored to the desired level on the overload being removed.

The propulsion control system will be interlocked with the motor starting sequence such that a propulsion or fire pump motor cannot be started unless: lubricating oil and cooling systems are operating, propeller pitch is at zero or a fire pump discharge valve is closed, clutch operating air is available, all other HT motors are stopped or their run up is complete, there are four main generators on line and two HT bus section circuit breakers closed.

Manual override is provided and will also allow motor starting with only two generators on line. This facility is provided to ensure that propulsive power may be readily restored in the event of power failure arising from the loss of one engine room, a pontoon pump room, or section of the main HT switchboard.

CONTROL STATIONS

The principal control station is the Control Bridge, from which all vessel operations are controlled. This area has all round visibility and contains the control consoles for navigation and normal propulsion, dynamic positioning, anchoring, ballasting, main bilge pumping, vessel fire mains, external fire fighting monitors, vessel drenching system, emergency services (fire and gas alarms and shut-downs, fire door and watertight door controls) and communications.

An emergency control station is provided at the after end of the vessel which may be used for control of operations taking place over the stern (such as fire fighting and crane operations) and in the event of the Control Bridge having to be evacuated.

The vessel is designed for unattended machinery space operation and normal control from the Control Bridge. However, a Machinery Control Room is situated outside and between the two engine rooms to facilitate setting up the required generating, propulsion and fire pump systems, for alarm monitoring displays and for emergency control of propulsion.

Each machinery space is provided with a local control centre. In the event of loss of the machinery control room, electrical switching and paralleling can be performed from the HT switchboard rooms, engine control may be achieved locally, and propeller pitch control and clutch control is available in each aft motor room.

MACHINERY SURVEILLANCE AND CONTROL

Each machinery space contains a local control centre (LCC) which comprises a section board of motor starters for pumps and equipment in that vicinity, local instrumentation, local alarms (grouped to the main display in the machinery control room), alarm beacons, group alarm indication, communications, Engineer's call alarm button and machinery round deadman alarm.

The machinery control room (MCR) display contains individual alarms which advise of major system faults, and group alarms indicating which LCC is in alarm. The alarms on LCC are secondary alarms which can be remedied only from the machinery spaces concerned, and also indicate which LCC is in alarm. Alarms can only be accepted at the panel on which they appear as individual alarms.

Full UMS operating philosophy applies, with the addition of a "deadman" system which ensures that, in the event of the Duty Engineer becoming incapacitated during his rounds, he can be quickly found.

Only selected instrumentation is provided in the MCR, other instrumentation must be read local to the equipment concerned. The alarm system provides minimal read out of system parameters, being basically a switched system.

Certain important alarms are taken to the relevant control consoles in the Control Bridge, and also to a master alarm panel between the manoeuvring console and dynamic positioning console on the Control Bridge.

The alarm system contains the following numbers of channels:

Control Bridge — 40 divided between three displays.
Machinery Control Room — 268 divided between two displays.
Engine Rooms — 84 in each space.
Local Control Centres — 144 divided between six units.

SAFETY OF VESSEL AND PERSONNEL IN DANGEROUS GAS CONCENTRATIONS

The ESV is designed to minimize the risk of ignition if it is caught in a dangerous gas concentration when performing the well kill or fire-fighting roles. It was not economically or technically justified to make the vessel entirely proof against flame or explosion for continued operation, but the vessel will be capable of withdrawing safely from such a situation.

Table II gives details of the gases which will be evolved at the well head in the event of a blow-out. The concentrations to be expected will lie within the ranges shown depending on the location of the well in the North Sea. For wells producing gas, as opposed to oil, the concentration of methane increases to about 94 molecular per cent, with four molecular per cent of other hydrocarbons, the balance being nitrogen, hydrogen and carbon dioxide. Pentane and heavier hydrocarbons, evolved at the blow-out, will condense at normal atmospheric conditions. Hydrogen sulphide is not normally present.

Any vessel, when operating in the vicinity of an installation experiencing a well blow-out, with or without fires, may be caught in a dangerous gas concentration. Factors to consider are no wind, change of wind direction, evaporation of an oil slick, local concentration of heavier-than-air gases and gas issuing from a well after a fire has been extinguished.

TABLE II. Details of gases evolved during a blow-out

COMPOSITION	RANGE MOL %	ATMOSPHERIC PRESSURE AND 15°C			IGN. TEMP °C
		DEN. REL. TO AIR	EXPLOS. LIMIT (% VOL AIR)		
			LOWER	UPPER	
Water vapour	0 —10		—	—	—
Nitrogen	0.5 — 6.2	0.97	—	—	—
Carbon dioxide	0.05— 1.6	1.52	—	—	—
Methane	35 —42	0.56	5	15	540
Ethane	9.3 —12.3	1.04	3	12.4	515
Propane	12.5 —22.1	1.52	2.1	9.5	450
n—butane	6 —11.2	2.00	1.8	8.4	405
i—butane	1.3 — 3.9	2.00	1.8	8.4	450
n—pentane	2.9 — 4.9	2.49*	1.4	7.8	260
i—pentane	1.8 — 3.7	2.49*	1.4	7.6	420
Hexane	2.1 —11.6	2.97*	1.2	7.4	225
Heptane	0.1 — 1.8	3.46*	1.05	6.7	215
Octane	0.01— 1.02	3.94*	0.95	3.2	220
Nonane	0 — 0.21	4.43*	0.85	2.9	206
Decane	0 — 0.22	4.91*	0.75	5.6	250

Molecular weight 36.4 to 38.4

Notes:

1. *Gas evolved at blow-out will condense at normal atmospheric conditions.
2. Hydrogen sulphide was not found in the samples taken from the three North Sea oilfields investigated.

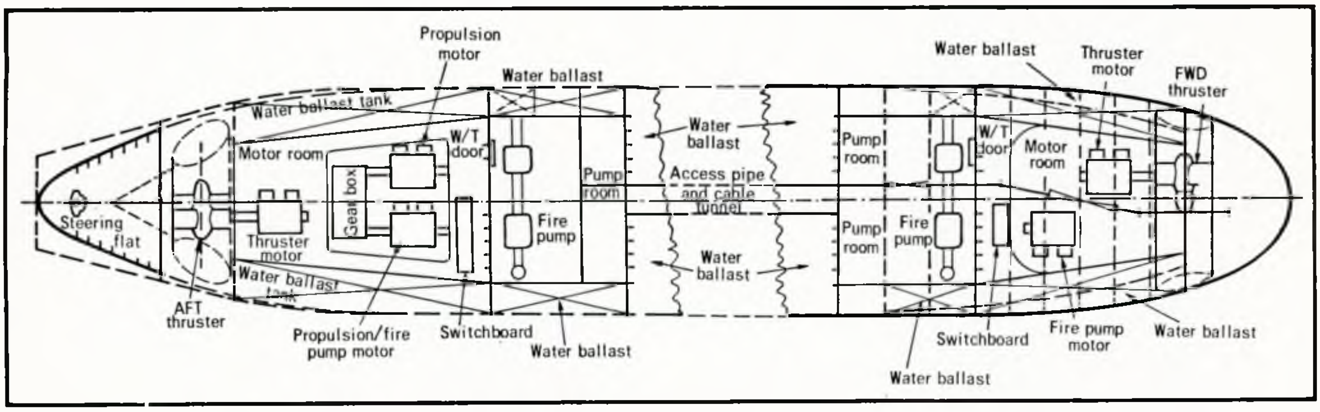


FIG. 6. Arrangement of pontoon spaces showing propulsion/fire pump drive

The capability of human beings to perform functions in a sustained manner deteriorates seriously when the oxygen content of air falls to 15%. This is equivalent to about 30% methane. In practice, the personnel will have been withdrawn long before this level is reached.

Toxicity of the gases varies: methane has no physiological effect if sufficient air for supporting life is present. Ethane is similar to methane at least up to 5% by volume, 10% by volume of propane may cause dizziness after short periods, 1% of butane causes drowsiness, 9% of pentane produces unconsciousness within one hour and 0.5% of hexane causes dizziness. Hydrogen sulphide can be fatal if a concentration above 600 ppm is experienced for 30 minutes.

Diesel engines when at about 40% load could run away at 2% by volume (40% LEL) of methane. At higher loads, they will probably run safely up to 3% by volume (60% LEL) of methane, although unstable running may occur. However, opinions vary and one authority believes that 8% by volume of methane would be the limiting concentration for overspeed. The other hydrocarbons are more dangerous, since self ignition could take place in the turbocharger or cylinders at any concentration, and the engine could easily run away or become too unstable to retain load.

It would thus appear that the engines would have to be stopped before the lower explosive limit of methane is reached. Under circumstances where gas in such quantities is ingested with the combustion air, engines cannot be stopped by normal means and shut-off valves are required in the combustion air system.

The features of the design catering for gas operation are:

1) Provision of a gas detection and alarm system covering the entire vessel.
2) Means of securing non-essential areas prior to the vessel entering a potentially dangerous zone. This involves manual closure of ventilation intakes and exhausts (except for main engine rooms), stopping all non-essential space fans, placing air conditioning systems on full recirculation, tripping electrical supplies to exposed areas including radar and ship to shore transmitters, and shutting down unnecessary heat sources such as the galley and incinerator. All access to deck from the interior of the vessel is by air lock with an outer gastight door.
3) Provision of an alarm system to monitor whether air lock doors and ventilation closures are open or closed.
4) Means to close essential ventilation intakes and exhausts remotely on gas alarm. This is achieved from one push button on the Control Bridge. The engines have separately ducted air to their turbochargers, and these ducts are closed automatically on engine overspeed or unstable operation.
5) Electrical transformer, switchgear and equipment spaces are provided with space coolers so that these areas can be made secure prior to entering a potentially hazardous area.
6) Means to prevent surface temperatures in excess of 200°C, and for drenching of engine exhausts at funnel exits.
7) Means to achieve rapid disconnection of services supplied to an installation during emergency action (mud, fire main supply, compressed air) to enable the vessel to withdraw quickly.

Since there is a possibility of a total plant shut-down occurring when the vessel meets a hazardous gas concentration the vessel will approach an installation, from which gas is being released, from windward with at least two anchors deployed but using the dynamic positioning system. Non-essential services will have been shut down and associated areas secured.

The Forties Field installations have gas alarms set at 20% LEL methane (equivalent to 1% by volume), and shut-down set at 60% LEL methane (3% by volume), and these values have application to the ESV gas alarm system.

In the event of total plant shut-down occurring, a citadel has been provided in the diving complex to preserve the life of personnel until the vessel can be recovered by means of its anchor wires or until power can be safely restored. The supplies for the citadel are based on a one hundred man-day life support requirement.

FIG. 7. Waste heat system

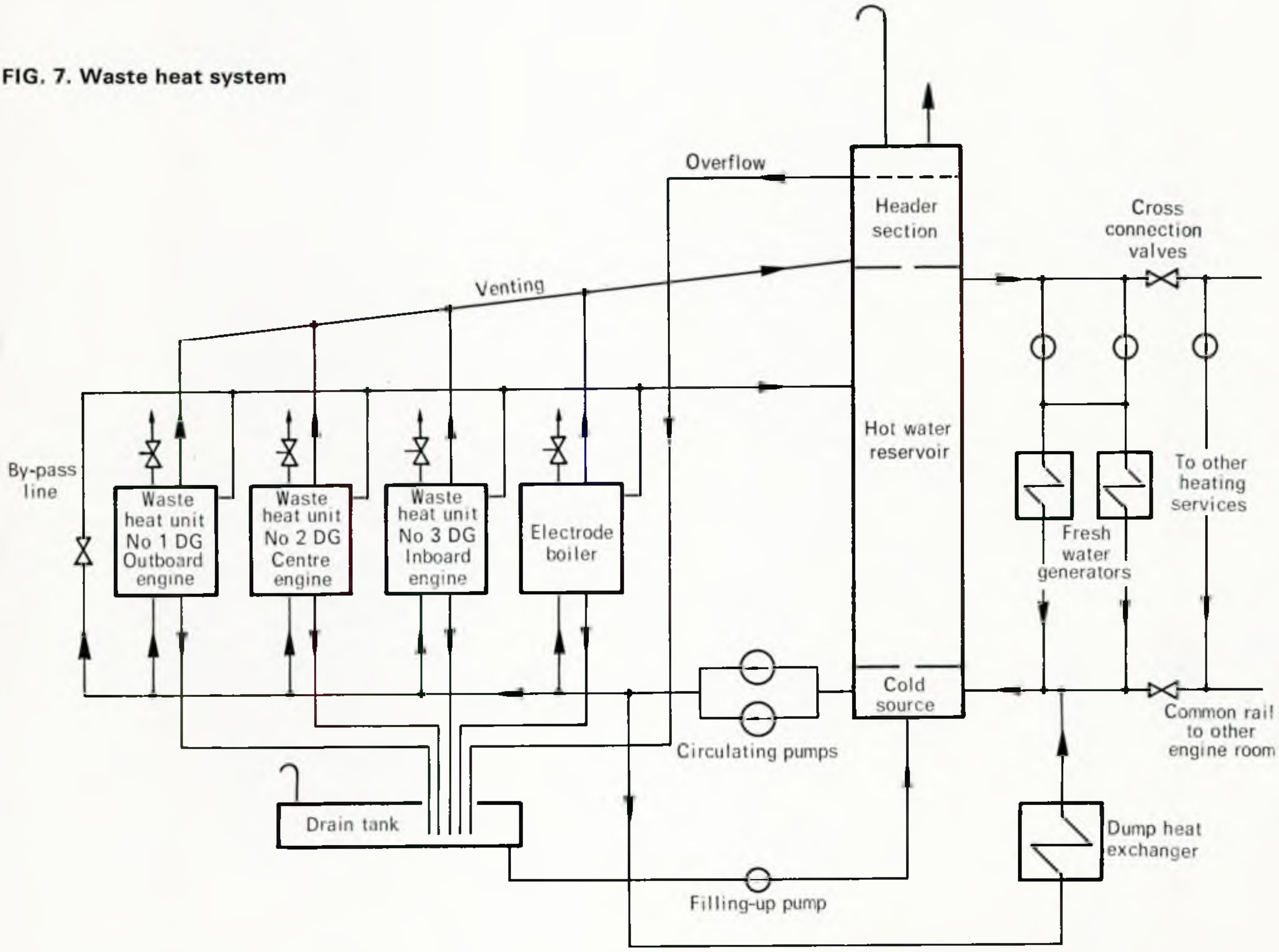
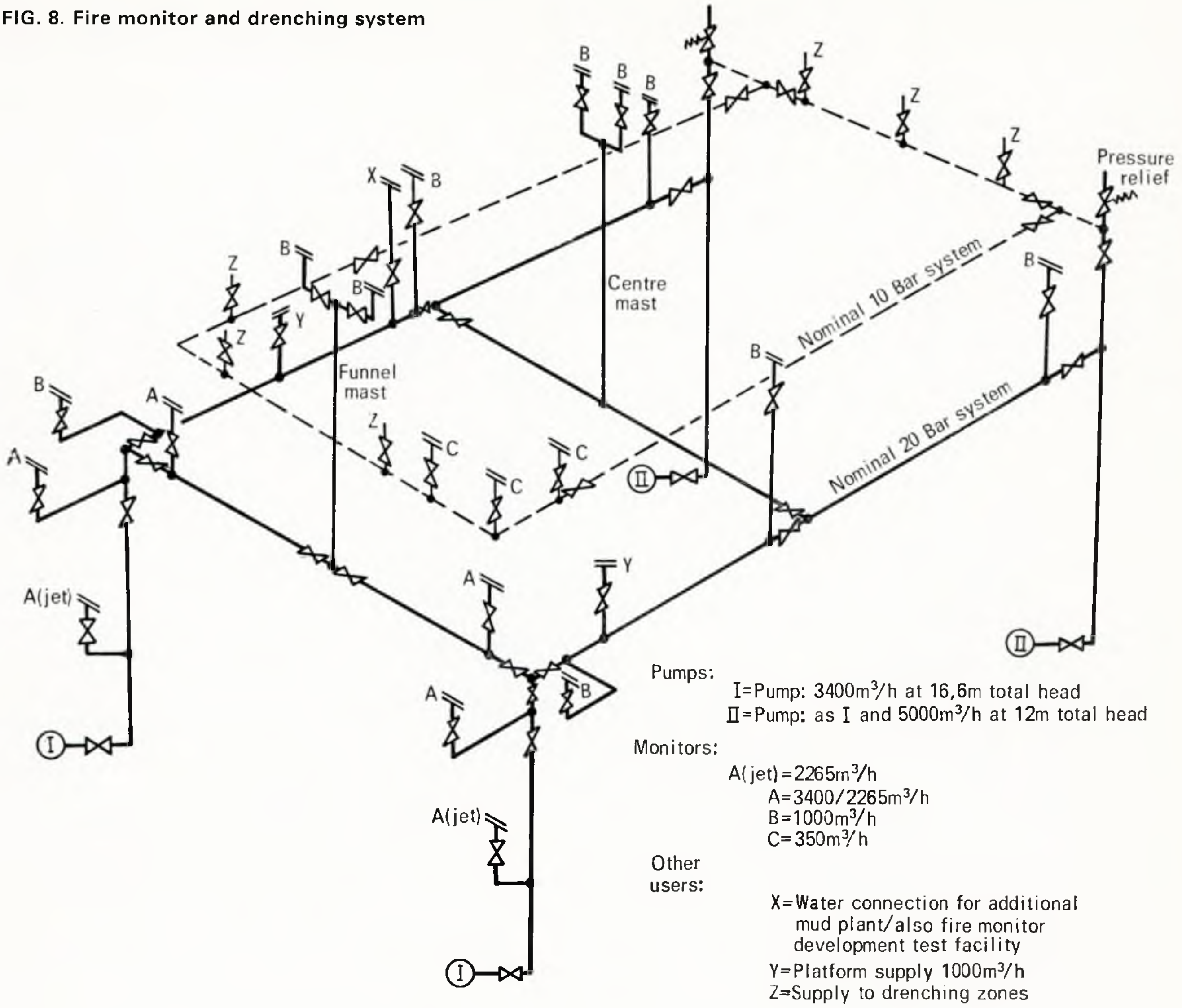


FIG. 8. Fire monitor and drenching system



REMOTE VALVE OPERATION

A complex remote valve operation system is necessary to facilitate safe operation of this type of vessel. Two power packs are employed, one to cover each side of the vessel, and cross connections are provided in event of failure. Each power pack has a running and a standby pump/motor set and a back up accumulator system. Electro-hydraulic control of valves is employed, with the interface hydraulic control racks being placed at suitable locations. For example, in the pontoons, one is placed at the bottom of the column above each pump room to operate all system valves in that area of the pontoon. These racks do not, in general, operate damage control valves.

Control of valves is from three areas:

1) Fire monitor and drenching system valves, main bilge system valves, vessel fire main valves in pontoons, and ballast system valves, are all controlled from the Control Bridge.
2) Fuel transfer valves and fresh water transfer valves in the pontoons are controlled from a panel in the appropriate engine room.
3) Damage control valves (shipside valves and watertight bulkhead valves) are directly hydraulically operated from special panels at the top of the column nearest to the valves concerned. These panels are fed from the main power packs, and are provided with their own accumulator as back-up and also with a hand pump.

All hydraulically controlled valves are provided with local plug-in connections for hand pump operation in event of main system failure, supply pipe failure, or for use during maintenance.

Mimic diagrams are provided at the consoles on the Control Bridge and in engine rooms to indicate valve location, and each valve control switch has open/shut/discrepancy indication.

WASTE HEAT SYSTEM

This is shown in Fig. 7. A separate system is provided for each engine room to provide low pressure hot water for accommodation and space heating, production of fresh water, domestic hot water, diver suit heating and machinery system heating requirements. To protect the integrity of the individual primary hot water circuits, heating services outside machinery spaces are supplied from one system only utilizing changeover valves situated between the two engine rooms.

The system utilizes the heat contained in the exhaust gases of the main diesel engines. When sufficient heat is not available from the exhausts of those engines in operation, a 1 MW electrode boiler automatically cuts in to meet the heat requirement. The electrode boiler is supplied from the main HT busbars via a transformer, hence, as more power is demanded by this boiler, engine load increases and the boiler modulates to an equilibrium heat output. No oil-fired boilers are provided.

Primary control of waste heat boiler output, and hence hot water temperature, is by automatic operation of the gas bypass valve on each boiler. Careful attention to control loop priority and sensitivity will be necessary to prevent hunting between gas bypass valve operation and electrode boiler modulation.

Any heat remaining in excess of demand in the primary circuit, after the gas bypass valves have diverted the full gas flow from the boilers and the electrode boiler has modulated to minimum load, is rejected to the sea via a dump heat exchanger circuit by automatic operation of a temperature controlled bypass valve in the primary circuit.

FIRE MONITOR AND DRENCHING SYSTEM

The Working Party study of the requirements for a fire-fighting vessel for offshore installations drew attention to the importance of the following factors:

a) The need to put sufficient water into the areas that matter whilst the vessel remains at a safe distance from the installation.

b) The need for an adequate drenching system capable of protecting all horizontal and vertical surfaces of the vessel likely to be exposed to radiated heat, thereby enabling the vessel to remain within working range of an installation for extended periods.

c) The need for monitors at different heights so that water can be directed both above and below the working areas of an oilfield platform structure.

d) The need for monitors suitable for long range and short range operation, capable of generating either a concentrated jet or a dispersed jet.

e) The need to provide washdown protection for personnel working on a damaged installation and transferring between the installation and the support vessel.

The installation on the ESV reflects these requirements and is in excess of the standards required by Lloyd's Fire Fighter 2 classification. Fig. 8 shows the arrangement of the fire monitor and drenching system.

Four fire pumps are installed, each with a capacity of 3400 m^3/h at 165 m total head. The two after pumps are driven from one of the two propulsion motors in the respective pontoon. The two forward pumps have independent motor drive through a variable speed hydraulic coupling to produce any desired output and pressure, up to a maximum output of 5000 m^3/h at 120 m total head from either pump.

A piped water curtain is provided around the vessel and over the exposed deck areas, superstructure, and deck equipment to completely shield the vessel from radiated heat. A spray curtain is arranged over all diesel engine exhausts. Coverage is designed for 600 litres/m^2/h over the entire surface area of the vessel.

Connections are provided on the drenching system main to supply 1000 m^3/h of water to the oilfield installation fire mains via a flexible hose.

Four large monitors are provided at the aft end of the vessel, intended for stand-off drenching of an installation, each having dual capacities of 3400 m^3/h and 2265 m^3/h with a minimum effective throw of 180 m. These monitors have remote hydraulic control from both the Control Bridge and from the emergency control station at the after end. Local manual control is also provided. Ten smaller monitors of 1000 m^3/h each are provided for close-in drenching of the platform and six of these can always be brought to bear on the target whether the vessel is starboard side, port side, or stern to the platform. A throw of 120 m is required for these monitors and they are fitted with remotely operated jet/spray nozzles. Control of these monitors is from the Control Bridge. Local hand control is also provided.

Three manually operated monitors of 350 m^3/h are provided for giving drenching cover for personnel boarding or leaving the platform over the emergency access gangway.

In order to achieve the required drenching cover of the platform support structure and of the riser area, one fixed water jet cannon of 2265 m^3/h is mounted in the after face of each aft column, positioned just above the working draught water line.

The stern of the vessel was chosen for mounting the large monitors in order to reduce noise intrusion into the Control Bridge and accommodation, and hence to relieve the personnel, both on and off duty, of noise stress during long periods of fire control from a standoff position. This period may be of several weeks duration.

Each large monitor produces a reaction force of seven tonnes at 3400 m^3/h throughput. The dynamic positioning system takes account of the magnitude and direction of each monitor reaction.

The main problem arising in the selection of available fire monitor designs is one of nozzle pressure. To achieve an economic pumping output based on the power available from a 2.24 MW (E) propulsion/fire pump motor, and in order to keep system pressures within reasonable bounds of material costs and weight, nozzle pressures of the order of 12 bar g were selected, which give closed valve pump discharge pressures of 20 bar g.

The requirements to maximize the effective throw of the large monitor water jets, to ensure that there is little tear-off or fall-out from the jet in any wind speed up to 35 knots at low nozzle

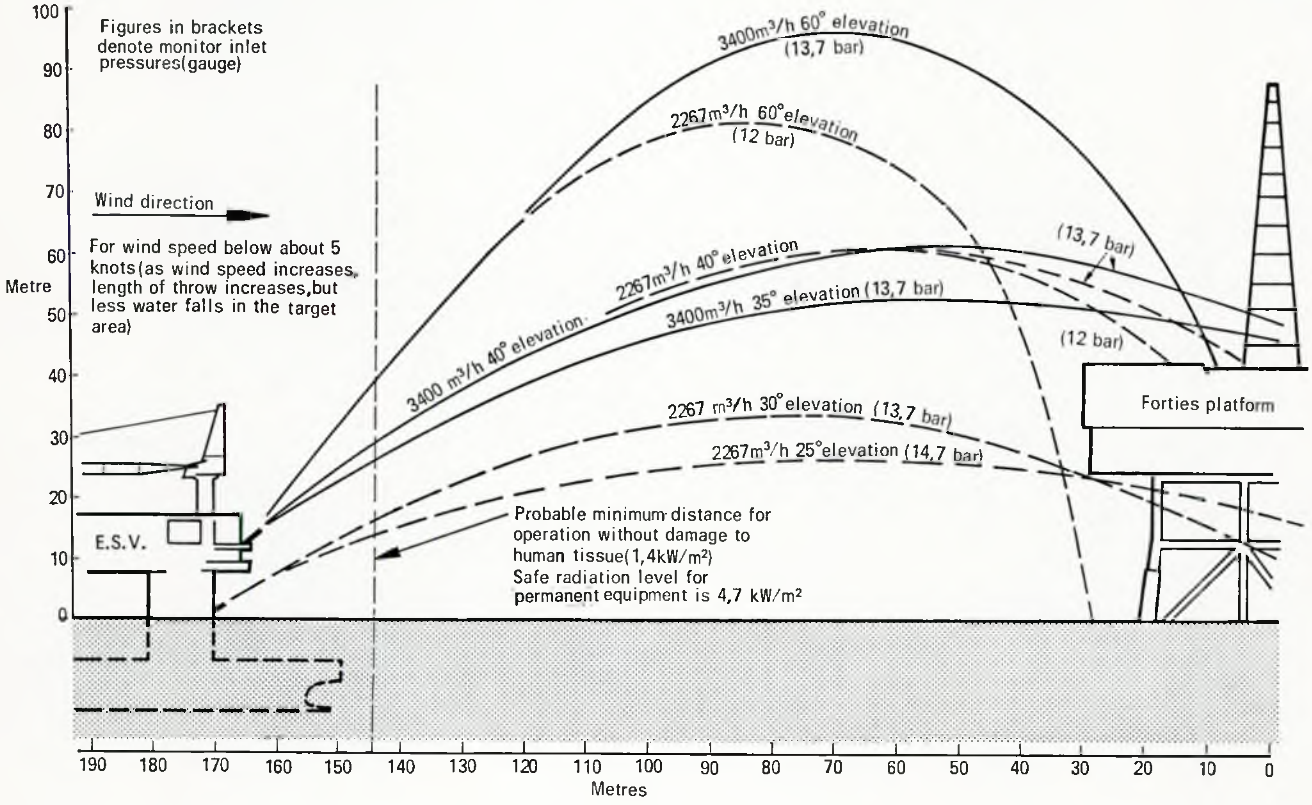


FIG. 9. Requirements for water jets

pressures, led to the specification requirement for a demonstration to be arranged by the selected monitor manufacturer. This demonstration has taken place and has proved successful. Details of jet requirements are given in Fig. 9.

Much work still has to be performed to determine the optimum nozzle design to obtain a throw of 180 to 200 m in realistic wind conditions. Throws in excess of 200 m are desirable for long term stand-off cooling operations, since then the vessel drenching system will probably not be required to operate in full, which will simplify vessel operation.

CONCLUSIONS

Safety standards for offshore vessels are becoming more stringent and, for special vessels like the ESV, every effort must be made in the design to create a vessel which is operationally secure and reliable.

The special requirements for this type of vessel have required new approaches to old problems to be adopted and for completely new ideas to be incorporated in vessel and machinery installation design. The industry is still learning from experience, and legislation and recommendations from Classification and Statutory Authorities are only now becoming available, in many cases still in draft or guideline form.

Equipment manufacturers must adopt a more flexible approach to modifying their standard packages for application to this type of vessel. In this respect, many manufacturers have not appreciated the need for high reliability, self-checking and fail-safe control systems, and much time has been wasted evaluating quotations which did not comply with the Specification.

Adequate emergency support for offshore personnel and installations is an expensive, but necessary business. The ESV specification, dating from May 1977 and only slightly modified since, has placed emphasis on system reliability under a wide range of fault conditions. However, the authors are gratified to see that present guidelines and draft rules for such vessels support, in many respects, the original design philosophy.

ACKNOWLEDGEMENTS

The authors wish to thank the Directors of The British Petroleum Company Limited for permission to publish this paper; and their colleagues within BP Tanker Company Limited and throughout the Group for their assistance and advice.

APPENDIX 1: PARTICULARS OF VESSEL

Length over pontoons	102 m
Breadth over pontoons	51.5 m
Depth to working deck	32.3 m
Operating draught	15.25 m
Transit draught	6.54 m
Operating displacement	19,600 tonnes

APPENDIX 2: PARTICULARS OF MAJOR EQUIPMENT

EQUIPMENT	NO. OFF	RATING	DETAILS
Main engines	6	3.5 MW	18 Cylinder Vee, 1000 rev/min
Standby engine	1	860 kW	6 Cylinder In-Line, 1000 rev/min
Emergency engine	1	250 kW	12 Cylinder Vee, 1500 rev/min
Main propellers	2	4.48 MW	220 rev/min CPP constant speed
Propulsion gearbox	2	4.48 MW	1500/220 rev/min twin 2.24 MW input
Thruster units	4	1.5 MW	CPP constant speed 207 rev/min
Fire pumps	4	2.24 MW	3400 m^3/h at 16 bars; 5000 m^3/h at 12 bar
HT motors	6	2.24 MW	6.6 kV 50 Hz
	4	1.5 MW	6.6 kV 50 Hz
Waste heat boilers	6	952 kW	Working pressure 1.5 bar g
Electrode boilers	2	1 MW	415 V 50 Hz
Starting air compressors	3	65 m^3/h	FAD 30 bar g
General service air compressors	2	600 m^3/h	FAD 8 bar g
Ballast pumps	4	600 m^3/h	30 m total head
Sea water circulating pumps	4	700 m^3/h	32 m total head
Steering gear	2	36 t – m	Rotary vane
FW generators	4	25 t/day	
FW system heat exchangers	4	4.63 MW	Plate

Discussion

MR. W. FERGUSON (Scott Lithgow Ltd) said that, as a member of the staff engaged in the contract, he would like to give some related information on what was surely one of the most complex commercial vessels to be designed and constructed in the UK. He also had a few comments to make on the authors' descriptive paper.

When the Company was invited to tender and was introduced to the design and specification of the vessel, it immediately became evident that the normal technical boundaries existing in a shipbuilding organization between naval architecture, mechanical and electrical engineering would have to be removed and a totally integrated approach to these disciplines adopted. The complex structural geometry of a semi-submersible and the systems required for the multi-functional nature of the emergency and support roles in which the vessel would be engaged had clearly illustrated the need for such integrated studies. Consequently, a technical team comprising representatives of the above disciplines had been set up to study the specification and operational aspects of the vessel and absorb the data from the BP studies which had preceded the production of the specification.

At that time the BP technical team took the fairly unprecedented, but noteworthy step, of visiting potential builders of the vessel to discuss in detail the philosophies and features of the design and their thought processes from which the specification had been developed. As stated by the authors, that had allowed shipbuilders to quote on a realistic basis for the contract.

The final issue of the tender specification was made by BP in April 1978, and, following an assessment of the various tenders submitted, the contributor's Company was selected for the construction of the vessel. From August 1978 until the formal contract was placed in January 1979, an intensive effort followed, by the technical teams of both companies, to finalize the design of the vessel, for the performance of which Scott Lithgow was contractually responsible, in addition to selecting the manufacturers of equipment.

As mentioned by the authors, system reliability, quality of materials and standards of manufacture, control systems, weight and ease of maintenance were the overriding considerations in the selection of equipment. Mr. Ferguson would echo their statements that much time was consumed ensuring that the quotations from suppliers complied with the specification requirements, and also in investigating the orientation of each package of equipment to suit the structural geometry of the vessel. It might be that some manufacturers had misinterpreted the information communicated to them as to available space and the high standard of specification required for the vessel or, in the interests of competitive tendering, had assumed that their standards would be sufficient. On hindsight, it would be interesting to hear the authors' views as to the techno/economic considerations of competitive tendering against pre-selection of manufacturers whose products were known to meet the specification requirements.

In the paper it had been stated that in the early days of the design, little guidance had been available from the Classification Societies and statutory authorities and that, in the absence of detailed rules and regulations for this type of vessel, continuing discussions had had to take place on the application of existing legislation to suit the operational roles of the vessel. For example, it had been found that existing statutory regulations could not sensibly be applied to crew accommodation, ventilation, navigation lights and emergency generator operational philosophy, and those had to be specially developed in conjunction with the statutory authorities. The Department of Trade and Lloyd's Register of Shipping had been fully co-operative in this respect, but it had been found that the time spiral of submitting design philosophies for approval, obtaining manufacturers' detailed offers, integrating the selected equipment into the design and obtaining final approval could be at variance with construction schedule requirements if not watched carefully. For such vessels the awaited rules and regulations from Classification Societies and statutory authorities were urgently required.

To achieve the operational philosophy of certain of the systems in the vessel, it had been necessary to adopt equipment not yet certified for the marine environment; such equipment was at present being tested for marine certification. Manufacturers should be encouraged to develop their equipment to suit the special marine requirements.

He would agree with the authors that a reduction in the number of hydraulic systems in the vessel would be desirable. That was an area of the specification where further studies into the operating pressures required by the various systems might have permitted more rationalization of components. That was a lesson for the future.

The multi-functional nature of the vessel had demanded a rigorous and extended test and commissioning period. The whole variety of plant protection, interlocking, standby and redundancy arrangements formed protective systems for a permutation of possible occurrences which would have to be simulated and verified by performance. Perhaps the authors could elaborate on how BP would ensure that, in service, the vessel would remain highly tuned to meet the various emergency and support roles.

The demands of translating such a complex design into a reality had been recognized by both companies. A rigorous system of quality control had been devised covering construction of the vessel, manufactured components of hull and equipment, and installation of equipment on board. The quality was monitored by a quality assurance department who, by means of inspections, audits and tests, ensured that the specified standards were being maintained. The department was empowered to reject work or equipment not conforming to the specified quality standards, either within the Company's works or those of its sub-contractors.

For that vessel the Company had adopted a technique of project management, generally favoured by oil companies for offshore projects, whereby a comprehensive team covered the various disciplines involved in the design, construction and outfitting aspects of the contract. The team interfaced with the technical, planning and production departments of the shipyard and worked in close co-operation with the BP London office and resident staff. The Company had undoubtedly benefited from the short lines of communication and from the frequent technical and managerial review meetings held with senior BP staff.

MR. F. H. MURDOCH (John G. Kincaid & Co. Ltd) said that, as the authors had stated, a great deal of research and design work, over a period of four years had been carried out before the specification had been finalized. Thereafter, as principal engineering contractor to Scott Lithgow for the vessel, it had been his Company's responsibility to complete the detailed design, and install and commission all machinery and associated piping systems.

The preparation of detailed installation drawings, as mentioned in the paper, had been protracted because of the restricted spaces available for the necessary equipment and pipe systems. As stated by the authors, much of the design of the machinery systems was novel, either in concept or scope of application. Freshwater coolers dissipating 9.3 MW were not uncommon, but fitting them into a space 3.25 m x 6.9 m, together with associated pumps, fittings and pipes was another matter. Generally, many aspects of the installation entailed considerable modification to standard items of equipment, with ensuing delays while the specification requirements were worked through in detail. As an indication of the workload involved due to the complexity of the installation, it was estimated that there were more than twice the number of machinery drawings for the ESV than for a 250,000 tonne oil tanker.

Painting of equipment was an area which caused difficulties for suppliers. For additional security, all parts in machinery spaces required to be painted with a two-pack epoxy system, with a Fire Retardant Certificate, and, as much of the equipment purchased was manufactured on a production line basis, suppliers wished to sell their standard finish and were reluctant to change. His Company was experiencing some problems with such a paint system, as items of equipment had to be fully painted before installation on board. Up to six coats might be required and, with an epoxy system, once the painting had started it had to be completed without interruption.

During the actual design of the vessel and selection of agreed sub-contractors, it was found that, whilst every care had been taken to ensure maximum compliance with the specification, compromises had had to be made, as the normal drive at such a time was to obtain agreement on the principal content of the contract, with the controls and other detail points having to be negotiated separately. Attempts were made to induce sub-contractors to incorporate all the considered "good points" from each tender. Such discussions tended to be non-productive as the system design had been developed by each company over a certain period and had only a limited ability to be modified.

The brake, motors, clutch, propeller and main alternator system design had had the most far-reaching consequences, occasioned by the need to ensure power integrity of the plant. In all there were: 6 main alternators; 10 HT motors; 6 propellers and thrusters; 1 DP system; where, in addition to the requirement to provide a workable integrated system, consideration of failure modes of any single one of those items had to be anticipated in relation to the effect on the other. (That was not the same as the power simulation study, which considered the performance of the vessel relative to the probable failure of those items.)

The classification of UMS placed great reliance on the alarm system, the maintaining of it and the associated transducers in good working order, and a regular testing of set points and operating levels, and he wondered if more use of analogue channels, with their inherent self-check facilities, would not have cut down substantially the routine checking time in service.

On behalf of his Company he took the opportunity to thank the owners, Department of Trade and Lloyd's Register of Shipping for the assistance given in resolving many of the problems associated with that particular design of vessel.

MR. V. CARRELL (Worthington Simpson Ltd) said that the authors had outlined the stringent requirements for the firefighting and protection systems of the ESV. To meet those requirements extensive hydraulic studies had been necessary due to the lack of data on firefighting systems of that size. In addition, full capacity testing had been required to confirm the theoretical development and to establish new empirical data. Those investigations could be broken down into threee main categories with clearly defined objectives.

The first objective was to establish data on the water jet, i.e., trajectory capacity, and coherence. As could be seen from Fig. D1 a floating test rig was constructed which included a pump capable of 3600 m^3/h at 165 m head, with a speed of 1480 rev/min, driven by a 2500 kW electric motor with 5.5 kV electric supply. The electro-hydraulic remote-controlled monitor was connected to the pump with a 20 in steel pipe. The hydraulic power pack for the monitor drive, was also mounted on the pontoon with flexible electrical and hydraulic connections. The monitor control cabin fitted out with full instrumentation was mounted on the quay, as was all the starting equipment for the electric motor.

FIG. D1 Floating test rig

Having a pump capable of 3600 m^3/h allowed tests to be made in the capacity ranges of 3600 m, 2400 m and 1200 m^3/h, at varying inlet pressures, to determine capacities, trajectories, and jet appearance and to compare the differences of various inlet pressures, both technically and commercially.

Fig. D2 gave an idea of the throws that were obtained and demonstrated the jet appearance. Accurate methods of measuring jet height and length had to be developed and his Company had placed a contract with the BSRA of Wallsend on Tyne to assist in developing a measuring system.

The principal method adopted was based on an accurate survey of the north bank of the Tyne from a fixed position on the south bank, and from that a system was developed so that a grid could be placed over photographs taken from the selected fixed position.

In addition, the jetty on the north bank was physically marked for quick reference during the test, and a triangulation system of spot measurement of the footprint was developed as an early check.

That was a very brief description of a complicated system but the tests undertaken were to be the subject of a separate paper at a later date.

The second objective was to ensure the compatibility of the multi-pump arrangement system, particularly in relation to monitor sizes and positions, heights above datum in conjunction with pipe losses, induced turbulence, water hammer and swirl. The basis of the system was that shown as Fig. 8 in the paper, which had not taken into account any building problems or where pipes could, or could not, be placed; and, from that point, as the pipework drawings were produced and the actual routes determined, so the diagram was modified to that shown.

Fig. D3 had been prepared to ensure that at any given point in the system with any number of pumps from two to four, running pressure would balance and the system curves would be equitable. In addition, the monitors were situated at various heights and, although an optimum inlet pressure was stated, that would only apply to those monitors situated at the highest point. Those at a lower position would get a slightly higher pressure and, to allow for the monitor nozzles to be manufactured correctly, that pressure must be known.

A number of cases were considered and isometric schemes were prepared. Those showed the flow path, flow rates and pressure, depending on which pump or monitor was in operation. The schemes also gave identification of reaction forces. Those system diagrams also showed the flow paths studied in selections identified by numbers which allowed for individual calculations at different flow velocities.

Calculations were made to check the actual pressure at the

FIG. D2 Jet appearance

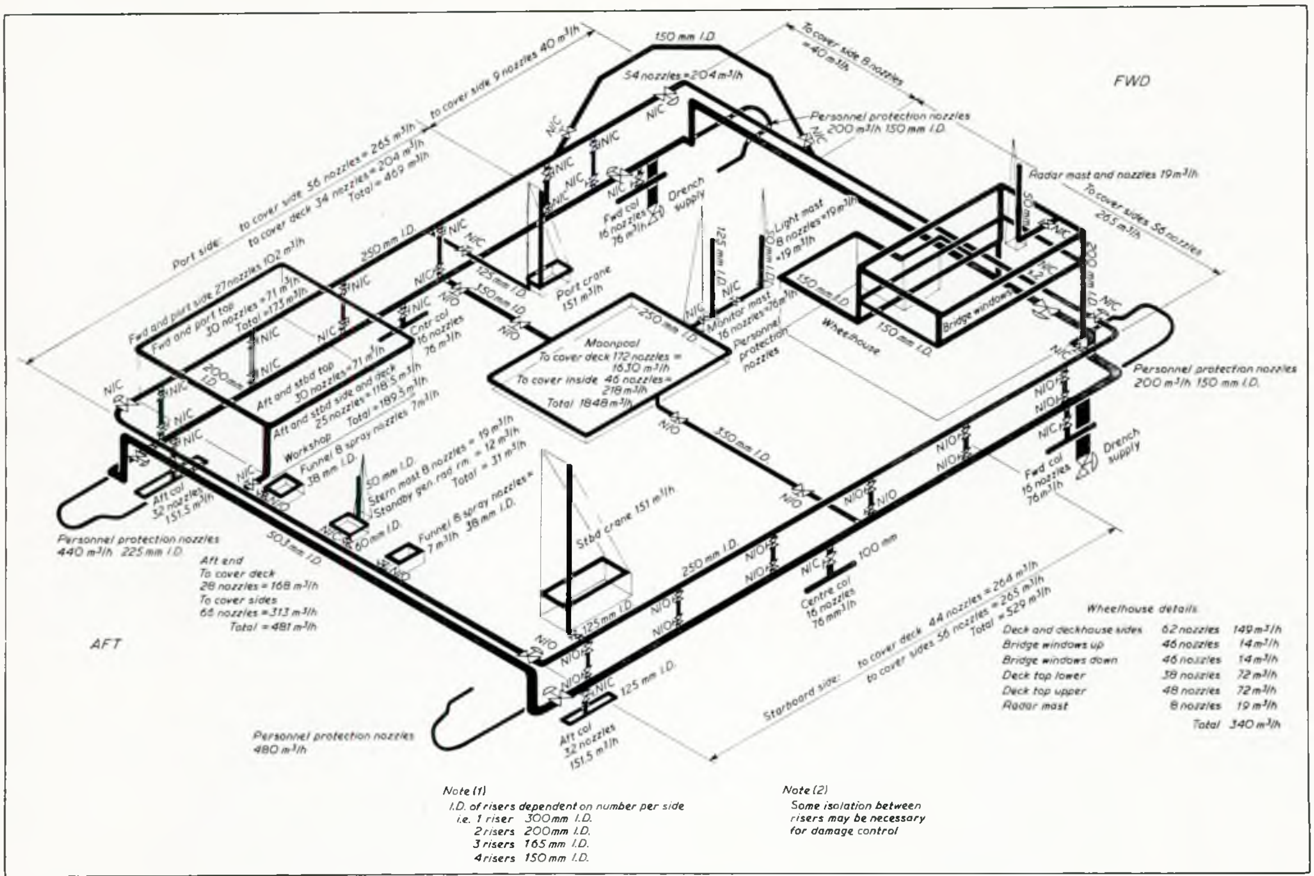


FIG. D3 Diagram of system

pump discharge when closing valves, so that the pressure could be kept within the design limits.

The other consideration pertained to turbulence, as that was one of the factors in obtaining a coherent jet. Taking the construction and fitting of the pipework into account the best approaches to the monitor inlets were deduced to reduce the amount of generated turbulence and swirl within the system.

The final objective was the drenching system which had evolved from consultations with the owners and builders. The degree and area were dependent on the method of operation of the vessel at any given time. The parameters for that system were that adequate water coverage was required against radiated heat either in the "stand off" or "close in" positions and also for the "gas cloud" condition; at the same time, the working surfaces of the vessel were to be kept clear of the pipework, as far as possible. Fig. D4 showed the arrangement of the pipework.

Fig. D5 showed how the coverage of the various areas was obtained. A certain amount of zoning was incorporated to cover for the attitude of the vessel to the hazard. The quantity of drenching water, therefore, varied to accommodate that, each one of the forward pumps being capable of supplying the total needs of the system. Those pumps were controlled by variable speed couplings so that optimum pressure and power usage were obtained. In all those studies, the rules of the Classification Societies had been used as a basis, although it had been demonstrated that the results were in excess of those requirements. At all times, consideration had been given to economy in respect of capital cost, power, weight and operation, but without detriment to overall efficiency.

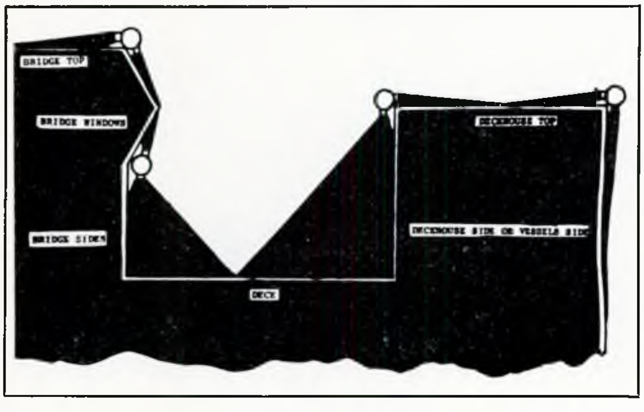


FIG. D5 Possible arrangement of spray nozzles

DR. A. P. HATTON, FIMechE, (UMIST) representing Knowsley Engineering Co. Ltd offered some further information regarding the demonstration tests of the large water monitors the authors had mentioned.

Studies of the extensive literature available on water jets had shown that the suppression of turbulence and swirl was of primary importance. The nozzle, so long as it was a smooth and appropriate shape, did not appear to have a significant effect. However, it was considered that the change of scale for the proposed jets was so large (the largest jet being more than twice the diameter of any previously tested) that a proving run ought to be carried out. Since the design concept of the vessel in its fire-fighting role depended on meeting certain performance criteria, it was necessary to prove that those would be achieved. At the same time, the opportunity was taken to investigate the parameters affecting large jet behaviour. The objectives therefore were to investigate:

1) swirl and turbulence suppression devices;
2) nozzle designs;
3) effect of operating pressure;
4) wind effects;

with the overriding objective of achieving the optimum design.

The test rig was arranged on a pontoon at BSRA. The monitor was fully instrumented for flow rate and pressure using calibrated test gauges, high pressure mercury "U" tubes, and a duplicate system using electronic transducers to obtain direct print-outs. The jets were photographed against a surveyed background and the trajectories subsequently measured with a calibrated grid.

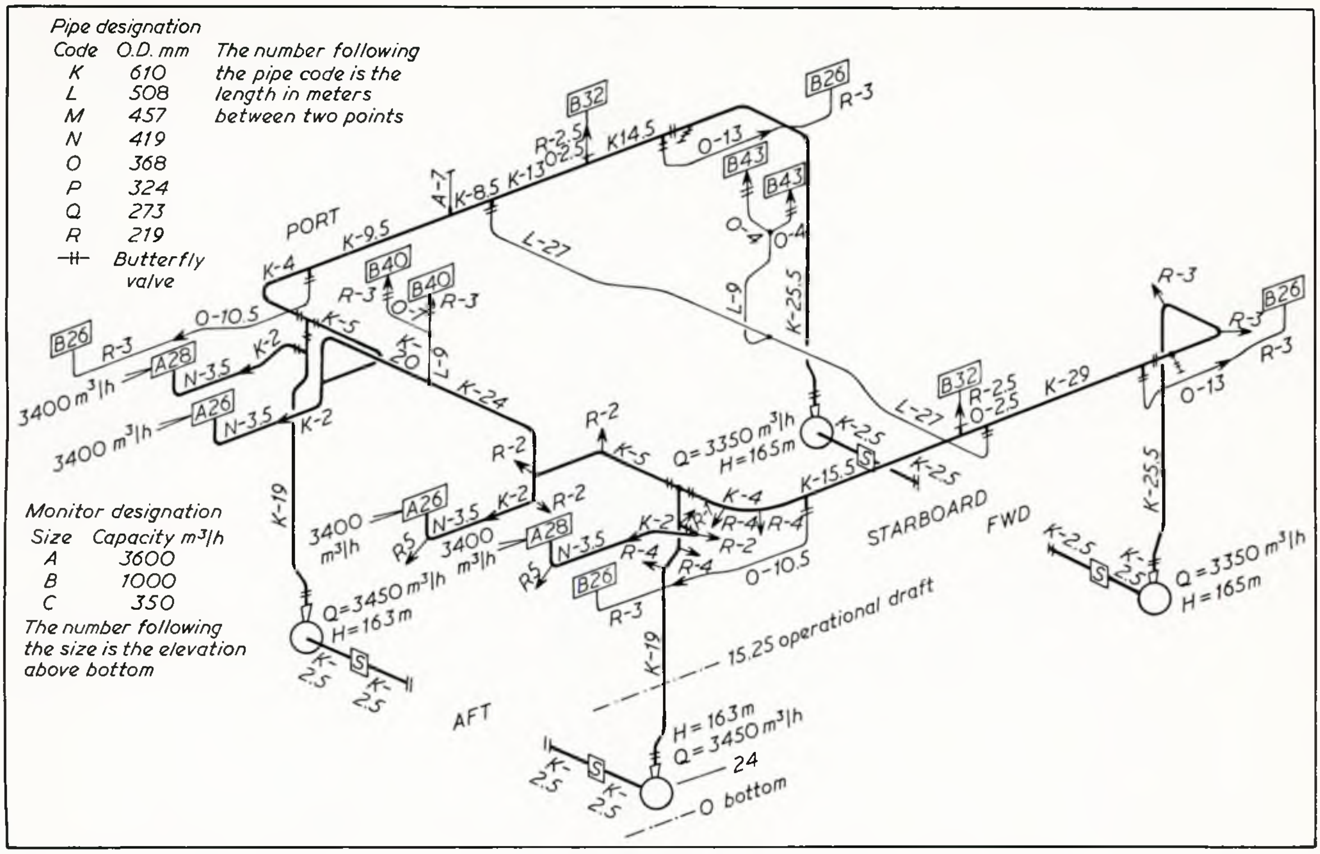


FIG. D4 Arrangement of pipework

Much of the experience available for wind tunnel design could be applied to water monitors. Turbulence was damped in steadily accelerating flows, which was the reason for choosing the long converging branch pipe. Honeycomb flow straighteners were incorporated in different positions and a number of size combinations tried. The addition of flow straighteners produced a considerable improvement in jet coherence, arriving at an effective combination.

The various nozzle shapes were then tested and the best shape was established to be a slow conical convergence blending smoothly into a short parallel exit portion. Nozzles without the parallel exit portion, e.g. the Rouse design, were markedly poorer both in range and coherence.

Sets of nozzles of the same shape were designed to produce the same flow rate at three different pressures. A computer simulation* of jet behaviour had indicated an optimum pressure for 2400 m^3/h of approximately 13 bar. Runs at 12, 13.5 and 14.7 bar had shown very little change of range, but the highest pressure jet had shown much poorer coherence.

In general, the agreement with the simulation was good (10%) but the extensive information obtained would be used to improve the drag approximation and the simulation generally.

Unfortunately, site restrictions prohibited operation in strong winds. However, the limited data obtained in light winds had shown the importance of that effect. A change of wind speed from 2.5 knots from astern to 5 knots from ahead produced a reduction in measured range of 15%.

It was hoped to publish those results in more detail in due course.

MR. D. WATMUFF (Harland and Wolff Ltd) said that the paper had dealt effectively with many of the special and extraordinary requirements of an advanced design vessel intended to meet all anticipated offshore oil field operations and emergencies.

Computer programs had been developed and used extensively to compare all aspects of the different types and designs of machinery available, and his Company was pleased to have been selected to supply main generator engines from the MAN designs they manufactured under licence.

With respect to Mr. Ferguson, those engines had been designed essentially to marine requirements, but the very special nature of the service, e.g. the operation in a gaseous atmosphere, did impose new and particular studies, which were carried out in great detail in conjunction with the BP engineers.

To meet the design specifications, the authors had been obliged to place many restrictions on the builders, and all details of the machinery installation had been extensively monitored by them. While he fully agreed that safety measures were absolutely essential for a vessel of that type, would the authors not agree that it was possible to be over cautious to such an extent that there were safety systems monitoring safety systems? At what level did one decide that the optimum balance between system failure and safety system failure had been achieved, i.e. which was the more likely to fail?

MR. E. ØREBECH, BSc, MSc (Kongsberg Ltd, Maritime Division) felt that because of the wide interest in the offshore industry caused by this ambitious and technically advanced vessel, and by the valuable paper describing some aspects of its engineering design, it was relevant to refer to the main features of the dynamic positioning system which, in addition to its task of controlling the propulsion and manoeuvring systems, was also involved in the monitoring of the power generation equipment on board and in extensive logging and data recording duties.

Introduction

Dynamic Positioning (DP) could be defined as the technique of maintaining the position and heading of a floating vessel by means of active thrust controlled by a computer.

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* HATTON, A. P. and OSBORNE, M. J., 1979, "The Trajectories of Large Firefighting Jets". *Int. J. Heat & Fluid Flow (I.Mech.E.) Vol.* 1 *No.* 1.

The DP system for the ESV was the only sub-system with a BF specification of its own, in addition to the machinery specification, electrical specification, etc. and that proved the particular emphasis put on the DP system. The system was a tailor-made adaptation for the particular vessel, and contained various options and system features not found in any other DP system.

However, the DP system did have to satisfy the other general specifications for the vessel, so as to become as integral a part of the vessel as possible. That applied to the control/manoeuvring philosophy, alarm philosophy, the paint specifications, overall console and display features, intrinsic safety, etc.

Interfacing and hardware features

The technique used in the interfacing of the DP system with the thrusters, propellers, power system and sensor systems was extremely important, with consideration of such features as signal isolation, separation of power supplies and redundancy. Power, current as well as status signals, were fed from the high tension switch board, the thruster/propeller motors and other major users, for the DP power management system contained in the DP system. That was to ensure that the DP system did not overload the vessel's power system, either in power or in current, at any one time.

The propeller/thruster motor power and current feedbacks were also used (in addition to the pitch feedback) as an extra safety feature to provide a cross-check that the thruster/propeller motors were performing as expected, giving the right pitch. Hence there was triple signal redundancy and, the pitch feedback signal could be lost without consequence.

The entire system was powered from a duel uninterrupted power supply (UPS), with 30 minutes of battery back-up and as, a further back-up, should the total UPS for some reason be off line, power would be fed from the ship's mains via a bypass transformer to the DP system.

To enhance fault-finding in the system, an engineer's panel enabled the ship's electricians to monitor easily in or outgoing lines feared to have failed. Also, when fault finding and commissioning, a voice communication system connected the central computer of the DP system with the remote sub-systems, i.e. transducer hull units, taut wire system, etc.

Overall system philosophy

The reference systems

The dual computer-controlled DP system featured the following reference systems:

- —microwave-based surface reference system;
- —super short baseline hydro-acoustic system;
- —lightweight taut wire system;
- —alternative radio location system;

all of which produced position information. In addition, velocity measurements were obtained from the cross track Doppler log.

The taut wire system for the ESV had been specifically designed to enable it to be located in the taut wire space inside the vessel at the lower deck, and those component parts exposed to the atmosphere were intrinsically safe.

Minimum requirements for operation were that at least two reference systems should be working satisfactorily. However, up to four reference systems plus the Doppler log might input simultaneously to the DP system.

The sensors

The sensors involved were dual gyrocompasses for providing vessel heading, dual pitch/roll sensors for compensation of the effects of vessel movements on antennae and transducers, and dual wind sensors (designed to be intrinsically safe) for the wind forces, including wind feed forward. The DP system was also presented with force, pan and tilt of the 16 water monitors fitted, so as to be able to compensate immediately for those large forces as soon as the firefighting system had been started.

The computer system

The two process computers performed all tasks in parallel, and all information from sub-systems entered them both in parallel. However, the process (i.e. the thrusters/propellers, etc.) was only controlled by one of them, and which of those two computers was to be on-line to the process was actually controlled by a third supervisory or ancillary computer. When a discrepancy between the two process computers was identified and the fault was present in the on-line computer, the output was switched to the other.

Logging, plotting

A second task of the supervisory/ancillary computer was to take care of certain "housekeeping" routines, like plotting on three five-channel strip chart recorders, and alarm and event logging on dual teletypewriters and cassettes. Cassette logs might also be played back on the strip chart recorders. Thus the documentation/data registration scheme was quite comprehensive. Still, it was also possible to interface the DP system via the supervisory/ancillary computer to other data monitoring/information systems if required.

The DP system might log data from its sensor systems, such as vessel heading, pitch and roll, wind speed/direction, apart from reference systems data, and measured and wanted position. In the ESV there was also a vertically mounted accelerometer, so that heave movement might be measured. The computer then related the heave to the vessel model and produced a read-out of wave height.

Display systems

The DP operators console on the starboard side of the bridge featured operators control of positioning modes and reference systems, an alarm system which tied in with the vessel's alarm system, dual CRT displays for displaying position plots, "pages" of information and other synthetic pictures, as well as radar information. Alarms and other information were also available on a matrix display.

Thruster/propeller/nozzle/interface

To position the vessel, the DP system controlled the four beam thrusters and the two main propellers. However, the operator might also control the two propeller nozzles individually, and that might be particularly useful in certain marginal conditions where the vessel might not have managed to keep station otherwise.

Trainer/simulator

A very special feature was the DP system's "On Board Trainer/Simulator", enabling personnel to go through DP operational training on the DP system itself as well as enabling the Captain to go through difficult manoeuvres on the simulator before taking a decision whether or not to carry them out in real life. The weather parameters and system parameters could be altered, so as to simulate exactly the prevailing conditions, and failure of a major component such as a propeller.

Software/system features

His Company's DP system belonged to a new generation of DP systems using Kalman filtering and optimal control theory, as opposed to conventional PID techniques.

The software contained a model describing the vessel by means of Newton's Laws. The vessel model or estimator consisted of two parts, the low frequency (LF) and the high frequency (HF) model.

The LF model described wind, current and thruster force induced movements on the vessel. From the model of the vessel behaviour, and environmental conditions, one would extract the information necessary to compute a proper set of forces and moment. That was done by exactly compensating for the wind forces (including feed forward) and for calculated current.

The HF model described motion induced by first order wave forces, and was near to a sinusoidal motion—the model was a harmonic oscillator with a self-adjusting centre frequency (adaptive). The model was forced to follow the oscillatory part of the measurements, and when it was added to the LF part of the model, one could get an accurate estimate of the position and velocity of the vessel. To improve the speed estimates, and to improve the overall performance, velocity measurement from the Doppler log was input to the system. The computed force and moment demand from the control feedback was computed from the low frequency model and, thus, no high frequency modulation of the thrusters would appear.

Measurements

It was necessary for the DP system to evaluate the reliability of the signals it was receiving from the reference systems in use.

The measurements from the reference systems all had different noise characteristics. So, all the reference system data were fed into the computers in parallel, and the best proportion of each signal was used to get the optimal signal. In order to achieve that, there were on-line variance computations on the signals from each measurement system, and each sensor system datum was given a weight according to that variance when the final signal was computed. A lower value of variance of the noise and signal corresponded to more accurate measurements, and would result in an increased weight value. Measurements outwith a pre-set limit would be excluded, and not contribute to the positioning.

Safety aspects in the software

1) The vessel model predicted movements in future time, and made computations of proper control forces possible, even if reference signals were lost for certain periods.

2) Due to the vessel model inherent in the software, the vessel could be turned or made to perform manoeuvres at relatively high speed, and still be within the positioning limits regarding overshoot and eventual positioning accuracy.

3) DP-assisted mooring (anchor assist), which was a feature included in the system, was used where the particular operation called for more system back-up than could be provided by the DP system on its own.

Only a few anchors might be necessary, and so time to move by anchors might be kept to a minimum.

When on anchors, the DP system might be needed to remove the oscillations induced on the vessel by the anchors, especially in deep sea conditions. Anchor-assisted DP might also be useful to reduce the power consumption if required, compared with a conventional DP operation.

Authors' Replies

In reply to Mr. Ferguson, the authors stated that the design study undertaken prior to putting the ESV specification out to tender reviewed all the possible suppliers of major equipment. That study was performed on the basis of competitive quotations from those manufacturers who, having been approached, had expressed interest in participating. On the basis of the quotations received, and on subsequent discussions and works visits, a list of preferred manufacturers was compiled. Some lesser items, however, were included on the list without competitive tendering, on the basis of proven good performance on Company vessels or known advantages over other products. Some manufacturers' equipment was excluded from the list because, although it might have appeared commercially attractive, it did not meet the standard required by the specification or its weight or maintenance requirements were considered to be excessive.

At the time of placing the contract, therefore, an appropriate list of all major suppliers had been decided upon. However, once it was known that the vessel would be built, the following occurred:

1) manufacturers who had declined to participate in the design study requested that they should be given a chance to tender;

2) manufacturers who had been eliminated during the design study re-tendered to the Shipyard on a more competitive basis, and

3) pressure to buy British was exerted.

The result was that the tendering process resumed with extensive re-evaluation of all tenders, many of which did not comply with the specification. That process prevented time being spent rationalizing the supply of equipment and system requirements and, more seriously, reduced the time available within the contract for system designs to be evaluated and improved.

The authors believed that the best procedure to follow was to pre-select a number of contractors who appeared to have potentially acceptable products and then to engage in a competitive tendering exercise. Care, however, must be taken to recognize the need for design and equipment development within the tendered price and to that end a level of mutual confidence and respect must exist between vendor and purchaser.

Another point raised by Mr. Ferguson had related to maintaining a high level of readiness and competency to meet the various emergency and support roles. A formal approach would be adopted towards practising emergency procedures in order to ensure that the vessel's personnel were fully familiar with all aspects of the facilities at their disposal. Operating manuals were being produced and would contain procedures, technical instructions and check lists for going into the various support and emergency roles.

Mr. Murdoch had expressed concern at the possible problems of keeping the alarm system in effective working order. The system might appear to be outdated by some standards, but the authors were confident that an optimum system had been achieved which allowed sensible surveillance under UMS conditions and from the Machinery Control Room during manoeuvring and changing mode, and provided good local coverage of alarms in the event of any machinery space having to be attended. The concept adopted was intended to reduce the amount of duplicated or unnecessary read-out facilities, since the authors felt strongly that the local instrumentation was more important than remote read-out for the majority of equipment and system parameters.

All level switches, pressure switches, temperature switches and temperature measuring equipment were capable of being checked and/or calibrated with reasonable ease, and a routine checking procedure would be developed.

On the subject of being able to check that alarm, control and safety equipment was functional, they had had difficulty obtaining acceptance of their specified requirement for level switches, which could not be otherwise easily checked, to be provided with a test device to enable manual tripping of the float. That made them wonder just how many vessels were sailing under UMS with level switches for alarm and shut-down functions which had never been proved in service because it was not possible or easy to check the alarm, short of draining tanks and sumps.

Mr. Carrell and Dr. Hatton had amplified the work that had been performed in order to ensure that the fire monitor performance would meet the specification requirements and their comments had complemented the paper. The tests had shown that, although the optimum pressure at the monitor inlet was slightly higher for low wind speeds than other studies had led them to believe, the value obtained justified their belief in low pressure monitor systems. However, the effect of high wind speeds on the optimum pressure had yet to be adequately demonstrated.

The authors wished to remind Mr. Watmuff of the well-known engineering law, one corollary of which could state that a system was more likely to fail when the safety system had been overridden or had itself failed. They did not believe that they had been over-cautious, because the consequences of some otherwise relatively minor failures could result in loss of a diver and bellman, damage to a platform support structure, partial sinking of the vessel, or, more seriously, explosion with the potential for hazarding all those on a platform and on the vessel. That point could be demonstrated by giving two examples of possible failures and their effects:

i) A blocked filter, or failed flexible pipe, on a thruster hydraulic unit could cause the vessel to collide with a platform or to drive off, dragging with it the diving bell and diver.

ii) If gas was ingested by a diesel generator and if, for whatever reason, the circuit breaker opened, then the normal overspeed shutdown device which operated on the fuel rack would have no effect.

In both those examples an alarm would be required to show that something was going wrong, and the thruster or diesel generator control system must be able to recognize that a dangerous situation had occurred and to take safe corrective action. In many other vessels, safe corrective action meant shutting down the plant concerned but, in that type of application, such action might, in certain operational roles, precipitate the above catastrophes. For those reasons particular attention had been given to the ensuring of both a fail-to-safe situation, and a means of identifying that such a failure had occurred.

The first example also emphasized why it was considered necessary to enforce what might seem to be stringent requirements of the specification.

The dynamic positioning computer equipment had been specified in detail to ensure that the requirements for operational performance and integrity would be met and to that extent had anticipated the requirements of the Department of Energy "Guidelines for the specification and operation of dynamically positioned diving support vessels". Selection was made by competitive tender and comparative technical evaluation culminating in a system that required development from previously established standards, and embracing comprehensive self-monitoring facilities for the complete DP system. The DP system as a whole had been procured from many suppliers of the component parts, and the establishment of a proper understanding of the roles and characteristics of the equipment and sub-systems by the vendors had required significant effort. Only when those aspects were properly understood by all concerned could effective software and interfacing be developed.

In conclusion, the authors observed that since the vessel had been conceived by a shipping company, many design and operational philosophies had been based on shipping practice. Other vessels of that type had been derived from drilling rig designs and, consequently, their design and operating philosophy reflected that. It would be interesting to see how those different philosophies would compare under operational conditions.

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