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ADAMS OFFSHORE SERVICES LIMITED

Failure Mode And Effect Analysis

of the Dynamically Positioned

Offshore Support Vessel

ADAMS AQUANAUT

Report No: GM-22884-1103-14747, Rev 3

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ISSUE	REV NO	DATE	REASON	AUTHOR	CHECKED	APPROVED
1	Draft	6/11/03	For Comment	ADF	RMN	RMN
1	1	22/12/03	For Issue	ADF	RMN	RMN
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1	3	13/08/07	Updated with owner's comments	YO	RMN	RMN

Amendment Record

Date	Descriptions	Reasons	Sections	Signed
	Various	Generally according to the email of 1/06/07 (Aquanaut FMEA Corrections) from Bill Parker of Adams Offshore Services Ltd.	Various	
	Previous paragraph 1 deleted.	This too readily identifies the wrong operator and a check of the other vessel's FMEA identifies that this paragraph is not included.	Summary	
	"Any DGPS fixes not out with rejection parameters can degrade the position keeping envelope" replced with " Any spurious fix which is not rejected can degrade the position keeping envelope"	For clarity	7.9.6a	YO (GMS), WP (AOL), RR (AOL)
	“Main switchboard UPS (205.7)” deleted.	The UPS is now replaced.	5.5.2	
	"Switchboard UPS will revert to battery and provide control system power for minimum 30 minutes” deleted.	The switchboard UPS is now removed and replaced with a direct feed from 24V batteries.	5.8.2	
	“Total failure of Switchboard UPS” replaced with “Failure of 24V feed to MSB control system”	UPS has been replaced with a direct feed from MSB	5.8.4	
	In the table, “DGPS1” replaced by “DGPS2”, and original entry for “DGPS2” in adjacent cell replaced with “DGPS1/XP and L1/L2 GPS”.	Rearrangement of consumers between UPS1 and UPS2	7.6.2	

Amendment Record *continues*

Date	Descriptions	Reasons	Sections	Signed
	"/The vessel is fitted with two Skyfix 90938 GPS units" changed to "The vessel is fitted with two DGPS systems (one Skyfix 90938 and one 4100LR DGPS unit) and a Multifix XP system providing a higher degree of referential integrity and accuracy. Each DGPS system operates independently. The output of DGPS1 unit is connected only to the Multifix system, which then feeds the DP desk via the DP system input channel assigned for DGPS1. The output of the DGPS2 unit is fed to the Multifix unit as well as directly fed to the DP desk"	To reflect new arrangement	7.9.1	YO (GMS), WP (AOL), RR (AOL)
	In table, DGPS2 type changed from "Skyfix 90938" to "4100LR".	To reflect the change	7.9.1	
	Sentence starting with "/The Skyfix 90938 receives the GPS…" changed to "The 90938 units receive the GPS signals and differential signals using 2 separate antennas and has the capability of only utilizing the correction from any one station, and performs the positioning calculation, to correct for any errors in the raw GPS signal. The 4100LR unit utilizes a combined antenna for GPS and differential signals and has an integrated VBS solution enabling it to perform positioning calculation using correction signals from multiple stations. The corrected position is then input to the DP system."	To reflect the change	7.9.2	

Amendment Record *continues*

Date	Descriptions	Reasons	Sections	Signed
	Table 7.9.3 now reads: DGPS1 Differential Signals :– Spotbeam, Inmarsat via minidome Interface :– Spotbeam antenna connected to Skyfix unit, Minidome antenna interfaced to 90928, Minidome controller connected to Skyfix unit DGPS12 Differential Signals :– Combined antenna Interface :– Combined antenna connected to 4100LR	To reflect new arrangement	7.9.3	YO (GMS), WP (AOL), RR (AOL)
	"Note" under table 7.9.3 now reads "DGPS 1 can operate with either Spotbeam or Minidome derived correction signals. A selection switch is fitted between the inputs, allowing the operator to switch between them".	To reflect new arrangement	7.9.3	
	"The" inserted at the beginning of the statement	Grammar	7.9.5	
	"Failure Modes" inserted	To describe prevailing failure modes	7.9.6	

SUMMARY

The FMEA and verifying trials have found no single failure that will result in the vessel being unable to maintain DP control. This is consistent with the ABS ✠DPS2 notation.

To maintain DPS2 operations the fuel oil supply should be operated as a split system. Two bow thrusters and both stern thrusters have to be running and selected on the DP system. One generator and one bow thruster have to be connected to each 440V busbar section with the bustie breaker open or closed.

When configured for DPS2 operations, the worst case system failure is a fuel oil failure by water contamination or other failure of supply from the port service tank, causing the loss of the port main engine and diesel generators 1 and 2. Subsequent to the failure the vessel would still be able to maintain position with one bow thruster and one azimuth thruster. With good shipboard fuel management techniques, the probability of water contamination of the fuel oil is negligible.

The worst case mechanical failure is the loss of a main engine. Subsequent to this failure the vessel would still be able to maintain position with two or three bow thrusters and one azimuth thruster.

The worst case electrical failure is a short circuit on one section of the main 440V switchboard, resulting in the loss of equipment connected to the faulty busbar. Initially the vessel will be able to maintain position with one bow thruster and one azimuth thruster. The DP operator can then reclutch and select in DP the failed stern thruster. The design of the switchboard will also allow the operator to connect generator 2 and bow thruster 2 to the healthy switchboard. Thus shortly after this failure, the vessel will be able to operate in DP with two bow thrusters and both azimuth thrusters.

For the generation of the DP capability charts, the worst case failure should be considered as the vessel being reduced to one bow thruster and one stern thruster.

TABLE OF CONTENTS

SECTION **PAGE**

1. INTRODUCTION

1.1 Instructions

1.1.1 Global Maritime Scotland Ltd (GM) was instructed by Khalifa A. Algosaibi Diving to carry out a Failure Mode Effect Analysis (FMEA) of the ROV/Diving support vessel, Aquanaut.

1.1.2 Instructions were received by fax from Mr Alex Brown of Khalifa A. Algosaibi Diving on 20th June 2003, in response to GM proposal P12579, of the 13th March 2003.

1.2 Scope of Work

1.2.1 The scope of work was for GM to compile a preliminary desktop Failure Mode and Effect Analysis (FMEA) of the vessel's DP related systems, which reviewed the design of the vessel; its power supplies, thrusters, references etc.

1.2.2 The vessel was then inspected to confirm the as-built arrangement. The effects of failure modes were demonstrated by conducting proving trials.

1.3 Conduct of Work

1.3.1 The work was completed in two stages, firstly a desk top study of the vessel drawings supplied by the Balenciaga shipyard. A draft report and test programme was produced after reviewing the drawings. The second stage was the physical inspection of the vessel and the FMEA proving trials.

1.3.2 The FMEA proving trials took place in two parts, firstly on the 5th of December 2003 and finally between 17th and 18th of December 2003. The trials were conducted off San Sebastian, Spain in light weather conditions in varying water depths between 50m and 150m.

1.3.3 The Issue 1 Rev 1 report was the first complete revision to include the failure mode effects as demonstrated during the verifying trials and reflected the as-built condition of the vessel.

1.3.4 This Issue 1 Rev 2 report has been updated to include the failure modes demonstrated during the first annual trials and reflects the modified as-built condition of the vessel.

1.3.5 This Issue 1 Rev 3 report has been further updated to include further modifications to describe the present as built condition of the vessel.

1.4 Vessel Description

1.4.1 The Aquanaut was built in 2003, at Astilleros Balenciaga, Spain, her design being a purpose built ROV/Survey/diving and general offshore support vessel. The vessel is to have the following ABS Classification Notations: ✠A1, Circle E, ✠AMS, ✠DPS2.

1.4.2 The vessel is mono-hull design and fitted with two azimuth thrusters at the stern and three tunnel thrusters at the bow. The two Schottel azimuthing thrusters are directly driven by two diesel engines and the bow tunnel thrusters are driven by electric motors supplied from the vessel's main switchboard.

1.4.3 The main 440V switchboard also supplies the vessel's other power demands. It is divided into two sections and is fitted with an automatic bus tie breaker. The switchboard is supplied by three Wartsila diesel generators, with two connected to one section and one connected to the other. No.2 generator can be connected to either section.

1.4.4 The vessel main dimensions are;

- Length 73.3 m
- Breadth 16.0 m
- Depth 7.5 m

1.4.5 Draft and displacement.

- Design Draft 5.25 m
- Deadweight 1815 tonnes

The vessel can be loaded to a draft of 5.85m for a deep load condition.

1.4.6 Machinery

- Main Electric Power; -3 x Wartsila 4R32 Turbo charged diesel engines, each rated at 1.950 kVA at 720 rpm driving brushless generators, each of 1620kW, 60Hz, 3 phase.
- Propulsion; - 2 x Schottel SRP 2020, azimuthing thrusters, variable pitch / constant speed, "bollard pull" of 35 tonnes each. 2 x Wartsila 6R32E diesel engines, each rated at 2460 kW at 750 rpm. On passage the thrusters can also be operated in Combinator mode i.e. variable pitch/rpm.
- 3 x 700kW Schottel STT 550 CP bow tunnel thrusters, fixed speed and variable pitch, each of 8.5 ton thrust output.

1.4.7 Positioning Control system

- Simrad SDP21 Dynamic Positioning control.

2. MACHINERY SYSTEMS

2.1 Compressed Air Systems

2.1.1 The vessel has two compressed air systems, the starting air system and the working air system. The compressed air is supplied by two electrically driven air compressors, each discharging at 30bar into a total of four air receivers. Two air receivers are located in the main engine room and the other two in the auxiliary engineroom. The power supplies to the air compressors are arranged as follows:

Air compressor	**Rating**	**Electrical supply**
No 1	$28m^3/h$ @ $30kg/cm^2$	440V starboard switchboard
No 2	$28m^3/h$ @ $30kg/cm^2$	440V emergency switchboard

2.1.2 The air receivers in the main engineroom supply air to the main engines, to the working air system, and to weed blowing connections for the main engineroom sea chests. The receivers located in the auxiliary engine room supply air to the diesel generators and weed blowing connections for the auxiliary engineroom sea chests. The weed blowing air is reduced from $30Kg/cm^2$ to $2Kg/cm^2$ by a reducing valve. The air supplied to the main engines and diesel generators is at $30Kg/cm^2$; this is used for engine starting air. The $30kg/cm^2$ is also used to supply control air for each engine, this is reduced to $7kg/cm^2$ on each engine.

2.1.3 The $30Kg/cm^2$ from the main engineroom is reduced to $12Kg/cm^2$ and passed through a drier unit to provide working air for the vessel. The working air is supplied around the vessel to the following consumers;

Port Schottel azimuth clutch
Starboard Schottel azimuth clutch
Main engine oil mist detectors
Diesel generator oil mist detectors
Ships whistle
Tautwire
Engineroom (general working air connection)
Bow thruster room (general working air connection)
Fuel oil purifier
Lub oil purifier
Deck (general working air connection)
Workshop (general working air connection)
Bilge water separator
Incinerator
Auxiliary engineroom

2.1.4 Each consumer is fitted with isolating valves, allowing it to be isolated for maintenance or in the event of a leak.

2.1.5 The air supply to the Schottel clutches is through a non-return valve. After the non-return valve an additional air receiver is fitted. The Schottel clutch will fail open on loss of air pressure, thus the air receiver is sized to provide suitable air supply to the clutch in the event of low air pressure on the vessel.

2.2 Failure modes

Failure	Effect	Alarm	Remarks
Compressor failure, mechanical or electrical	Loss of one compressor, air supply continues from other compressor	Low air bottle pressure	
High air consumption, Pipe failure	Loss of system air pressure, hence loss of tautwire.	Low air bottle pressure	Azimuth clutch will remain engaged for the duration of the additional air receiver.

2.3 Comments

2.3.1 In the event of total loss of starting air pressure the vessel will lose the use of the tautwire. This will have little effect on DP operations, as the vessel will be able to continue operations using the other positioning references, i.e. DGPS, Fanbeam and HPR.

2.3.2 With no starting air pressure, the operator will not be able to start additional diesel engines. To operate in Class 2 DP the vessel requires both main engines and two of the three generators. As the engines keep running on loss of air pressure, this failure has little effect.

2.3.3 The major consequence of loss of air pressure when conducting DP operations is the effect on the main propeller clutches. On loss of air pressure the clutch will open, resulting in the loss of the main propeller. To prevent this result in the loss of both propellers simultaneously, the supply to each clutch is through a non-return valve, with an air receiver after the non-return valve providing a backup air supply. The receiver holds sufficient air to provide in excess of 30 minutes clutch operation, following a loss of working air pressure.

2.3.4 The DP operators should be aware of the criticality and possible consequence of low working air pressure. Suitable procedures should be included in the DP procedures to warn operators of the possibility of this failure, and to mitigate the effects.

2.4 Seawater Cooling System

2.4.1 The vessel has two seawater systems; the main system provides cooling for the main engines and the auxiliary system provides cooling for the diesel generators and auxiliaries.

2.4.2 The main system consists of two sea chests, common seawater main, two central coolers and associated pipework. The port and starboard sea chest are connected to the common seawater main running across the vessel. Each of the sea chests is connected to the common main via a sea strainer with inlet and outlet isolating valves. Each sea chest is also fitted with an air vent, Cu/Al ion dosing connection, and weed blowing air connection.

2.4.3 The main seawater pumps take suction from the sea water main and discharge to their central cooler. The seawater flows through the cooler and overboard via the over board discharge. The seawater main is fitted with an isolating valve, allowing the main to be split into port and starboard systems. The main seawater pump suctions are arranged either side of this isolating valve. The discharge line of the seawater pumps is fitted with an interconnecting valve, allowing either seawater pump to supply both central coolers. The pumps and coolers are all fitted with isolating valves, allowing the equipment to be isolated for maintenance. All valves in the system are manually operated.

2.4.4 In normal operating conditions, one main seawater pump is running and one cooler is on line, with the other pump and cooler on standby. A single seawater pump and cooler are sized to supply the cooling requirements of both engines. In the event of a failure of the online seawater pump, a low pressure alarm will be generated on the alarm system. The operator then has to manually start the standby pump to restore the seawater cooling. The power supplies for the main seawater pumps are arranged as follows:

Main seawater pump	**Rating**	**Power supply**
No.1	$308m^3/h$	Port main 440V switchboard
No.2	$308m^3/h$	Starboard main 440V switchboard

2.4.5 The main seawater suction rail also supplies two general service pumps. The general service pumps are used for fire/bilge/ballast and wash down duties. The electrical supplies to the general service pumps are arranged as follows:

Seawater cooling pump	**Electrical supply**
General service 1	Engine room No. 1 switchboard
General service 2	Engine room No. 2 switchboard

2.4.6 The auxiliary seawater cooling system is similar in arrangement to the main seawater system. It consists of two sea chests, a common seawater main, two central coolers and associated pipework. The port and starboard sea chests are connected to the common seawater main running across the vessel. Each of the sea chests is connected to the common main via a sea strainer with inlet and outlet isolating valves. Each sea chest is fitted with a chemical dosing and a weed blowing air connection.

2.4.7 The auxiliary seawater pumps take suction from the sea water main and discharge to the central coolers. The seawater flows through the coolers and overboard via the over board discharge. The seawater main is fitted with an isolating valve, allowing the main to be split into port and starboard systems. The main seawater pump suctions are arranged either side of this isolating valve. The discharge line of the seawater pumps is fitted with an interconnecting valve, allowing either seawater pump to supply both central coolers. The pumps and coolers are all fitted with isolating valves, allowing the equipment to be isolated for maintenance. All valves in the system are manually operated.

2.4.8 In normal operating conditions, one main seawater pump and cooler are in operation with the other pump and cooler on standby. A single seawater pump can supply the cooling requirements for all three engines. In the event of a failure of the online seawater pump, a low pressure alarm will be generated on the alarm system. The operator then has to manually start the standby pump to restore the seawater cooling. The power supplies for the auxiliary seawater pumps are arranged as follows:

Auxiliary seawater pump	**Rating**	**Power supply**
No.1	206m^3/h	Port main 440V switchboard
No.2	206m^3/h	Starboard main 440V switchboard

2.4.9 The auxiliary seawater suction rail also supplies various seawater pumps that provide seawater cooling to auxiliary equipment. They are arranged as follows:

Seawater pump	**Rating**	**Power supply**
Switchboard room air conditioning	10m^3/h	AC swbd, port main 440V swbd
Provision refrigeration (two pumps)	2m^3/h	Fridge swbd, stbd main 440V swbd
Air conditioning (two pumps)	173m^3/h	AC swbd, port main 440V swbd
Deck supply	25m^3/h	Stbd main 440V swbd

2.5 Freshwater Cooling

2.5.1 The vessel has two freshwater cooling systems, the main engine system and the auxiliary engines system.

2.5.2 The main system provides freshwater cooling for the main engines, fuel oil cooler and azimuth hydraulic coolers. It consists of two central coolers, temperature control valve and pipework. The main section of the system is not fitted with circulating pumps; the main engine pumps circulate the cooling water around the main system.

2.5.3 The main engine HT and LT pumps take suction from the outlet side of the LT temperature control valve, fitted across the central cooler. Details of engine cooling are described in Sections 3 and 4. The spilled water flows to the central coolers inlet. If the LT water temperature is above the desired set point it is directed through the cooler and then to the engine pump suctions. If the LT cooling water is below the desired set point, the cooler is bypassed and the water is directed to the engine pump suctions.

2.5.4 The temperature control valve is an electrically operated three-way valve. The valve has an integral controller and actuator, which regulates the LT water temperature to the desired set point. The valve is fitted with a manual operating lever, allowing the operator to manually regulate the LT water temperature if required. The valve is powered as follows:

	Power supply
LT Temperature control valve	Port 220V services switchboard circuit 203.3

2.5.5 The cooling loop for the azimuth hydraulic coolers is fitted with two circulating pumps. In normal conditions, one circulating pump is in operation with the other pump on standby. In the event of a failure of the online circulating pump, a low pressure alarm will be generated on the alarm system. The operator then has to manually start the standby pump to restore the cooling. The power supplies for the azimuth cooling pumps are arranged as follows:

Azimuth cooling pump	**Rating**	**Power supply**
No.1	10 m^3/h	Port main 440V switchboard
No.2	10 m^3/h	Starboard main 440V switchboard

2.5.6 The auxiliary cooling system provides freshwater cooling for the diesel generators. It consists of two central coolers and the pipework. Like the main system it is not fitted with circulating pumps; the diesel generator LT and HT cooling pumps circulate the cooling water around the system.

2.5.7 The diesel generator HT and LT cooling pumps take suction from the outlet of the auxiliary central cooler. The cooling water is circulated around the engines and then is spilled into the out auxiliary cooling system. The cooling water then flows through the central cooler; the system is not fitted with a temperature control valve.

2.5.8 Both the main and auxiliary cooling systems are fitted with dedicated header tanks, i.e. one tank for each system. These tanks provided static pressure on the system. The header tanks are fitted with level switches, which provide the operator with an early indication of system leakage.

2.6 Failure Modes

Failure	Effect	Alarm	Remarks
Blocked or aerated main seawater suction	Low seawater pressure to central cooler. Reduced heat transfer in central cooler, engine operating temperatures rise.	Seawater cooling pressure low	Operator should be able to change over sea suction, without affecting engines
Blocked or aerated auxiliary seawater suction	Low seawater pressure to central cooler. Reduced heat transfer in central cooler, engine operating temperatures rise.	Seawater cooling pressure low	Operator should be able to change over sea suction, without affecting engines
Failure of seawater pump	Low seawater pressure on affected system. Standby pump to be started to restore cooling.	Seawater cooling pressure low	Operator to start standby pump.
Blocked cooler	Rise in individual engine operating temperatures.	Fresh water high temperature alarm	Operator will have to change over to standby central cooler.
Failure of seawater pipe.	Local flooding in local area, rise in engine temperatures.	Seawater low-pressure alarm, Bilge alarm for affected area.	System will have to be shut down and leak repaired.
Failure of port or starboard 440V switchboard	Loss of pumps powered from that side of the switchboard.	Seawater cooling pressure low	Operator to start standby pump.
Failure of engine driven pump	Loss of cooling flow through affected engine	Low cooling water pressure or high temperature	Operator will have to shut down the affected engine to repair the pump.
Power failure of temperature control valve	Valve fails as set	None, possibly high engine temperature if engine loads increase.	Operator can adjust valve setting manually.
Temperature sensor failure to controller	Valve fails to full cooling.	.	Operator can adjust valve setting manually.

2.7 Comments

2.7.1 The single worst failure affecting the seawater cooling system is a failure of a seawater pipe, causing loss of cooling and flooding of the engineroom. This failure mode is of a static component and is not considered in DP Class 2.

2.7.2 The seawater cooling is used to provide cooling for central cooling systems, one system for the main engine and one for the diesel generators. Both systems have redundant central coolers and seawater pumps. A failure of the online seawater pump will require the operator to start the standby pump. A failure of a central cooler will result in the rise in the operating temperature of the system. The system is monitored by the central alarm system; this will give the operator indication of the temperature rise and sufficient time to change over to the standby cooler.

2.7.3 The freshwater cooling systems are similar; one providing cooling for the main engines, the other for the diesel generators. As with the seawater system, a pipe failure could result in the loss of either main engines, or the generated power from the three diesel generators. As this is a failure of a static component it is not considered in DP Class 2. A failure of the LT temperature controller will result in the valve failing to full cooling or the valve failing as set. In both cases the operator can manually operate the valve to control the LT system temperature.

2.8 Fuel Oil Bunker System

2.8.1 The tanks are filled from deck from the port and starboard deck filling connections, through a bunker line, by gravity to the bunker manifold. The bunker manifold consists of a filling main and a suction main. Each bunker tank has a single suction/delivery line; this is connected to both the filling main and the suction main. A manual isolating valve is fitted in each of the suction and filling manifold connections to the tank suction/delivery lines. The tank capacities are as follows:

Fuel oil tank	**Capacity**
6 centre	81.2 m^3
7 port	117.7m^3
7 starboard	117.7m^3
8 port	73.0m^3
8 starboard	73.0m^3
9 port	75.0m^3
9 centre	75.0m^3
9 starboard	48.2m^3
13 port	58.9m^3
13 starboard	58.9m^3
10 port (Port gas oil service tank)	32.3m^3
10 starboard (Starboard gas oil service tank)	32.3m^3
11 port (Port gas oil settling tank)	35.3m^3
11 starboard (Starboard gas oil settling tank)	35.3m^3

2.8.2 The system has two fuel oil transfer pumps that take suction from the bunker suction valve manifolds and normally discharge to the fuel oil settling or service tanks. A connection is also provided to allow discharge to deck if required. Each of the pumps is fitted with suction filters and manually operated isolating valves. The transfer pumps are arranged as follows:

Fuel oil transfer pump	**Rating**	**Power supply**
Gas oil transfer pump no.1	25m^3/h @3.5bar	Fuel oil services swbd, supplied from port 440V main switchboard.
Gas oil transfer pump no.2	25m^3/h @3.5bar	Fuel oil services swbd, supplied from port 440V main switchboard.

2.9 Supply System

2.9.1 In normal circumstances, a single fuel purifier will take fuel from either of the settling tanks. After purification to remove contaminants and water, the fuel is discharged to either the port or starboard service tank. The purifier can also take suction from the service tanks or from the bunker tanks, via the bunker suction manifold if required. The service and settling tanks are fitted with drain valves to allow the engineroom staff to drain any water from these tanks.

2.9.2 The fuel oil purifier is arranged as follows:

Gas oil purifier	**Rating**	**Power supply**
Gas oil purifier	2100 l/h	Fuel oil and services swbd no.1, supplied from port 440V main switchboard.

2.9.3 The main engines and diesel generators are supplied with gas oil by gravity from the service tanks. The fuel oil is supplied to the engines after flowing through duplex filters, each engine having a dedicated filter. A fuel supply line interconnects the service tanks. This line is fitted with two isolating valves, splitting the fuel supply into port and starboard systems. The port fuel supply system provides fuel oil to the port main engine and diesel generator No.1. The starboard system provides fuel oil to the starboard main engine and diesel generator No.3. Diesel generator No. 2 fuel supply line is located between the two isolating valves, hence can be supplied from either the port or starboard system.

2.9.4 Any unused or “spilt” fuel from the main engines is returned to the service tanks, via a fuel oil cooler. Similarly the generator spilt fuel is returned to the service tanks. The return fuel from the engines and the generators can be directed to either of the service tanks.

2.9.5 The fuel tank suction and supply valves are remotely hydraulically operated quick closing valves. The valves are operated from the starboard side of the main deck, behind the accommodation block.

2.10 Failure Modes

Failure	Effect	Alarm	Comments
Water contamination of fuel oil bunkers	Possible failure of two (or one) diesel generators and one main engine	Switchboard tripped alarm. Engine group alarm.	Correct operation of the purifier should remove the water contamination.
Fuel oil pipe failure	Possible loss of two (or one) diesel generators	Switchboard tripped alarm. Engine group alarm.	Running a split fuel system, the worst failure will result in the vessel having one main engine and one diesel generator remaining.
Blocked fuel oil filter	Loss of fuel supply to diesel engines, engines shut down.	Switchboard tripped alarm. Engine group alarm.	Running a split fuel system, the worst failure will result in the vessel losing one main engine or one diesel generator.
Inadvertent operation of quick closing valves	Loss of fuel supply to diesel engines, engines shut down.	Switchboard tripped alarm. Engine group alarm.	Running a split fuel system, the worst failure will result in the vessel losing one main engine or two diesel generators.

2.11 Comments

2.11.1 Provided that the fuel system is operated as a split system, the worst case failure is the loss of one side of the system. This could be caused by pipe failure, inadvertent operation of the quick closing valve or water contamination of the fuel oil. In the worst instance, this would result in the loss of one azimuth thruster engine and two diesel generators. The vessel will still be able to maintain position in DP with one azimuth thruster and one bow thruster, powered from the remaining running diesel generator, although with reduced station keeping capability.

2.11.2 The port fuel oil supply system can be cross connected to the starboard fuel system via isolating valves, service tank can supply all of the diesel engines by making the system common. Under normal circumstances, and to comply with DP2 requirements, the fuel supply should be configured as a split system. No.2 diesel generator can be supplied with fuel from either full tank. As this engine will be used when No.1 or No.3 diesel generator is under maintenance, the status of the fuel supply to diesel generator No.2 should be included in the engineroom DP checklist, to prevent both engines being supplied from a single service tank.

2.11.3 With good watch keeping practice and correct operation of the fuel oil purifier the probability of water contamination of the fuel oil will be reduced to negligible. The engineroom routine should include regular draining of the service and settling tanks; to detect and remove any build up of water in these tanks. When purifying fuel, only one service tank at a time should be filled. This will prevent any purifier malfunction affecting both service tanks.

2.11.4 When storing gas oil, it is possible that after exposure to seawater, the oil becomes contaminated with bacteria. This produces a “growth” that can block fuel filters, and in some circumstances can be sufficient to stop the flow of fuel. It is recommended that the vessel operates a fuel oil testing program, to detect the presence of microbiological bacteria in the fuel. A stock of biocide should be retained onboard to treat any fuel that is contaminated.

3. MAIN ENGINES

3.1 Introduction

3.1.1 The vessel has two main engines, port and starboard, that each drive an azimuthing thruster unit. The engines specifications are as follows:

Engine	Make Type	Rating	Location
Port	WARTSILA 6R32E	2460 kW at 750 rpm	Main engineroom
Starboard	WARTSILA 6R32E	2460 kW at 750 rpm	Main engineroom

3.1.2 Each main engine is 6 cylinder inline, 4 stroke, and turbocharged. It directly drives the azimuthing propeller unit via a drive shaft and clutch arrangement. The engines are started by direct injection of starting air into the cylinders.

3.2 Fuel System

3.2.1 Each engine has its own engine driven fuel pump, this is supplied with fuel oil by gravity from the respective service tank, through a 30 micron duplex primary filter and an engine mounted 15micron duplex filter. The fuel supply is served by individual pumps connected to the cylinder injectors by high pressure piping. The quantity of fuel discharged by the fuel pump and injected into the cylinders is regulated by the governor. Any internal leakage or “spill” fuel from the engine fuel system is routed through a fuel oil cooler and back to either of the fuel oil service tanks.

3.3 Cooling Systems

3.3.1 The engine cooling water system consists of a high temperature (HT) and a low temperature (LT) system. The cooling water is circulated around the engines by engine driven pumps. The main engines are connected to the engineroom central cooling system.

3.3.2 The LT system is used to cool the charge air cooler and the lub. oil cooler. The water is taken from the central cooling system and circulated round the coolers by a dedicated engine driven pump. It is then passed through a 3-way wax type temperature control valve. This valve will either re-circulate the cooling water around the engine or spill it into the central cooling system.

3.3.3 The HT system is used to cool the turbocharger and the engine jacket system. The water is taken from the central cooling system and circulated by a dedicated engine driven pump. It is then passed through a 3-way wax type temperature control valve. This valve will either re-circulate the cooling water or spill it into the auxiliary central cooling system. The HT water either passes through the HT cooler, or is passed through a 3-way wax valve and back to the diesel engines.

3.3.4 The cooling water systems have vent lines that spill into a header tank, this ensures a minimum flow of cooling water and that no air locks can occur in the system. The system has one header tank which maintains a static pressure on the system. The engines are also provided with a preheating unit that can circulate the engines with heated water, to avoid starting the engines from cold. The preheating unit is controlled by the engine control system; when an engine stops the unit is automatically started. When the engine is restarted and the speed is greater than 300rpm, the preheater unit will be stopped.

3.4 Lubricating Oil System

3.4.1 Each engine has its own dedicated integral lub. oil system. An engine driven pump circulates the engine with lub. oil. The pump draws suction from the engine sump, and discharges through an engine mounted lub. oil cooler. A temperature control valve, 3-way wax type, controls the flow of oil through or bypasses the cooler. The oil then passes through an automatic filter, before being distributed in the internal engine system. A centrifugal filter is also fitted to the system, to clean the system oil on bypass.

3.4.2 The engine is provided with an electrically driven priming oil pump. When the diesel engine is stopped, this pump is run to keep the engine lub oil system primed. The diesel will be start blocked if low pre-lub oil pressure is detected. The main engine room has a lub oil purifier unit, which allows main engine oil to be cleaned by purification.

3.5 Compressed Air Systems

3.5.1 The engine has two compressed air systems, starting air and control air, both supplied with 30bar air from the main compressed air system. The starting air is used to start the engine, by direct injection of air into the cylinders. The timing of the air injection into the cylinders is controlled by the engine driven start air distributor. The engine control air is used for the shut down cylinders, starting and stopping control.

3.5.2 The oil mist detector is provided with air from the vessel’s control air system at 2bar.

3.6 Combustion air

3.6.1 The engine takes its combustion air supply from the engine room. The turbocharger supplies pressurised air which is then cooled by the air cooler and flows to the scavenge trunk. The combustion air is then supplied to the individual cylinder by the scavenge trunk.

3.6.2 The main engineroom is supplied with fresh air by two supply fans, which can also be reversed. An exhaust fan draws air form the engineroom to ensure airflow through the space. The power supplies to the fans are arranged as follows:

Fan	**Power supply**
Supply fan No.1	Engineroom ventilation swbd no.1
Supply fan No.2	Engineroom ventilation swbd no.2
Exhaust fan	440V emergency switchboard

3.7 Clutching

3.7.1 The driveline is fitted with a pneumatically operated clutch. The clutch is automatically disengaged by spring pressure. To close the clutch, compressed air at 11 bar is admitted to the operating mechanism.

3.7.2 The control of the clutch is achieved by the local operating panel. The panel consists of an air filter unit, two electrically operated solenoid valves, restriction valve and pressure switch. The operating panel is supplied with 24VDC from the Schottel control system. The clutch can be operated from the local panel or from the remote operating panels on the bridge.

3.7.3 To close the clutch the solenoid close coil is energised by an operator action on the control panel. This action allows pressurised air to flow into the clutch, this overcomes the internal spring pressure and closes the clutch. To open the clutch, the open coil is energised. This vents the air pressure and the clutch internal springs open the clutch.

3.7.4 Since the clutch opens on loss of air pressure, each clutch has an air receiver after the air isolating non-return valve. The air receiver provides a backup supply when the working air pressure is low. When the clutch is operated the rate of air venting is controlled by the restriction valve, this is adjusted to ensure a smooth and controlled engagement.

3.8 Speed Control

3.8.1 The engine speed is controlled by a Woodward 723 electronic governor. This system comprises the electronic governor, two speed sensors and an Electro/mechanical PG-EG 58 actuator. The governor controls the engine speed at the desired value by adjusting the engine fuel rack position, using the engine speed as the feedback for the control loop. The actuator positions the fuel rail, the actuator command signals are from the 723 unit.

3.8.2 The 723 unit uses a proximity type speed sensor to monitor the engine speed. It is fitted with two speed sensors; one is in use the other on hot standby. In the event of a failure of the online sensor, the standby senor will automatically be used and the 723 governor will continue to operate. If the second sensor fails the 723 will lose its control input and the engine will be shut down.

3.8.3 The PG-EG 58 actuator is a mechanical/ hydraulic governor with an electrical solenoid for remote speed setting. The hydraulic pressure is generated internally in the actuator and is used to generate the power to position the governor output linkage and hence the engine fuel rail. The output of the actuator is controlled by the electrical solenoid adjusting the speed setting internally in the actuator. The actuator has a mechanical backup function, in the event of a failure of the electronic governor; the mechanical backup governor will take over.

3.8.4 When the vessel is operating in DP the engine is run at a constant speed. The governor receives a constant speed signal from the DP system.

3.8.5 The 723 units are located in the dedicated engine control panels and powered from the engine control system.

3.9 Alarms and Monitoring

3.9.1 Each of the engines has a dedicated engine control panel providing local alarms, monitoring, control and protection. The local panel is interfaced with a remote display unit sited in the ECR, and into the ships alarm system, providing a remote alarm. The Panel contains the engine governor, Despemes speed control unit, protection system and the alarm/monitoring system

3.9.2 The panel is powered from the ships 24VDC systems. Each control panel has two supplies, fitted with an automatic change over. The change over is not bumpless, as it is performed by relays. The power supplies are arranged as follows:

Main engine control panel	**Power supply**	
Main engine No.1	Main supply	24VDC Engineroom services switchboard
	Standby supply	24VDC Wheelhouse services switchboard
Main engine No.2	Main supply	24VDC Wheelhouse services switchboard
	Standby supply	24VDC Engineroom services switchboard

3.9.3 The Despemes unit measures the engine's speed and turbocharger speed. The measured speed signal is used for the electronic overspeed protection, engine running signal and control of the jacket water preheating pump. The Despemes unit is powered by 24VDC from the engine control panel.

3.9.4 The engine protection system and the alarm/monitoring system is a Programmable Logic Control (PLC) based system. The engine parameters are interfaced with the PLC, the PLC software performing the control and protection functions. The engine control panel provides the following shutdowns;

Parameter	**Action**
Overspeed (electronic)	Shutdown
Overspeed (mechanical)	Shutdown
Low low lub oil pressure	Shutdown
High high jacket water temperature	Shutdown
Oil mist	Shutdown
Charge air temperature	Shutdown
Main bearing temperature	Shutdown

3.9.5 The engine control panel provides a comprehensive alarm and engine parameter monitoring. These are interfaced with the engine alarm system giving remote indication of the alarms in the engine control system.

3.9.6 Each engine has a dedicated remote alarm and monitoring panel located in the ECR. The remote panel is also interfaced into the ship's alarm system. The following parameters are monitored:

	Parameter	**Alarm**
FW Expansion tank	Low level	ECR main alarm panel
Seawater cooling LP	Pressure indication	ECR main alarm panel
HT & LT water LP & HT	Low press/High temp	Local and ECR panel
Lubricating oil pressure	Pressure indication	Local and ECR panel
Start Air pressure	Pressure indication	Local and ECR panel
Lubricating oil temperature	Temperature	Local and ECR panel
Fuel Oil pressure	Pressure indication	Local and ECR panel

3.10 Failure modes

Failure	Effect	Alarm	Comments
Failure power supply to engineroom ventilation switchboard	Loss of 50% of combustion air supply to main engines.	None	Engine continues to operate, with no temperature rise.
Freshwater cooling pipe failure	Loss of system cooling water.	Expansion tank low level	Rate of loss will depend on size of leakage. In the worst instance the could result in the loss of both main engines and DP control
Freshwater circulating pump failure	Loss of cooling water circulation.	Fresh water high temperature	Each engine has its own engine driven pumps. The engine will require to be shut down for repair.
Engine freshwater temperature control valve failure.	Dependent on failure	Fresh water high temperature	Will depend on the point of failure of the thermostat. In the worst case the cooler will be bypassed and the engine overheat and shutdown.
System freshwater temperature control valve failure	Valve remains in last position at power loss, no immediate effect.	None, unless engine load increase, then engine high temperature.	Valve can be operated electrically in auto/manual, or manually.
Lub. oil circulating pump failure	Loss of lub oil pressure, engine shutdown – loss of one thruster.	Low oil pressure, engine shut down	As the each engine has an independent lub oil system, this failure can only affect one engine.
Lub oil thermostat failure	High lub oil temperature, resulting in low lub oil pressure, engine shuts down	Low oil pressure, engine shut	As the each engine has an independent lub oil system, this failure can only affect one engine.
Lub oil pipe failure	Loss of circulating lub oil.	Low oil pressure, engine shut down	As the each engine has an independent lub oil system, this failure can only affect one engine.
Fuel oil supply failure, blocked filter or valve closed	Loss of fuel supply, engine will slow and shutdown.		If filter blockage occurs operator will be able to change over filter and restore supply.
Failure of fuel oil pipe	Loss of fuel supply, engine will slow and shutdown.		

Failure	Effect	Alarm	Comments
Failure of engine speed sensor	Auto change over to second speed sensor.	Engine alarm.	Minor alarm, engine will continue to operate.
Failure of second engine speed sensor	Engine will shut down.	Engine alarm	Major alarm, engine will shut down.
Power failure to engine control panel	Engine continues to run but thruster ready signal lost.	Engine alarm	Re-powering will shut down engine.
Failure of engine governor	Mechanical backup governor will take over. Engine will continue to run, but loss of thruster ready signal	Engine alarm	

3.11 Comments

3.11.1 Each engine is self contained in respect of its auxiliary supporting systems; the only common systems being combustion air, freshwater cooling and fuel supply. Any individual engine failure will only result in the loss of one azimuth thruster. A failure of the engineroom ventilation has little effect on the operation of the engines.

3.11.2 When considering the failure of the freshwater cooling system, each engine has its own pumps and internal temperature controllers. Hence a failure in these items will only affect one engine. The LT cooling system has a single temperature control valve; a failure with this valve could affect both main engines. The control valve is fitted with a manual control, so in the event of a failure the operator can manually intervene to prevent the loss of both main engines. As discussed previously, the failure of the freshwater cooling piping is not considered for Class 2 DP, as it is a static component.

3.11.3 To comply with DP Class 2, the fuel system should be run as a split system. In the event of any of these failures occurring the vessel will still be able to maintain DP, with the minimum of one bow thruster and one azimuth thruster. The status of the fuel system should be included in the engineroom DP checklist.

3.11.4 A failure of the main engine electronic governor will result in the mechanical backup governor taking over. When the vessel is operating in DP this will result in engine speed increasing to the mechanical governor speed setting, the thruster ready signal is lost and the thruster pitch is reduced to zero. Hence this failure has the same effect as the vessel losing an azimuth thruster.

4. POWER GENERATION

4.1 Diesel Generators

4.1.1 The vessel has three diesel driven alternators that provide the main ship's electrical power, they are arranged as follows:

Diesel generator	Make Type	Rating	Location
1	WARTSILA 4R32	1.950 KVA	Auxiliary engineroom
2	WARTSILA 4R32	1.950 KVA	Auxiliary engineroom
3	WARTSILA 4R32	1.950 KVA	Auxiliary engineroom

4.1.2 Each generator engine is 4 cylinder inline, 4 stroke, and turbocharged, and is directly coupled to a brushless alternator. The engines are started by air start motor pinion engaging with the fly wheel.

4.2 Fuel System

4.2.1 Each engine has its own engine driven fuel pump; this is supplied with fuel oil by gravity from the respective service tank, through a 30 micron duplex primary filter and a 15 micron engine mounted duplex filter. The fuel supply is served by individual pumps connected to the cylinder injectors by high pressure piping. The quantity of fuel injected into the cylinders is regulated by the governor. Any internal leakage or "spill" fuel from the engine fuel system is routed back to either of the fuel oil service tanks.

4.3 Cooling Systems

4.3.1 The engine cooling water system consists of a high temperature (HT) and a low temperature (LT) system. The cooling water is circulated around the engines by engine driven pumps. The diesel generators are connected to the auxiliary engineroom central cooling system.

4.3.2 The LT system is used to cool the charge air cooler and the lub. oil cooler. The water is taken from the central cooling system and circulated round the coolers by a dedicated engine driven pump. It is then passed through a 3-way wax type temperature control valve. This valve will either re-circulate the cooling water around the engine or spill it into the auxiliary central cooling system.

4.3.3 The HT system is used to cool the turbocharger and the engine jacket system. The water is taken from the central cooling system and circulated round the coolers by a dedicated engine driven pump. It is then passed through a 3-way wax type temperature control valve. This valve will either re-circulate the cooling water or spill it into the auxiliary central cooling system. The HT water either passes through the HT cooler, or is passed through a 3-way wax valve and back to the diesel engines.

4.3.4 The cooling water systems have vent lines that spill into a header tank, this ensures a minimum flow of cooling water and that no air locks can occur in the system. The system has one header tank which maintains a static pressure on the system. The engines are also provided with a preheating unit that can circulate the engines with heated water, to avoid starting the engines from cold. The preheating unit is controlled by the engine control system; when an engine stops the unit is automatically started. When the engine is restarted and the speed is greater than 300rpm, the preheater unit will be stopped.

4.4 Lub Oil Systems

4.4.1 Each engine has its own dedicated integral lube oil system. An engine driven pump circulates the engine with lube oil. The pump draws suction from the engine sump, and discharges through an engine mounted lube oil cooler. For temperature regulation, a 3-way wax type temperature control valve controls the flow of oil through the cooler or cooler bypass. The oil then passes through a duplex paper element filter, before being distributed in the internal engine system. A centrifugal filter is also fitted to the system, to clean the system oil on bypass.

4.4.2 The engine is provided with an electrically driven priming oil pump. When the diesel engine is stopped, this pump is run to keep the engine lub oil system primed. The diesel will be start blocked if low pre-lub oil pressure is detected. The engineroom has a lub oil purifier unit, allowing engine oil to by cleaned by purification.

4.5 Compressed Air Systems

4.5.1 The engine has two compressed air systems, starting air and control air both supplied with 30bar air from the auxiliary compressed air system. The starting air is used to start the engine, by driving an air starter motor. The motor drives a pinion that engages with the engine flywheel. The engine control air is used for the shut down cylinder, starting and stopping control.

4.5.2 The oil mist detector is provided with air from the vessels control air system at 2bar.

4.6 Combustion Air

4.6.1 The engine takes its combustion air supply from the engine room. The turbocharger supplies pressurised air to the air cooler, for cooling. The combustion air is then supplied to the individual cylinders by the scavenge trunk.

4.6.2 The auxiliary engineroom is supplied by two reversible fans. The power supplies to the fans are arranged as follows:

Fan	**Power supply**
Aux ER supply/exhaust fan No.1	Engineroom ventilation swbd No1
Aux ER supply/exhaust fan No.2	Engineroom ventilation swbd No2

4.7 Speed Control

4.7.1 The engine speed is controlled by an electronic governor, Woodward 723. This consists of the electronic governor, two speed sensors and an Electro/mechanical PG-EG 58 actuator.

4.7.2 The governor monitors the engine speed with one of the two speed sensors; the second speed sensor is on hot standby. In the event of a failure of the online sensor, the standby senor will automatically be used and the 723 governor will continue to operate. If the second sensor fails the 723 will lose its control input and the engine will be shut down. The governor controls the engine speed by adjusting the position of the actuator and hence the quantity of fuel being injected into the engine. The actuator is an Electro/hydraulic unit and is driven by the engine. This generates hydraulic power to adjust the actuator output arm and hence the amount of fuel injected into the cylinders. The actuator output is controlled by an electric solenoid that adjusts a hydraulic spool valve and hence the actuator output arm.

4.7.3 The speed setting of the governor is adjusted dependant on the generator load sharing mode, this is discussed in detail in the power management section of the report.

4.7.4 The actuator is mounted on the engine and the 723 unit is mounted in and powered from the engine control panel.

4.8 Alarms and Monitoring

4.8.1 Each of the engines has a dedicated engine control panel providing local alarms, monitoring, control and protection. The local panel is interfaced into the ships alarm system, providing a remote alarm. The Panel contains the engine governor, Despemes speed control unit, protection system and the alarm/monitoring system.

4.8.2 The engine control panels are powered from the ships 24VDC systems. Each control panel has two supplies, fitted with an automatic change over. The change over is arranged by relays and is not bumpless. In the case of diesel generator No.2, this is controlled by the busbar selection switch. This arrangement is to ensure that when DG No.2 is used with DG No.1 or No.3 that the control power is from the appropriate supply. The power supplies are arranged as follows:

<table>
<tr><th>Diesel engine control panel</th><th colspan="2">Power supply</th></tr>
<tr><td rowspan="2">DG No.1</td><td>Main supply</td><td>24VDC Engineroom services switchboard</td></tr>
<tr><td>Standby supply</td><td>24VDC Wheelhouse services switchboard</td></tr>
<tr><td rowspan="2">DG No.2</td><td>Main supply</td><td>24VDC Engineroom services switchboard or 24VDC Wheelhouse services switchboard</td></tr>
<tr><td>Standby supply</td><td>24VDC Wheelhouse services switchboard or 24VDC Engineroom services switchboard</td></tr>
<tr><td rowspan="2">DG No.3</td><td>Main supply</td><td>24VDC Wheelhouse services switchboard</td></tr>
<tr><td>Standby supply</td><td>24VDC Engineroom services switchboard</td></tr>
</table>

4.8.3 The Woodward 723 governor is described in detail in the power management section of this report.

4.8.4 The Despemes unit measures the engine speed and turbocharger speed. The measured speed signal is used for the electronic overspeed protection, engine running signal and control of the jacket water preheating pump. The Despemes unit is powered by 24VDC from the engine control panel.

4.8.5 The engine protection system and the alarm/monitoring system is a Programmable Logic Control (PLC) based system. The engine parameters are interfaced with the PLC, the PLC software performing the control and protection functions. The engine control panel provides the following shutdowns;

Parameter	**Action**
Overspeed (electronic)	Shutdown
Overspeed (mechanical)	Shutdown
Low low lub oil pressure	Shutdown
High high jacket water temperature	Shutdown
Oil mist	Shutdown
Charge air temperature	Shutdown
Main bearing temperature	Shutdown

4.8.6 The engine control panel provides a comprehensive alarm and engine parameter monitoring. These are interfaced to the engine alarm system giving remote indication of the alarms in the engine control system.

4.9 Alternators

4.9.1 The diesel engine is directly coupled to a 440V, 60Hz, self exciting synchronous alternator. The rotor is mounted on two roller bearings. The alternator is cooled by the air circulated around the alternator housing by a shaft mounted fan, the air drawn for the engineroom. .

4.9.2 An Automatic Voltage Regulator (AVR) controls the output voltage of the generator. This adjusts the voltage to compensate for speed and load demand changes. The AVR is contained in the generator, with no external power sources required.

4.10 Failure Modes

Failure	Effect	Alarm	Comments
Failure power supply to engineroom ventilation switchboard	50% loss of combustion air supply to main engines and generators.	None	Engine continues to operate, with no temperature rise.
Fresh water cooling pipe failure	Loss of system cooling water.	Expansion tank low level	Rate of loss will depend on size of leakage. In the worst instance the engine will require to be shut down for repair.
Fresh water circulating pump failure	Loss of cooling water circulation.	Fresh water high temperature	The engine will require to be shut down for repair.
Fresh water thermostat failure	Dependent on failure mode of thermostat – probable failure of one thruster on high temperature.	Fresh water high temperature	Will depend on the point of failure of the thermostat. In the worst case the cooler will be bypassed and the engine overheat and shutdown.
Lub. oil circulating pump failure	Loss of lub oil pressure, engine shutdown – loss of one thruster.	Low oil pressure, engine shut down	
Lub oil thermostat failure	Dependant on failure mode of thermostat – loss of one thruster.		Will depend on the point of failure of the thermostat. In the worst case the cooler will be bypassed and the engine overheats.
Lub oil pipe failure	Loss of circulating lub oil.	Low oil pressure, engine shut down	
Fuel oil supply failure, blocked filter or valve closed	Loss of fuel supply, engine will slow and shutdown.		If filter blockage operator will be able to change over filter and restore supply.
Failure of fuel oil pipe	Loss of fuel supply, engine will slow and shutdown.		
Failure of engine governor	Engine will shut down.	Breaker tripped alarm.	
Failure of engine speed sensor	Engine will shut down.	Breaker tripped alarm.	
Power failure to engine control panel	Engine will shut down.	Breaker tripped alarm	Engine control panel supplies engine governor

4.11 Comments

4.11.1 Each diesel generator engine is self contained in respect of its auxiliary supporting systems, the only common systems being combustion air, seawater cooling and fuel oil. Any individual engine failure will only result in the loss of one diesel generator.

4.11.2 When considering the failure of the freshwater cooling system, each engine has its own pumps and internal temperature controllers. Hence a failure in these items will only affect one engine. As discussed previously, the failure of the freshwater cooling piping is not considered for Class 2 DP, as it is a static component.

4.11.3 The worst case failure of the common system for the diesel generators is a fuel oil failure. When configured as a split system, this can result in the loss of one (or two) diesel generator(s). If the fuel supply system is run as a common system, a single fuel failure will result in the loss of three generators and consequently loss of DP control (no bow thrusters).

4.11.4 Fuel oil supply failures that could cause this are; the operation of a quick closing valve, fuel oil supply pipe failure or water contamination of the fuel oil. The operation of a quick closing valve requires operator intervention and is not considered in DP Class 2. The fuel oil piping is good quality and correctly secured and supported, consequently is not considered in DP Class 2. The probability of water contamination of the fuel oil, with good fuel management and diligent watch keepers is negligible.

4.11.5 To comply with DP Class 2, the fuel supply should be run as a split system. In the event of any of the aforementioned failures occurring on the vessel, it will still be able to maintain DP, with the minimum of one bow thruster and one azimuth thruster.

5. POWER DISTRIBUTION

5.1 440V

5.1.1 The three main diesel generators, 1, 2 and 3, supply the main 440V switchboard.

5.1.2 The main switchboard is split into two sections, port and starboard, with an interconnecting bustie breaker. The generator connections and the large consumers of switchboards are arranged as follows:

Port 440V switchboard	
Supply	**Consumers**
Generator 1	Bow thruster no.1
Generator 2	Bow thruster no.2
Starboard 440V switchboard via bustie breaker	Port motors and consumers

Starboard 440V switchboard	
Supply	**Consumers**
Generator 3	Bow thruster no.3
Generator 2	Bow thruster no.2
Port 440V switchboard via bustie breaker	Starboard motors and consumers

5.1.3 The remaining 440V consumers are arranged as per the following table. Only the supplies that are involved in DP operations are listed:

Port switchboard	
Consumer	**Circuit**
Emergency switchboard	
440/110V transformer no.1	101
Engineroom power swbd no. 1	106
Fuel oil and services swbd	108
Air conditioning swbd	110
Auxiliary room swbd no.1	112
ECR air conditioning	114
Engine room ventilation swbd no.1	118
Crane	121
Windlass	123
Deck services swbd	124
Port sockets distribution swbd	125
MMEE preheating	137
Port Schottel hydraulic pump busbar 1	127
Starboard Schottel hydraulic pump busbar 1	128.1
DPS No.1 busbar 1	129
DPS No.2 busbar 1	130.1
Deck SW supply pump main ER	139

Starboard switchboard	
Consumer	**Circuit**
Emergency switchboard	
440/110V transformer no.2	102
Engineroom power swbd no. 2	107
440/220V transformer	115
Out of engineroom ventilation swbd	119
Capstan	120
Auxiliary room swbd no.2	122
Port Schottel hydraulic pump busbar 2	127.1
Starboard Schottel hydraulic pump busbar 2	128
DPS No.1 busbar 2	129.1
DPS No.2 busbar 2	130
Engine room ventilation swbd no.2	134
AAEE preheating	138
Starting air compressor No.1	133
ROV supply	142
Stbd sockets distribution swbd	126
Deck SW supply pump Aux ER	140

5.1.4 The engineroom motor supplies are arranged as follows:

Engineroom swbd no. 1	
Consumer	**Circuit**
General services pump no.1	106.1
Main engine seawater pump no.1	106.2

Engineroom swbd no. 2	
Consumer	**Circuit**
General services pump no.2	107.1
Main engine seawater pump no.2	107.2
Freshwater transfer pump	107.4

Fuel oil and services swbd no.1	
Consumer	**Circuit**
Gas transfer pump no.1	108.1
Gas transfer pump no.2	108.2
Sludge pump	108.3
Main engine no.1 prelub oil pump	108.4
Main engine no.2 prelub oil pump	108.5
Aux engine no.1 prelub oil pump	108.6
Aux engine no.2 prelub oil pump	108.7
Aux engine no.3 prelub oil pump	108.8
Lub oil purifier	108.10
Gas oil purifier	108.11
Bilge water separator pump	108.12
Portable Lub oil transfer pump	108.13

Auxiliary room no.1 switchboard	
Consumer	**Circuit**
Auxiliary engine seawater cooling pump no.1	112.1
Hydrophore pumps	112.4
Freshwater generator	112.5
Hot water heaters accommodation	112.6

Auxiliary room no.2 switchboard	
Consumer	**Circuit**
Auxiliary engine seawater cooling pump no.2	122.1
Hot water circ pump accommodation	122.2
Chloro pack	122.4
Freshwater generator	122.5
Hot water heaters accommodation	122.6
Sewage vacuum pump	122.8
HiPAP hoist motor	122.9

5.1.5 The engineroom ventilation supplies are arranged as follows:

Engineroom ventilation switchboard no. 1	
Consumer	**Circuit**
Engineroom supply/exhaust fan no.1	C118.1
Bow thruster supply fan no.1	C118.2
Aft thruster supply fan no.1	C118.3
Stores fan	C118.4
Auxiliary engineroom supply/exhaust fan no. 1	C118.5

Engineroom ventilation switchboard no. 2	
Consumer	**Circuit**
Engineroom supply/exhaust fan no.2	C134.1
Bow thruster supply fan no.2	C134.2
Aft thruster exhaust fan no.1	C134.3
Stores fan	C134.4
Auxiliary engineroom supply/exhaust fan no. 2	C134.5

5.1.6 The deck services switchboard supplies are arranged as follows:

Deck services switchboard	
Consumer	**Circuit**
Tautwire winch	C124.1

5.2 Switchboard Control and Protection

5.2.1 The switchboard is fitted with electrical protection to protect the connected equipment and the switchboard in case of a fault. The protection is configured to provide suitable discrimination, when exposed to directional faults (current), to isolate the faulty section of the switchboard. The breaker discrimination is also configured to prevent a fault on a lower voltage switchboard progressing upwards and tripping the supplying switchboards. The switchboard protection is arranged as follows:

Diesel generators		
Protection unit	**Protection provided**	**Action**
Merlin Gerlin Masterpact NW32 H1 and Micrologic 5.0a	Short circuit	Trip generator breaker
	Over current	Trip generator breaker
Set @ 5%, delay 5 seconds	Reverse power	Trip generator breaker
Switchboard PLC	Under voltage	Trip generator breaker

Busbar		
Protection unit	**Protection provided**	**Action**
Merlin Gerlin Masterpact NW40 H2 and Micrologic 5.0a	Short circuit	Trip bustie breaker
	Over current	Trip bustie breaker
Switchboard PLC	Under voltage	Trip bustie breaker

Transformer TR1 and TR2		
Protection unit	**Protection provided**	**Action**
Merlin Gerlin Compact NS160L	Over current	Trips transformer
	Short circuit	Trips transformer
Switchboard PLC	Under voltage	Trip generator breaker

Thruster 1, 2 and 3		
Protection unit	**Protection provided**	**Action**
Merlin Gerlin Masterpact NW12 H2a and Micrologic 5.0a	Over current	Trips thruster breaker
	Short circuit	Trips thruster breaker
Switchboard PLC	Under voltage	Trip generator breaker

5.2.2 The bustie breaker reaction time is faster than the generator breakers, such that, in the event of a fault on the switchboard, the bustie breaker will open before the generator breakers. The fault will be isolated on the affected switchboard, providing electrical discrimination, and ensuring that single electrical faults will not black out the vessel. The PLC and DP system both monitor the status of the bustie breaker.

5.2.3 The switchboard main breakers are supplied with 110VAC from the switchboard control voltage. The generator control voltage is derived from the generator incomer to the breaker, via step-down transformers. The thruster breakers and transformer breakers are manual breakers, with manual opening/closing remote under voltage tripping.

5.2.4 The bustie breaker control system is derived from the main bus bars. The power is supplied from only one bus bar, with an auto changeover relay. The relay will automatically change over to maintain the power supply to the bustie breaker control system.

5.2.5 The switchboard can be operated manually on the switchboard front or automatically using the switchboard Programmable Logic Controllers (PLC's). Each switchboard has its own dedicated PLC, interfaced with the major switchboard equipment. The PLC's are interlinked via a communications link, to transfer information between each of the PLC's. The power supplies to the PLC's are arranged as follows:

PLC	**Power supply**
1	Engineroom 24VDC switchboard circuit BV-6.2
2	Bridge 24VDC switchboard circuit 517.2.7

5.2.6 The PLC's perform automatic switchboard functions; to do this the switchboard has to be operating in automatic mode (selector switch). The PLC's perform the following switchboard functions:

Interlocking of generator breakers
Interlocking of thruster breakers
Interlocking of 440/110V supply breaker
Interlocking of the emergency switchboard supply
Load sharing monitoring

5.2.7 The PLC interlocking is configured as follows:

- With one generator connected only one bow thruster can be connected to the switchboard. To connect another bow thruster a second generator has to be connected to the switchboard, before the second thruster can be started.
- With two generators connected, three bow thrusters can be powered from a switchboard. With the bustie closed all three bow thrusters can be operated from the "single" switchboard.
- When three thrusters are connected to the single switchboard powered by two generators and the bustie breaker opens, the following will happen; the last connected thruster will be tripped and one 440/110 supply breaker will be tripped, to prevent the connection of unsynchronised loads.
- When three thrusters are connected to a single switchboard powered by two generators and a generator trips, the following will happen; two bow thrusters will be tripped.

5.2.8 The PLC monitors the load sharing between the connected generators. In the event of a failure of load sharing the PLC will take action to prevent a blackout. The PLC calculates the "ideal" load sharing between the connected generators, i.e. the average. It compares this calculated figure to the actual generator load. If the load sharing is out by 20% for 5 seconds, the PLC will switch the governors from isochronous load sharing to droop load sharing, generating an alarm on the central alarm system. The generators will then load share on the governor droop settings, the operator can then use the manual governor speed up/down switch to balance the loads. If the load sharing further degrades, by 30% for 7 seconds, the PLC will open the bustie breaker. This splits the system into two separate and unconnected systems.

5.2.9 Under normal operating conditions, the generators are coupled to the switchboard manually, using a synchronising relay. The relay can be bypassed in emergency conditions, by operation of an "auto/manual" switch on the switchboard. The generators can then be synchronised using the synchronising lights.

5.2.10 The control system power supply for the generator breaker is derived from the incoming generator bus bars via transformer. No external power source is required. The status of the generator breakers is monitored by the switchboard PLCs and the DP system.

5.3 Power Management

5.3.1 Each diesel generator engine is fitted with a Woodward 723 electronic governor, and Woodward PG-EG 58 electro/mechanical actuator. The governor controls the engine speed at the desired value by adjusting the engine fuel rack position, using the engine speed as the feedback for the control loop. The actuator positions the fuel rail, the actuator command signals are from the 723 unit. The 723 has a default speed set point of 720 rpm to provide 60Hz on the switchboard.

5.3.2 The 723 unit uses a proximity type speed sensor to monitor the engine speed. It is fitted with two speed sensors; one is in use the other on hot standby. In the event of a failure of the online sensor, the standby sensor will automatically be used and the 723 governor will continue to operate. If the second sensor fails the 723 will lose its control input and the engine will be shut down.

5.3.3 The PG-EG 58 actuator is a mechanical/ hydraulic governor with an electrical solenoid for remote speed setting. The hydraulic pressure is generated internally in the actuator and is used to generate the power to position the governor output linkage and hence the engine fuel rail. The output of the actuator is controlled by the electrical solenoid adjusting the speed setting internally in the actuator.

5.3.4 The load sharing between the generators is performed by the 723 governors. The governors are connected together by a load sharing line, used to communicate load information between the engines. The load sharing line is fitted with relays interlocked with the bustie breaker status. When the bustie is closed the relay is closed, connecting the load sharing line of the connected generators. When the bustie breaker is open, the relays open splitting the load sharing line.

5.3.5 The 723 units can load share in Isochronous or droop load sharing. The mode of operating is selected on the switchboard front. In Isochronous mode the generators will equally load share between the connected engines. The 723 governor measures the generator load with a kW sensor. It communicates the generator load with the other engine via the load sharing line. If the generators are not equally load sharing the governor will adjust the actuator output, adjusting the generator speed and hence generator load to achieve equal load sharing. This calculation of the load sharing and engine speed is a continuous process when two or three machines are running in parallel.

5.3.6 When the engines are in droop load sharing, the engines will load share on the governors internal droop settings. If the load share drifts off, the operator will have to manually intervene on the switchboard front, using the “speed up/speed down” switch. This switch produces an input to the 723; this will adjust the governor speed set point accordingly.

5.3.7 The 723 units are powered from the generator’s engine control system, as described in the power generation section of this report.

5.3.8 The switchboard is fitted with non-essential tripping, to prevent the vessel blacking out. A further level of load limiting is provided by the DP system, which monitors the switchboard load and limits thruster load as required, to prevent generator overload and consequent blackout.

5.3.9 Each of the generators is provided with an overload relay. When the generator is overloaded for 7 seconds the relay will produce an output. The overload protection circuit will then trip the first set of consumers. If this condition continues for a further 4 seconds, the overload protection circuit will trip the second set of consumers. If the condition remains for a total of 15 seconds, the crane will be tripped. The non-essential trips are arranged as follows:

Non-essential tripping	
Overload after	**Breakers tripped**
7 seconds	Galley services, C-109
	Laundry services, C-111
	Cold store, C-116
	Workshop services, C-117
11 seconds	Air conditioning
	ECR air conditioning
15 seconds	Crane

5.3.10 The DP system includes a pitch reduction system preventing the thrusters blacking out the vessel. The DP system operates the pitch reduction function at a power consumption of around 90% of that available. Due to the size of the diesel generators, the thrusters and the vessel’s normal hotel loads, coupled with the interlocking of the PLC, it is not possible to be in a position where this function will operate.

5.3.11 The vessel is fitted with a blackout restart system. The unit will start and connect the standby generator to the switchboard after a blackout. The blackout has to be detected on both switchboards, before the unit will operate. The system is not interlocked with the main breakers on the switchboard, and will not be used when the vessel is operating in DP, to prevent the standby generator connecting to a faulty switchboard.

5.4 Emergency Switchboard

5.4.1 The emergency switchboard has supplies from the port and starboard sections of the main 440V switchboard, and from the emergency generator. The supply breakers are controlled and interlocked by the switchboard PLC. This allows only one supply breaker to be closed at one time. In the event of this breaker tripping, the PLC will automatically close the other breaker, restoring the supply. In the event of a failure of both 440V supplies, the emergency generator will automatically start and supply the emergency switchboard.

5.4.2 The 440V emergency switchboard consumers are arranged as follows:

Emergency 440V switchboard	
Power supply	Port main 440V switchboard via 440/110V transformer
	Starboard main 440V switchboard via 440/110V transformer
	Emergency generator
Distribution	
Consumer	**Circuit**
110V emergency switchboard via 440/110V trafo	401
110V emergency switchboard via 440/110V trafo	402
Local FiFi system SW pump	403
Engineroom exhaust fan	404
Emergency Fire fighting pump	405
Rescue boat davit	406
Starting air compressor No.2	407
Watertight doors	408
Emergency room supply fan	409

5.5 220V

5.5.1 The vessel has a single main 220V switchboard, the major consumers are as follows:

Main 220V switchboard	
Power supply	Starboard main 440V switchboard via 440/220V transformer
Distribution	
Consumer	**Circuit**
Port Deck sockets	202
Port services switchboard	203
Starboard Deck sockets	204
Starboard services switchboard	205

5.5.2 The services switchboards are arranged as follows;

220V Port services switchboard		
Power supply	Main 220V switchboard	
Consumers		**Circuit**
Lighting		203.1 to 203.3
Galley		203.4
Bow thruster No.3 heating		203.5
Air drier		203.6
Ultra violet		203.7
Simrad Joystick system		203.8

220V Starboard services switchboard		
Power supply	Main 220V switchboard	
Consumers		**Circuit**
Lighting		205.1 to 205.3
Cold store		205.4
Bow thruster No.1 heating		205.5
Bow thruster No.2 heating		205.6
Local area net.		205.8

5.6 110V

5.6.1 The vessel has a main 110V switchboard and an emergency switchboard; the major consumers with respect to DP are as follows:

Main 110V switchboard	
Power supply	Port main 440V switchboard via 440/110V transformer No.1
	Starboard main 440V switchboard via 440/110V transformer No.2
Distribution	
Consumer	**Circuit**
Searchlight switchboard	302
Outside lighting	303
Navigation equipment switchboard	304
Special services switchboard	305
External lighting	306, 307, 308
Internal lighting	309
Galley	310, 311
Deck sockets	312, 313
Generator heating	314
Main switchboard lighting	315

Emergency 110V switchboard	
Power supply	440V emergency switchboard via 440/110V transformer
	440V emergency switchboard via 440/110V transformer
Distribution	
Consumer	**Circuit**
Navigation light switchboard	502
Outside light switchboard	503
Navigation equipment switchboard	504
Special services switchboard	505
Deck lighting	506, 507, 508, 509
Engineroom lighting	510, 511, 512, 513, 514
24VDC services switchboard battery charger	516
Emergency generator starter battery charger	515
24VDC wheelhouse services battery charger	517
GMDSS battery charger	518
Emergency generator heating	519, 520
Low voltage switchboard relay	521
24VDC services switchboard transformer rectifier	522

5.6.2 The navigational equipment switchboard is are arranged as follows:

Navigational equipment switchboard	
Power supply	Main 110V switchboard
	Emergency 110V switchboard
Consumers	**Circuit**
24VDC services switchboard charger/rectifier	516
24VDC wheelhouse services switchboard charger rectifier	517

5.6.3 The main 110V switchboard has a supply from both the port and starboard sections of the 440V switchboard, via 440/110V transformer. The supply breakers are controlled and interlocked by the switchboard PLC. When the bustie breaker is closed the PLC will allow both breakers to be closed. When the bus tie is open, to prevent circulating currents, the 110V switchboard can only be supplied by one transformer. On opening the bustie breaker the PLC will automatically open one of the 110V supply breakers. The PLC automatically selects the switchboard that the first generator was connected to, as the master switchboard. In the event of the bustie opening, the 110V supply breaker on the master switchboards will remain closed; the other 110V breaker will be opened.

5.7 24VDC

5.7.1 The vessel has two main 24VDC systems with DP consumers, being the 24VDC services system and the wheelhouse services system. Each system consists of a charger rectifier unit and batteries. In normal conditions the charger unit provides a 24VDC output to the batteries and consumers. In the event of a failure of the rectifier incoming power supply, the system will switch to the battery backup. The battery backup is sized to provide at least 30 minutes supply to its consumers.

5.7.2 The 24VDC services switchboard is split into two sections, the emergency light section and the 24VDC services. The sections are interconnected with a bustie breaker. Each section has a dedicated power supply; the bustie breaker allows either power supply to power both sections if required.

24VDC services switchboard	
Main power supply	110V emergency switchboard via transformer rectifier
Second power supply	Navigational equipment switchboard via transformer rectifier
Third power supply	Emergency services battery charger from 24VDC emergency lighting switchboard via bustie breaker
Consumers	
ROV sockets (Aldis lamp)	BV-3 (BV-4)
Typhon	BV-5
Engineroom 24VDC services switchboard	BV-6
Desk signals	BV-7
Navigational switchboard	BV-8
Sound power telephone	BV-9
Automatic telephones	BV-10
Fire dampers	BV-11
Watertight bulkheads	BV-12
Binnacle light	BV-13
Telegraph	BV-14
Man overboard alarm	BV-15
Cold room alarm	BV-16
Hospital alarm	BV-17
Gyro control unit	BV-18
Fire detection system	BV-19
Spare	BV-20
Autopilot	BV-21
Spare	BV-22
Gyro nautical alarm	BV-23
SDP-OS1 console	BV-24
Spare	BV-25
Gyro no.1	BV-26

24VDC emergency lighting	
Main power supply	Emergency services battery charger
Second power supply	110V emergency switchboard via transformer rectifier from 24VDC services switchboard via bustie breaker
Consumers	
24VDC Emergency lighting	E-1 to E-11

24VDC Engineroom services switchboard	
Main power supply	24VDC low voltage services switchboard
Consumers	
Telephone indicating lights	BV-6.1
Main switchboard PLC busbar 2	BV-6.2
Hydrophone	BV-6.3
Port Schottel	BV-6.4
Starboard Schottel	BV-6.5
Signalling system	BV-6.6
CO2 system	BV-6.7
AA. EE standby	BV-6.8
Capstan	BV-6.9
Starting air compressor switchboard	BV-6.10
Alarms system	BV-6.11
Watertight bulkhead doors	BV-6.12
Emergency stop	BV-6.13
Auxiliary engine No.1	BV-6.14
Auxiliary engine No.2	BV-6.15
Auxiliary engine No.3	BV-6.16
Main engine port	BV-6.17
Main engine starboard	BV-6.18

24VDC Wheelhouse services switchboard	
Main power supply	Wheelhouse services battery charger via fuse box, powered from 110V emergency switchboard
Second power supply	Navigational equipment switchboard
Consumers	
Inmarsat	517.21
Facsimile	517.22
Mimi-M	517.23
Echo sounder	517.24
Sailor 1900	517.25
Ecdis	517.26
Main switchboard PLC busbar 1	517.27
Port Schottel indicators	517.28
Gyro No.2	517.210
Gyro No.3	517.211
Gyro control unit	517.212
Remote alarm panel	517.213
Radars	517.214 and 517.215
Bow thruster 3	517.216
Auxiliary engine No.1	517.217
Auxiliary engine No.2	517.218
Auxiliary engine No.3	517.219
Main engine port	517.220
Main engine starboard	517.221
Starboard Schottel indicators	517.222

5.7.3 Both the 24VDC services switchboard and the 24VDC wheelhouse services switchboard are provided with two power supplies. One supply is from the 110V emergency switchboard the other from the navigational equipment switchboard. The operator selects the power supply via a change over switch on each of the chargers. A failure of the power supply to either charger unit will generate an alarm on the central alarm system, advising the operator to change over the supply.

5.8 Failure Modes

5.8.1 The worst case failure of the 440V section is the loss of one section of the main bus through either two generators failing or a bus fault. The consumers lost on each section will be as listed above in the section concerning the 440V supplies.

Failure	**Effect**	**Alarm**	**Comments**
Earth or bus fault	Failure of one HV section – loss of consumers as listed.	Engine room alarm and DP alarm	Bustie breaker will open isolating the fault. Vessel will still maintain DP with "healthy" section of the switchboard.
AVR failure on one machine	Generator breaker opens	Engine room alarm and DP alarm	This failure will only affect one machine.
Generator governor failure	Generator breaker opens on reverse power	Engine room alarm and DP alarm	This failure will only affect one machine.
Failure of generator load sharing	Load sharing drifts off, PLC switches governors to droop load sharing	Engine room alarm	When the governors have defaulted into droop control, the operator can balance the loads using the governor speed up/down switch.
Total failure of generator load sharing, one machine taking all the load	Large inbalance in load sharing, PLC opens bustie	None	System split into two separate systems.
Failure of bustie breaker control system	Bustie breaker opens.	DP alarm	Vessel will continue to operate in DP with split switchboard.

5.8.2 Failure of the 220V switchboards will result in the loss of consumers listed, which will not affect the vessels DP capability.

5.8.3 Failure of the 110V section would result in the loss of the consumers as listed, which will not affect DP capability. In any event, depending upon the failure, this should be mitigated by the fact that the secondary transformer breaker can be closed to restore power. On the DP trials, both the main and emergency 110V switchboards were blacked out. In both instances the vessel maintained DP, with no loss of critical operations.

5.8.4 Failure of the 110V supply to the battery chargers will cause the 24VDC supplies to revert to battery back up. A failure of the 24V bus will result in a loss of the consumers as listed.

Failure	Effect	Alarm	Comments
Supply failure to mains supply and charger	System defaults to batteries	Engineroom alarm	Batteries supply 30 minute duration
Total failure of 24VDC low voltage switchboard, short circuit or battery exhaustion.	Loss of DG 2 and 3 and thrusters 2, 3 and 5.	DP and ER alarm	After the failure, thruster 5 can be clutched in and reselected in DP.. Generator No.2 can be started and reconnected and thruster 2 restarted and reselected in DP.
Total failure of 24VDC wheelhouse switchboard, short circuit or battery exhaustion.	Loss of DG 1 and 2 and thrusters 1, 2 and 4.	DP and ER alarm	After the failure, thruster 4 can be clutched in and reselected in DP.. Generator No.2 can be started and reconnected and thruster 2 restarted and reselected in DP.
Failure of 24VDC supply to PLC 1	Generator and thruster breakers open on bus 1.	DP and ER alarm	Vessel will still maintain DP on bus 2, with two azimuth units and one bow thruster. Thruster 2 can be manually connected to bus 2.
Failure of 24VDC supply to PLC 2	Generator and thruster breakers open on bus 2.	DP and ER alarm	Vessel will still maintain DP on bus 1, with two azimuth units and one bow thruster. Thruster 2 can be manually connected to bus 1.
Failure of 24VDC supply to MSB control system	Bustie opens, thrusters and generators remain connected	ER alarm	Vessel will remain in DP with all thrusters.

5.9 Comments

5.9.1 The worst case single failure is a short circuit on the main switchboard. This will result in the bustie breaker opening and the generator breakers connected to the faulty switchboard opening. Immediately after the short circuit, the vessel will remain operating in DP with one bow thruster and one stern thruster. The DP operator can then reclutch and select in DP the “failed” stern thruster, due to the automatic change over of the hydraulic pump power supplies. Due to the flexible nature of the switchboard, the operator can then connect No.2 diesel generator and the other bow thruster to the healthy side of the switchboard. The vessel will then be able to operate in DP with two bow thrusters and both azimuth thruster, although the vessel will not be operating in DP Class 2.

5.9.2 The load sharing between the diesel generators is monitored by the switchboard PLC. In the event that there is unequal load sharing between the generators the PLC will take action. In the first instance the PLC will switch the governors into droop load sharing. The generators will load share on the governor droop load settings, the operator can balance the loads using the governor speed up/down switch on the switchboard front. If the load sharing drifts off further the PLC will automatically open the bustie breaker, splitting the electrical system into two separate systems. This prevents a load sharing fault affecting both switchboards.

5.9.3 Total failure of a 24VDC supply will initially result in the loss of diesel generators and thrusters, the vessel will remain in DP with at least one stern thrusters, and one bow thruster powered by one generator. After the failure the “failed” stern thruster can be clutched in and reselected in DP. The operator can then restart diesel generator No.2 and bow thruster No.2 due to the dual 24VDC power arrangements.

6. THRUSTERS

6.1 Stern Thrusters

6.1.1 The vessel has two diesel driven Schottel azimuthing stern thrusters, port and starboard. The propellers are the controllable pitch type. The stern thrusters ratings are as follows:

	Make and type	Rating
Stern thruster	Schottel SRP2020	35 tons
Diesel engine	WARTSILA 6R32	2460 kW at 750 rpm

6.1.2 When operating in DP the diesel engine is run at constant speed. To achieve the variation of thruster output the propeller pitch is adjusted. The direction of the thrust is varied by controlling the direction in azimuth of the thruster. When the vessel is in transit the main propellers can be run in combinator mode, variable speed and variable pitch. Since fixed speed, variable pitch is only used in DP this is the only mode of operation that will be considered in this study.

6.1.3 Each azimuth thruster consists of a drive gearbox with clutch, and an azimuthing unit containing the controllable pitch propeller and shaft seal.The horizontal drive from the diesel engine inputs into an air operated clutch mounted on the main gearbox housing. The main gearbox output is a hollow vertical drive shaft to the propeller housing. The propeller housing has a horizontal drive shaft on which the controllable pitch propeller is mounted. The output shaft is fitted with a shaft seal, to prevent the ingress of water into the thruster housing. The propeller housing is mounted in bearings and has a sun gear wheel mounted to it. The housing is rotated by three hydraulic motors, driving planetary gear wheels engaging with the sun gear wheel.

6.1.4 Each thruster has a self contained lubricating oil system. Oil is circulated around the thruster by natural circulation generated by the internal gears. When the thruster is rotating, this is forced down into the propeller housing, and returns to the main gearbox housing through the hollow drive shaft. An oil circulating pump is mounted on the main gearbox housing and is directly coupled to the main input shaft. When the thruster is running, the pump draws oil from the thruster housing. It is pumped through a flow sensor, temperature sensor, and duplex filter and into the upper gearbox. The oil then flows down into the lower gearbox to be circulated by the internal gears. The upper gearbox acts as the system header tank, ensuring the thruster is under positive oil pressure to prevent seawater leakage into the thruster housing. The lub oil is cooled by virtue of the propeller housing being immersed in seawater. The following alarms are interfaced into the vessels alarm system:

Alarm	Setpoint
Lub oil level	Low
Lub oil temperature	High
Lub oil filter no.1	Clogged
Lub oil filter no.2	Clogged
Hydraulic Oil temperature	High
CPP filter	Clogged

6.1.5 The thruster is fitted with two hydraulic systems, the azimuth system and the pitch system.

6.1.6 The azimuth system controls the rotation of the thruster body and hence the direction of the thrust output. The rotation of the thruster housing is achieved by three hydraulic motors, the output shaft of the motors engaging with the thruster sun wheel. A single electrically driven hydraulic pump provides the hydraulic power for the system. The pump is supplied with two electrical supplies, one from each side of the main switchboard. The normal power supply to the pump is arranged from its respective side of the switchboard. The power supplies to the hydraulic pumps are arranged as follows:

Azimuth Hydraulic Pump	**Power supply**	
Port Schottel	Main:	Port main 440V switchboard
	Standby:	Starboard main 440V switchboard
Starboard Schottel	Main:	Starboard main440V switchboard
	Standby:	Port main 440V switchboard

6.1.7 The hydraulic pump actually comprises two pumps mounted on a single shaft. One pump is a fixed displacement type, providing oil pressure for the control system. The other pump is a bi-directional, variable displacement pump, providing hydraulic power to the azimuthing motors.

6.1.8 The azimuthing power system is a closed circuit hydraulic system; both of the pump ports are connected to the motors. The pump can discharge through either port, when discharging through one port the other port acts as the inlet. Both of the ports are connected to the azimuthing motors. The direction of motors rotation, hence thruster rotation, will depend on the discharge port of the pump. The output volume of the pump will affect the rotation speed of the azimuth motor, and hence the thruster rotation speed. The higher the pump output the greater the speed of rotation. The output of the pump adjusted by moving the pump swash plate, controlled by the hydraulic control system.

6.1.9 The hydraulic control system consists of a control oil supply system; two control solenoids and a control linkage. The control linkage consists of a control cylinder, control valve and a power cylinder. The power cylinder is attached to the pump swashplate.

6.1.10 The control oil pump draws oil from the reservoir tank and discharges through a filter unit to the control oil main. The oil main is connected to both sides of the main pump discharge lines, by non-return valves. This is used to replenish the low pressure side of the main system to take account of any system leakage. The oil main also supplies oil to the control solenoids and the control valve. The spilled oil from the hydraulic motors passes through cooler before flowing in to the reservoir tank. The cooler is cooled with LT freshwater from the main central cooling system. The LT freshwater is circulated by one of two circulating pumps: the pumps are powered from either side of the main 440V switchboard. Each LT pump discharge line is fitted with a low pressure alarm. In the event of a low system pressure alarm, the operator will have to manually start the standby pump to restore the cooling flow.

6.1.11 The control solenoids are connected to the control cylinder. The solenoids are electrically operated from the remote control point or can be manually operated locally, by push button. The solenoids are connected to either end of the cylinder body, with the ram centred by springs on either side of it. With the thruster in the desired position, the cylinder is pressurised with oil from both solenoids. Opening one of the solenoids vents the oil pressure from that side of the cylinder, causing it to move. The control cylinder is attached to a control valve that controls the flow of oil to the power cylinder.

6.1.12 The control valve supplies oil to the power cylinder. The power cylinder is centred by a spring arrangement either side of the ram, with the oil inlets at either end of the ram. Movement of the control valve will allow control oil to flow into one side of the power cylinder and exhaust from the other side. This will cause the power cylinder to move adjusting the position of the swash plate. This in turn will cause the main hydraulic pump to start pumping, driving the hydraulic motors, causing the thruster to rotate. The control solenoids are interfaced with the thruster ECU and the thruster azimuth is measured by an azimuth potentiometer. The ECU uses the azimuth feedback for the control feedback loop.

6.1.13 The pitch system is fitted with two hydraulic oil pumps. CPP pump No1 is used for DP control. CPP pump No2 controls are configured for time dependant control only and cannot be used for DP. In the event of failure of No1 pump, the change over from No1 to No2 pump is automatic but DP pitch control will be lost. The power supplies to the pitch pumps are the same arrangement as the azimuth pumps. The pumps are supplied with two electrical supplies, one from each side of the main switchboard. The normal power supply to the pump is arranged from its respective side of the switchboard. The power supplies to the hydraulic pitch pumps are arranged as follows:

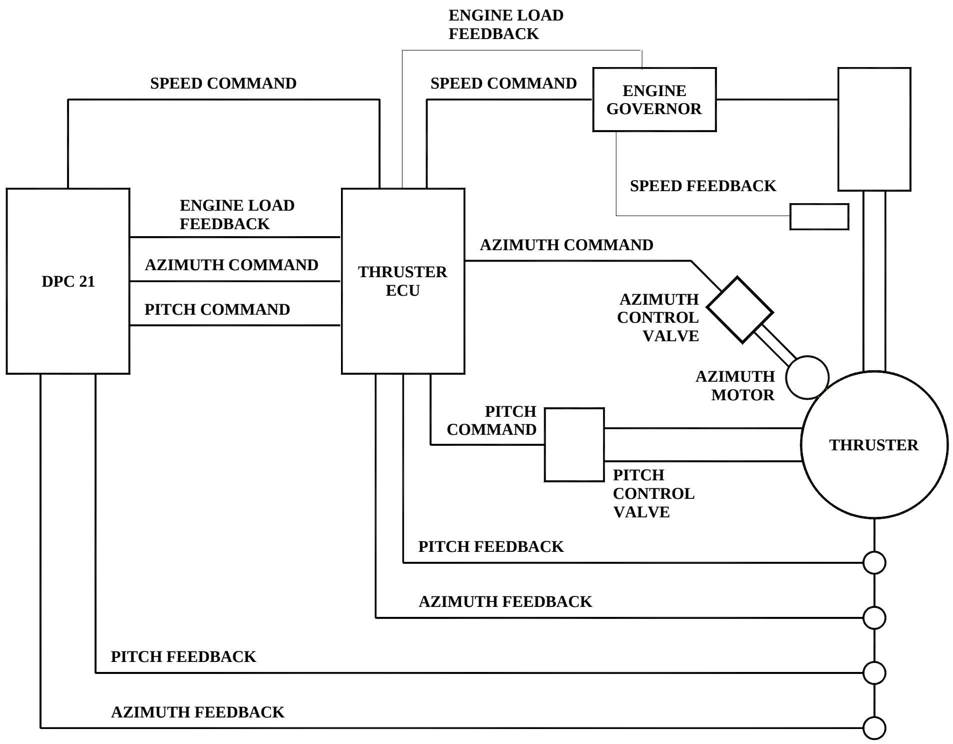
Pitch Hydraulic Pump	**Power supply**	
Port pitch pump no.1 Port pitch pump no.2	Main:	Port main 440V switchboard
	Standby:	Starboard main 440V switchboard
Starboard pitch pump no.1 Starboard pitch pump no.2	Main:	Starboard main440V switchboard
	Standby:	Port main 440V switchboard

6.1.14 The pitch hydraulic pump consists of two identical power packs. The power pack consists of a hydraulic pump, filter and control valves. The hydraulic pumps take suction from the thruster housing and discharge through the filter to the control valve block, where the flow of oil to the controllable pitch propeller hub is controlled by a proportional valve. The proportional valve controls and regulates the flow of oil and not in an on/off manner. The proportional valve is controlled by the thruster ECU using a pitch feedback potentiometer for the control feedback.

6.1.15 The valve control block also contains valves to protect the system from over pressure and valves that ensure that the hydraulic oil circulates, to prevent overheating, when the thruster is at the desired pitch.

6.1.16 The ECU controls the thruster pitch by adjusting the position of the pitch control valve. The ECU will receive a pitch command signal, and compare this with actual thruster pitch. It will then command the pitch control valve to move, allowing oil to flow into the thruster hub, until the desired pitch is achieved. The pitch control valve is a proportional control valve; therefore the flow of oil is regulated in a controlled manner and not on/off. The propeller pitch is monitored by a feedback potentiometer; this is used as the feedback for the control loop.

6.1.17 The thruster electronic control unit (ECU) is a programmable logic controller (PLC). The ECU performs the azimuth and pitch control functions. It also performs the alarm and monitoring functions for the thruster. The connections between the DP, ECU and the thruster are as follows:



6.1.18 The ECU is powered from the 440V power to the hydraulic pumps. This supply is transformed and rectified to produce 24VDC for the ECU. A second "emergency" 24VDC supply is provided from the vessel's UPS supplies. The ECU power supplies are arranged as follows:

ECU	**Power supply**	
Port Schottel	Main:	Port hydraulic pump supply
	Standby:	24VDC Engineroom services switchboard
Starboard Schottel	Main:	Starboard hydraulic pump supply
	Standby:	24VDC Engineroom services switchboard

6.1.19 The control interfaces between the DP system and the thruster ECU are as follows

Signal	**DP system input/output**
Engine speed command	4-20mA (set at fixed value)
Engine load	4-20mA
Azimuth command	+/- 10V
Azimuth feedback to ECU	4-20mA
Azimuth feedback to DP	Sin/Cos +/- 10V
Pitch command	+/- 10V
Pitch feedback to ECU	Sin/Cos +/- 10V
Pitch feedback to DP	Sin/Cos +/- 10V

6.1.20 The Schottel ECU also performs the engine overload protection. When the engine is overloaded, measured by the engine load feedback signal, the Schottel control system will reduce the propeller pitch to reduce the engine load. This function should not normally operate in DP mode, as the DP system can only demand 80% of the available propeller pitch.

6.1.21 The ECU provides the following alarms:

Alarm	**Set point**
Failure AC/DC converter	Low
Failure 24VDC “emergency” supply	
Failure RPM control	
Failure time dependant RPM control	
Failure follow up steering	
Failure time dependant steering	
Failure follow up pitch control	
Failure time dependant pitch control	
Control air pressure	Low
Follow up steering locking	
Failure desk control	
Hydraulic oil steering level	Low
Hydraulic pump boost oil pressure	Low
Hydraulic oil temperature	High
Hydraulic oil pressure	High
Lub oil level	Low
Lub oil temperature	High
Lub oil filter dirty	
Lub oil flow	Low
Pitch oil pressure pump No.1	Low
Pitch filter dirty pump No.1	
Pitch oil pressure	High
Pitch oil pressure pump No.1	Low
Pitch filter dirty pump No.1	

6.1.22 The thruster can be controlled from the engine control room, the forward bridge and aft bridge. The thruster can also be controlled by the DP system. To select the thruster for DP control the thruster DP selector switch must be in the DP position. This gives each of the thruster's ECU's a digital input, instructing them to take commands from the DP system. The DP selector switch is located on the aft main propeller control panel. The switch has three positions; Co-pilot control, DP-mode and Joystick mode. The DP selector switch is a multi pole switch with an independent set of contacts for each of the stern thrusters. The contacts are interfaced and powered from their respective thruster ECU; no external power supply is required.

6.1.23 To enable the thruster control system to receive instruction from the DP system, the DP selection mode must be selected. However, the following parameters must be met before DP control of the thruster is accepted:

Hydraulic pump running	Running
Follow up steering	In service
DP control	In service
Engine RPM control	Ready

6.1.24 The thruster is fitted with stop buttons on the forward and aft bridge operating panels. An emergency stop button is also located on the aft bridge console, next to the DP console. This allows the DP operator to stop the thruster, if required.

6.2 Failure modes

Failure	Effect	Alarm	Comments
Fail air supply to clutch	Clutch will fail open	Clutch air pressure low	Each clutch is supplied by a dedicated reservoir, so this failure can only affect a single propeller, unless DP operations have continued after receiving a low system air pressure alarm.
Loss of 440V power supply	Hydraulic pump stops, thruster deselects from DP desk.	DP system, thruster not ready alarm.	Operator can reclutch and reselect the thruster in DP control as the pumps are supplied from either side of the main switchboard.
Fail governor speed command signal	Engine continue to operate at last speed setting		Does not affect operation of thruster.
Fail DP speed feedback signal	Thruster continues to run un-effected		Does not affect operation of thruster.
Fail DP pitch command	Thruster pitch fails to zero pitch	DP system, "thruster prediction error" alarm.	Other stern thruster will compensate for loss of thruster.
Fail DP pitch feedback	Thruster continues to operate to DP commands, loss of feedback to DP.	DP system, "thruster prediction error" alarm	Does not affect operation of thruster, only reduces the amount of information to DP operator.
Fail Schottel pitch command	Thruster declutches	DP system, "thruster not ready: alarm.	Other stern thruster will compensate for loss of thruster.
Fail Schottel pitch feedback	Thruster declutches	DP system, "thruster not ready: alarm.	Other stern thruster will compensate for loss of thruster.
Fail azimuth command signal (DP)	Thruster defaults to thruster astern	DP system, "thruster prediction error" alarm.	DP operator will have to manually deselect thruster to reduce pitch.
Fail azimuth command signal (Schottel)	Thruster declutches	DP system, "thruster not ready: alarm.	Other stern thruster will compensate for loss of thruster.
Fail azimuth feedback signal (DP)	Thruster continues to run un-effected	DP system, thruster compares alarm.	Does not affect operation of thruster, restricts information given to DP operator.
Fail azimuth feedback signal (Schottel)	Thruster declutches	DP system, "thruster not ready: alarm.	Other stern thruster will compensate for loss of thruster.

6.3 Comments

6.3.1 The azimuth thrusters are independent units having separate control and power supplies; any single failure on these systems will only affect one thruster. The only failures that will affect both thrusters are failures associated with the drive engines and clutch air supply.

6.3.2 The main engine fuel system can be run as a common system or as a split system. If the system is run as a common system, a fault in the fuel system could affect both engines. In the worst case this could result in loss of DP control. To prevent this occurring the fuel system should be operated as a split system, then a fuel failure will only be able to affect a single engine and hence main propeller.

6.3.3 The propeller clutch will fail open on loss of air pressure. To prevent a loss of air pressure resulting in both clutches opening simultaneously, backup air reservoirs have been fitted to the system. Each propeller clutch has a dedicated backup air reservoir; in the event of low vessel working air pressure the reservoir will continue to supply air to the clutch. The reservoirs are connected to the vessel air system through a non-return valve to isolate them from the rest of the system.

6.3.4 When the Simrad azimuth command signal fails, the thruster will default to thrusting astern, as this position corresponds with a 0V signal from the DP system. In certain circumstances this may result in a degradation of station keeping. It is important that the DP operators are made aware of this failure mode. In DP operations the thruster page should be reviewed after a thruster prediction warning has been generated. If this failure occurs, the DP operator has to deselect the thruster from the DP desk, the thruster pitch will then reduce to zero, removing the unbalancing force.

6.4 Bow Thrusters

6.4.1 The vessel has three electrically driven Schottel bow thrusters. The output of the thruster is varied by controlling the pitch of the propeller. Hence the thruster is driven by a constant speed electric motor.

	Type	**Rating**
Bow thruster	Schottel STT 550 CP	700kW
Electric motor	Zoller RH 450 M6	700kW

6.4.2 The vertically mounted drive motor is directly coupled to the drive shaft and into the gearbox. The output of the gearbox is horizontal with the propeller mounted on this shaft. The shaft seal is mounted to the gearbox housing, sealing the shaft. The gearbox is filled with lubricating oil and kept under pressure by a header tank. The oil lubricates the gearbox internals and shaft seal. In the event of any seal leakage, the height of the header tank ensures that oil will leak out, preventing water ingress into the thruster gearbox.

6.4.3 The electric motor is an air cooled synchronous motor and fitted with the following monitoring and protection:

Parameter	**Action**
Motor temperature >140°C	Alarm
Motor temperature >150°C	Shut down
Over current	Shut down

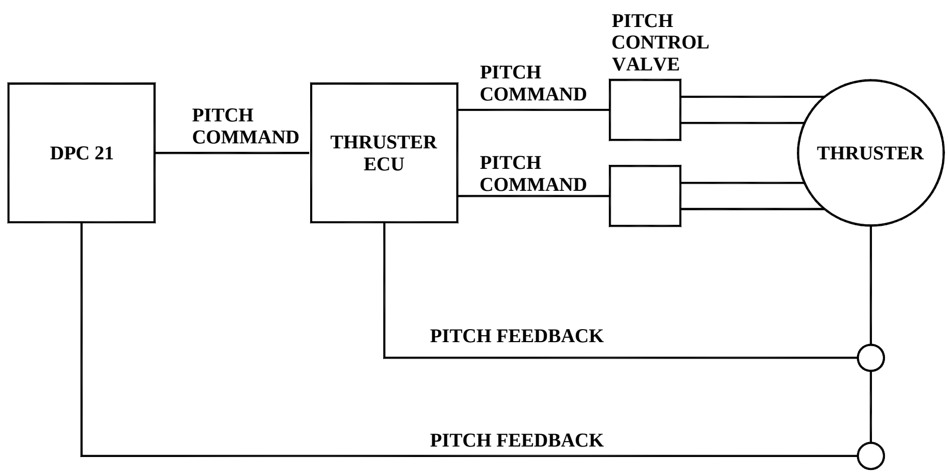
6.4.4 Each thruster has an attached hydraulic pitch control system. The pitch control system utilizes the gearbox (hub) oil to supply a single electrically driven hydraulic pump, filter and pitch control valve. The pitch control pump oil is drawn from the gearbox, and when there is no pitch demand, returned to the gearbox having passed through the filter and control valve. The electrical supplies for the hydraulic pitch pumps are arranged as follows;

Thruster	**Pump**	**Supply**
No.1 Bow	Hydraulic servo	Derived from thruster 440V starter cabinet
No.2 Bow	Hydraulic servo	Derived from thruster 440V starter cabinet
No.3 Bow	Hydraulic servo	Derived from thruster 440V starter cabinet

6.4.5 The thruster control is performed by the Electronic Control Unit, ECU. Each thruster has a dedicated ECU, which performs the functions of thruster protection, start interlocking and thruster pitch control. The ECU is powered from the 440V starter cabinet via a 440V/24VDC transformer rectifier:

ECU	**ECU location**	**Power supply**
Bow thruster No.1	Bridge	Derived from thruster 440V starter cabinet
Bow thruster No.2	Bridge	Derived from thruster 440V starter cabinet
Bow thruster No.3	Bridge	Derived from thruster 440V starter cabinet

6.4.6 The ECU controls the thruster pitch by adjusting the position of the pitch control valve. The ECU will receive a pitch command signal, and compare this with actual thruster pitch. It will then command the pitch control valve to move, allowing oil to flow into the thruster hub, until the desired pitch is achieved. The pitch control valve is a proportional control valve; therefore the flow of oil is regulated in a controlled manner and not on/off. The propeller pitch is monitored by a feedback potentiometer; this is used as the feedback for the control loop. The control interface with the DP system is arranged as follows:



6.4.7 The thruster signal types are as follows:

Signal	Type
Pitch command signal from DP	+10V port -10V starboard
Pitch feedback from thruster to ECU	Sin/cos +/-10V
Pitch command from ECU to thruster	4-20mA
Pitch feedback from thruster to DP	+/-10V

6.4.8 The bow thrusters have two manual control panels one on the forward bridge, one on the aft bridge panel. The thrusters can be started at the aft or forward panel. From the bridge panels the operator can take control of the thruster, and adjust the thrust output and direction. Each panel is fitted with an emergency stop and bow thruster status indicator lights. The panels are fitted with the following indication:

Ready for operation	Lamp
Thruster motor running	Lamp
Pitch neutral position	Lamp
DP/joystick control ready	Lamp
Motor current	Ammeter
Pitch indication	Meter
Follow up control (common lever for 3 thrusters)	Lever
Control On/Off	Pushbutton/lamp
Emergency stop	Push button

Hydraulic pump off	Light
Ford/Aft bridge selector	Switch
Emergency pitch operation (one for each thruster)	Lever
Lamp test	Bush button
Hydraulic motor start/running	Pushbutton/lamp
Take over	Pushbutton/lamp

6.4.9 To operate the bow thrusters in DP control, the thruster DP selector switchboard must be in the DP position. This gives each of the thruster ECU a digital input, instructing them to take commands from the DP system. The DP selector switch is located on the aft main propeller control panel. The switch has three positions, Co-pilot control, DP-mode and Joystick mode.

6.4.10 Each thruster is fitted with an additional mode switch. The switch has two positions, manual and DP/joystick. The mode switch allows the bow thrusters to be individually switched in and out of DP control, without the requirement for taking all three thrusters out of DP control. Both the thruster DP selector switch and the bow thruster mode switch contacts are powered from their respective thruster ECU, no external power supply is required.

6.4.11 The thruster ECU provides the following alarms:

Alarm	**Set point**
Overload hydraulic motor	
Over current thruster motor	
Thruster motor temperature 140°C	
Thruster motor temperature 150°C	Trip
Oil level low	
Hydraulic oil filter clogged	
Minimum hydraulic oil pressure	Low
Failure analog station 1A5/2A5	
Main source power fail	
Control source power failure	
Transformer temp 130°C	
Transformer temp 150°C	Trip
Max hydraulic oil pressure	
Hydraulic oil temp high	

6.5 Failure Modes

Failure	Effect	Alarm	Comments
Loss of 440V power supply	Thruster shuts down.	DP system, thruster not ready alarm	Failure will only affect one thruster
Failure of pitch pump	Thruster shuts down	DP system, thruster not ready alarm	Failure will only affect one thruster
Failure of thruster ECU	Thruster shuts down	DP system, thruster not ready alarm	Failure will only affect one thruster
Failure of 24VDC power supply	Loss of 24VDC control voltage, Thruster stops	DP system, thruster not ready alarm	Failure will only affect one thruster
Motor high temperature	Thruster shuts down.	DP system, thruster not ready alarm. Bow thruster default alarm	Failure will only affect one thruster
Failure of DP pitch command signal	Thruster pitch fails to zero	DP system, "thruster prediction error" alarm.	Failure will only affect one thruster
Failure of pitch command signal from ECU to thruster	Thruster pitch freeze	DP system, "thruster prediction error" alarm.	Failure will only affect one thruster
Failure of pitch feedback signal to DP	Thruster continues to operate to DP commands, no feedback to DP system	DP system, "thruster prediction error" alarm.	
Failure of pitch feedback signal from thruster to ECU.	Thruster trips	DP system, "thruster not ready" alarm	
Internal mechanical failure in pitch control mechanism.	Thruster may fail to full pitch or operate erratically.	DP system, "thruster prediction error" alarm.	Operator would have trip thruster to prevent degradation of station keeping.

6.6 Comments

6.6.1 The bow thrusters are independent units; any single failure will only affect one thruster. The feedback and command signal failures comply with IMO/IMCA guidelines, as demonstrated during the FMEA proving trials.

7. DP SYSTEM

7.1 Introduction

7.1.1 The vessel is fitted with a Kongsberg SDP21 duplex DP system. The philosophy of the SDP 21 system is that a single failure will not result in the loss of DP control.

7.2 DP System

7.2.1 The DP system is a Kongsberg SDP-21 duplex redundant system, located on the bridge. The SDP21 consists of the following components:

- Operating stations, (OS1 and OS2)
- Data Network
- DPC-21, redundant computer system
- Redundant UPS power system
- Positioning references
- Environmental references

7.3 Operator Stations

7.3.1 The Operator station (OS) acts as the operator interface with the system. It consists of a screen, keypad interface and computer, utilising Microsoft Windows NT. Each of the operator stations is dedicated to a particular task. By using the screen and keypad the operator can read and change operational parameters as required. The operator stations provide the following functions:

Designation	Parameter	Remarks
SDP	Dynamic Positioning	On the SDP-OS the operator controls and monitors the vessel's DP system.

7.3.2 The operator stations and power supplies are arranged as follows;

Operator station	Function	Location	Power supply
SDP-OS1	DP	Aft Bridge	UPS 1
SDP-OS2	DP	Aft Bridge	UPS 2

7.4 Data Network

7.4.1 The system is fitted with a redundant network, net A and net B. The networks connect, and are used to transmit information between, the SDP OS, the DPC21 and the HiPAP APC-10 computer.

7.4.2 Information is continually passed between the SDP OS, DPC21 and APC-10. When the operator alters an operating parameter on the OS, the instruction will be passed to the DPC21 or APC-10. The equipment configuration or setup is altered to reflect this instruction.

7.4.3 Each piece of equipment connected to the network has an interface, which are arranged and powered as follows:

Equipment	Network interface	Power supply
SDP-0S1	Net A and B	UPS 1, derived from OS power supply
SDP-0S1	Net A and B	UPS 2, derived from OS power supply
DPC-21A	Net A and B	UPS 1, derived from DPC power supply
DPC-21B	Net A and B	UPS 2, derived from DPC power supply
ATC-10	Net A and B	UPS2, derived from ATC-10 power supply

7.4.4 Data is transmitted on both networks simultaneously; the system using the information that is received first, and the second message being disregarded. In the event of a network failure, communications will continue over the healthy network.

7.5 DPC-21

7.5.1 The Dynamic Positioning Computer, DPC, consists of two independent computers (DPC-21A and DPC-21B). The position reference and environmental sensors are interfaced into the system direct via the DPC-21 system. Sensor inputs are to both computer systems simultaneously with only the online computer having access to the output signal function. A computer fault, including power supply fault, will generate a bumpless transfer to the off-line computer.

7.5.2 The DPC unit controls the thruster outputs to maintain the vessel position. It receives inputs from the environmental and positioning references; it then calculates the thruster output required to maintain the operator selected position. The DPC computer generates and maintains a mathematical model of the thruster outputs for the specific weather conditions. The model is built up over time to account for the current loading on the vessel, measured by the vessel offset from the desired position. The wind loading is derived from the wind speed and direction measured by the wind sensors; this is “fed forward” and the thruster output adjusted, before the vessel has moved of position. The OS unit acts as the operator interface, allowing changes to the vessel position and selection of references and thrusters to be used by the DPC.

7.5.3 The DPC also monitors the available electrical load. In the event of a high electrical power consumption, the DPC will automatically reduce the thruster outputs to prevent the vessel blacking out, generating a pitch reduction alarm on the OS unit.

7.5.4 In the event of a total failure of the positioning references the DP system will revert to model control. The DP will continue controlling the thrusters using the last mathematical model of the vessel and the wind input from the wind sensors. The DP system will continue to operate in this mode, until a positioning reference becomes online or the operator manually intervenes.

7.5.5 Each of the DPC performs error checking on the reference inputs. It monitors the input signal using voting techniques to discriminate against spurious, degraded or faulty inputs, which will then be rejected by the DPC. Voting is performed on two levels:

1st level - For each computer, the individual reference values are compared with the median. If the individual differences are greater than a predetermined limit the interface is considered faulty.

2nd level - Each individual value is compared with the median of all the medians from the first level. If one individual value differs considerably from the other two the sensor is considered faulty.

Error-detection algorithms are also implemented in the software.

7.5.6 Each DPC consist of a single board computer (SBC), this performs the DP calculations. Each DPC is supplied with a single power supply from its respective UPS. The power supplies are arranged as follows:

	Location	**Power supply**
DPC-21A	Bridge	UPS 1
DPC-22B	Bridge	UPS 2

7.5.7 The DPC is connected to the field equipment via Input/Output (I/O) cards. These cards have connections to both DPC and have dual power supplies. The I/O distribution is arranged in such a way that a single card failure will not result in a loss of DP control. The cards are arranged as follows:

U31	
I/O	**Signal type**
Thruster 1 ready	DI
Thruster 5 ready	DI
Thruster 5 pitch reduction ready	DI
Generator 1 connected	DI
Bus tie 1 (in)	DI
Alert common	DI
Alert off	DI
Alert common	DI
Alert Green	DI
Alert common	DI
Alert Yellow	DI
Alert common	DI
Alert Red	DI
Gyro 1 OK	DI
VRS 1 OK	DI
UPS 1 alarm	DI

U32	
I/O	**Signal type**
Thruster 3 ready	DI
Thruster 4 ready	DI
Thruster 4 pitch reduction ready	DI
Generator 3 connected	DI
Tautwire Mooring	DI
Tautwire Warning	DI
Tautwire Alarm	DI
Tautwire Select	DI
Gyro 2 OK	DI
VRS 2 OK	DI
UPS 2 alarm	DI

U33	
I/O	**Signal type**
Thruster 2 ready	DI
Generator 2 connected to bus 1	DI
Generator 2 connected to bus 2	DI
Thruster 2 connected to bus 1	DI
Thruster 2 connected to bus 2	DI
Gyro 3 OK	DI

U41	
I/O	**Signal type**
Tautwire Along ship	AI
Tautwire Beam	AI
Tautwire Wire length	AI

U42	
I/O	**Signal type**
Thruster 1 pitch feedback	AI
Thruster 5 pitch feedback	AI
Thruster 5 Azimuth sin feedback	AI
Thruster 5 Azimuth cos feedback	AI
Generator 1 load	AI
VRS 1 roll	AI
VRS 1 pitch	AI
Self test	AI
Thruster 1 pitch command	AO
Thruster 5 pitch command	AO
Thruster 5 azimuth command	AO
Self test	AO

U51	
I/O	**Signal type**
Thruster 3 pitch feedback	AI
Thruster 4 pitch feedback	AI
Thruster 4 Azimuth sin feedback	AI
Thruster 4 Azimuth cos feedback	AI
Generator 3 load	AI
VRS 2 roll	AI
VRS 2 pitch	AI
Self test	AI
Thruster 3 pitch command	AO
Thruster 4 pitch command	AO
Thruster 4 azimuth command	AO
Self test	AO

U52	
I/O	**Signal type**
Thruster 2 pitch feedback	AI
Generator 2 load	AI
Self test	AI
Thruster 2 pitch command	AO
Self test	AO

7.6 Power Supplies

7.6.1 The Kongsberg SDP 21 system has its own uninterruptible power supplies. These units are supplied with 230V, from a 440/230V transformer. The UPS consists of a battery bank, charger and inverter, and outputs 230VAC. The UPS' provide the system with a "clean" electrical power supply. In the event of an inlet power failure to the UPS, the unit will automatically change over to battery backup, generating an alarm on the DP and SVC OS. The UPS battery bank is sized to provide 30 minutes of power in the event of a power failure. A manual bypass switch is fitted to the system, allowing the operator to bypass the UPS unit, and supplying the consumers with an unclean power supply. This is arranged so that the bypass power is from the same power supply as the UPS input.

7.6.2 The UPS are supplied with power from both sides of the main 440V switchboard, via a change over relay arrangement. The relay is configured to prevent the connections of both supplies simultaneously, and such that the UPS main supply is from its respective side of the switchboard. The DP UPS power supplies and consumers are arranged as follow

UPS 1	
Main supply	Port main 440V swbd
Standby supply	Starboard main 440V swbd
Consumers	
DPC21A	
SDP OS1	
Alarm printer 1	

UPS 2	
Main supply	Starboard main 440V swbd
Standby supply	Port main 440V swbd
Consumers	
DPC21B	
SDP OS2	
Hard copy unit	

Fanbeam power supply	HiPAP APC 10 computer
Fanbeam monitor	HiPAP transceiver
Control cabinet remote alarm	Wind display 2
Tautwire	Wind display 3
Wind display 1	DGPS 1/XP + L1/L2 GPS
DGPS 2	Inmarsat demodulator
	Minidome down converter

7.7 Positioning Sensors

7.7.1 The vessel has four types of positioning sensors, the HPR HiPAP underwater acoustic system, the DGPS satellite positioning system, the tautwire system and the Fanbeam laser system.

7.8 HPR HiPAP

7.8.1 The HiPAP (**Hi**gh **P**recision **A**coustic **P**ositioning) is an underwater acoustic positioning system. It consists of an electronic computer unit, an underwater transceiver unit and a transponder. The transceiver is mounted in the vessel's hull and lowered beneath the hull during operation; the transponder is located on the seabed.

7.8.2 The system works by the transceiver sending an acoustic signal to the transponder. Once the transponder has detected this signal, it will send back a reply. The transceiver can then calculate the relative position of the transponder, by Ultra Short Baseline (USBL) trigonometry techniques.

7.8.3 The HiPAP transceiver is a semi-spherical transceiver with over 220 elements and electronic controls that enables narrow beam transmission and focused reception in the direction of the transponder, thus reducing the noise that would otherwise be received from other areas of the sphere. The system calculates a three-dimensional sub sea position of a transponder relative to the vessel mounted transceiver unit. The directional stability of the unit is obtained by firstly fixing the transponder location by a wide beam and subsequently by aiming a narrow reception beam towards the transponder. The system uses a digital beam form, which takes its input from all the transceiver elements. The system controls the beam dynamically so it is always pointing towards the target. Vessel roll, pitch and yaw is input to the tracking algorithm to direct the beam in the correct direction thus enabling the correction for these motions to be effectively applied continuously.

7.8.4 The HiPAP is fitted with an Acoustic Positioning Computer, APC. This unit acts as the operator interface with the HiPAP system. The APC system consists of monitor, keyboard and computer. This monitor and keyboard allows the operator to select transponders/responders and interrogation rates etc. The transceiver performs the positioning calculation, this is input to the APC. The APC then transmits this information over the network to the DPC.

7.8.5 The HiPAP system requires to be interfaced with an MRU and a Gyrocompass to provide a signal suitable for positioning the vessel. The MRU providing the vessel motions to correcting the positioning calculation, removing the effect of the vessel motions. The gyrocompass provides a heading for the positioning calculation. The DGPS input is used for calibrating the HiPAP alignment and LBL. The HiPAP is interfaced as follows:

	Interfaced	Remarks
HiPAP	DPC 21	Via network A and B
	MRU 2	Serial line
	Gyro 2	Serial line
	DGPS 1	Serial line

7.8.6 The power supplies for the HiPAP system are arranged as follows;

	Equipment	Power supply
HiPAP	Transceiver unit	UPS 2
	Hoist control unit	ES2
APC	Computer	UPS 2
	Monitor	UPS 2

7.9 DGPS

7.9.1 The Differential Global Positioning System (DGPS) consists of a Global Positioning System, (GPS) unit, utilising the US military positioning satellites, and a differential correction signal. The vessel is fitted with two DGPS systems (one Skyfix 90938 and one 4100LR DGPS unit) and a Multifix XP system providing a higher degree of referential integrity and accuracy. Each DGPS system operates independently. The output of DGPS1 unit is connected only to the Multifix system, which then feeds the DP desk via the DP system input channel assigned for DGPS1. The output of the DGPS2 unit is fed to the Multifix unit as well as directly fed to the DP desk. Each DGPS system consists of a GPS antenna, GPS unit including demodulator, and differential antennae. The power supplies for the DGPS are arranged as follows;

	Type	Power supply
DGPS 1	Skyfix 90938	DP UPS 1
DGPS 2	4100LR	DP UPS 2
	Minidome down converter	DP UPS 2
	Inmarsat demodulator	DP UPS 2

7.9.2 The raw GPS signal is sometimes not accurate enough for the positioning of the vessel, so a differential correction signal (based on the continuous comparison of a known land position with that of the GPS position) is used to improve the accuracy of the system. The 90938 units receive the GPS signals and differential signals using 2 separate antennas and have the capability of only utilizing the correction from any one station, and perform the positioning calculation, to correct for any errors in the raw GPS signal. The 4100LR unit utilizes a combined antenna for GPS and differential signals and has an integrated VBS solution enabling it to perform positioning calculation using correction signals from multiple stations. The corrected position is then input to the DP system.

7.9.3 The DGPS utilise Spotbeam and Inmarsat differential correction signals. These are received by dedicated aerials. The interfaces are arranged as follows:

<table>
<tr><th></th><th>Differential signal</th><th>Interface</th></tr>
<tr><td rowspan="2">DGPS 1</td><td>Spotbeam</td><td>Spotbeam antenna connected to Skyfix unit</td></tr>
<tr><td>Inmarsat via minidome</td><td>Minidome antenna interfaced to 90928
Minidome controller connected to Skyfix unit</td></tr>
<tr><td>DGPS 2</td><td>Combined antenna</td><td>Combined antenna connected to 4100LR</td></tr>
</table>

Note: DGPS 1 can operate with either Spotbeam or Minidome derived correction signals. A selection switch is fitted between the inputs, allowing the operator to switch between them.

7.9.4 In the event of a total loss of differential signals, the operator can select uncorrected GPS input into the DP system. The suitability of the GPS as a positioning reference will depend on the raw GPS data. The US military used to corrupt the civilian GPS, by introducing an error called Selective Availability, (SA). The SA has been removed since 1st May 2000; and the GPS available to civilians now provides an accuracy of around 5m. This signal is usually suitable for DP operations, although a potential error of plus/minus 5 metres can lead to DP rejection problems. Also the US has stated that it may reintroduce SA at any time. Hence the correction signals are still used.

7.9.5 The XP Multifix is fed an SCF raw data from both DGPS units, and the failure of any one DGPS input does not affect the XP position accuracy. The Multifix system also has a separate multi channel (L1/L2) GPS unit connected to it.

7.9.6 Failure Modes:

a. Normally, failure of any single component of the DGPS, including loss of correction signal, will cause a rejection from the DP system. Any spurious fix which is not rejected, can degrade the position keeping envelope. This is true in the case of DGPS2 in the current setup. However, with the XP system feeding the DP desk in lieu of DGPS1, failure of DGPS1 by itself does not affect the DP system in any manner as the XP is still providing accurate data. However, the data tracking signal in the XP screen would indicate a lack of input from DGPS1.

b. In the event of a Multifix failure, the DGPS1 unit can be directly connected to the DP desk.

c. Each system is supported by UPS 1 or UPS 2 in such a way so that in the event of complete power loss of a UPS, one system survives.

7.10 Tautwire

7.10.1 The vessel is fitted with a Bandak Mark-14 Lightweight taut wire (LTW). The taut wire is rated for operation in up to 350m water depth.

7.10.2 The taut wire consists of a clump weight, connecting wire, gimbal head fitted with potentiometers, a winch and a pneumatic cylinder to apply constant tension. The taut wire operates by measuring the wire angle and length. The wire angle is measured by the potentiometers in the gimbal head and wire length by a payout meter on the winch drum. With these measurements the DPC can calculate the vessel position, motion measurements from the MRU are used to correct the calculation.

7.10.3 The taut wire requires the following supplies to operate;

	Power supply	**Comments**
Compressed air	Working air system	Constant tension cylinder.
440V	Deck services switchboard, derived from 440V port main switchboard	Winch
220V	DP UPS 1	Control

7.11 Fanbeam Laser System

7.11.1 The vessel is fitted with a MDL Fanbeam laser radar system. This system is a line of sight positioning system, utilising a laser beam.

7.11.2 The system consists of a laser head, control unit and reflector. The laser emits a pulse of light, this is reflected of the target and the reflection is detected by the laser head. The control unit controls the laser head and performs the positioning calculation. The control unit calculates the range and bearing of the target from the laser head, this figure is output to the DP system.

7.11.3 The power supplies for the Fanbeam laser system are arranged as follows:

	Power supply
Control unit	DP UPS 1
Monitor	DP UPS 1
Laser head	Control unit

7.12 Vessel/Environmental Sensors

7.12.1 The DP system is fitted with three types of vessel/environmental sensors: gyrocompass, motion reference unit (MRU) and wind sensors.

7.13 Gyro Compass

7.13.1 The vessel is equipped with three Anschutz standard 20 gyrocompasses. They are interfaced into the DP system, via the DPC, to provide a reference for monitoring and controlling the vessel's heading.

7.13.2 The gyrocompasses are supplied with 24VDC from the vessel 24VDC systems. The location and power supplies are arranged as follows;

Gyro compass	Location	Power supply
1	Bridge	24VDC Low voltage switchboard
2	Bridge	24VDC Wheelhouse switchboard
3	Bridge	24VDC Wheelhouse switchboard

7.14 MRU

7.14.1 The vessel is equipped with two MRU's. They are interfaced into the DP system, via the DPC, to correct the positioning calculations for vessel motions. The location and power supplies are arranged as follows;

MRU	Location	Power supply
1	HiPAP pole compartment	DPC-21A & B
2	HiPAP pole compartment	DPC-21A & B

7.14.2 The MRU2 is also interfaced with HiPAP, providing vessel motion information for the HiPAP calcualtions.

7.15 Wind Sensors

7.15.1 The vessel is equipped with three wind sensors, although only two are used as DP inputs. They are interfaced into the DP system to provide a reference for monitoring wind speed and direction. The wind speed is "fed forward" into the DP model. This allows the DP system to react and provide thrust to counteract the wind force without waiting until the vessel is blown off position or heading. The location and power supplies of the units are arranged as follows;

Wind sensor	Location	Power supply
1	Main mast	UPS 1
2	Main mast	UPS 2
3 (Not interfaced with DP)	Main mast	UPS 2

7.16 Failure Modes

Failure	Effect	Remarks
Failure of DP OS	Loss of DP information to operator. Vessel remains in DP	Operator switches to remaining healthy OS for continued DP operation.
Failure of DPC	Loss of one DP controller. System automatically switches to standby. Vessel remains in DP.	
Failure of a network, line break or hub failure.	Loss of one network. Communications continue on healthy network Vessel remains in DP.	
Failure of power supply to UPS	UPS switches to battery backup, batteries provide 30 minutes duration	
Total failure of UPS 1, i.e. batteries exhausted or UPS internal fault.	Loss of the following equipment: DPC-21A SDP OS 1, hence net A Alarm printer 1 Fanbeam laser Tautwire Wind sensors 1 DGPS 1 Vessel remains in DP on DPC-21B and SDP OS2, on network B, DGPS 2, HiPAP and Gyro 1, 2 and 3.	

Failure	Effect	Remarks
Total failure of UPS 2, i.e. batteries exhausted or UPS internal fault.	Loss of the following equipment: DPC-21B SDP OS2, hence net B HiPAP Wind sensor 2 Wind sensor 3 DGPS 2 Vessel remains in DP on DPC-22A and SDP OS1, on network A, DGPS 1, HiPAP and Gyro 1, 2 and 3.	
Failure of positioning reference, power failure.	Reference rejected from DP system. Vessel remains in DP on healthy references.	
Total failure of positioning references.	DP system switches to “model control”, position keeping slowly degrades.	
Failure of gyro, power failure or gyro “wandering” off.	Gyro rejected by voting on DP system. Vessel remains in DP on remaining two gyros.	
Failure of MRU, power failure.	MRU rejected by DP system. Vessel remains in DP on remaining MRU.	
Failure of wind sensor, power failure.	Wind sensor rejected by DP system. Vessel remains in DP on remaining Wind sensor	DP system can operate without the wind senor inputs, with greater positional footprint.

Failure	**Effect**	**Remarks**
Failure of I/O card U11/P4, Internal fault	Loss of: Wind sensor 1 Operator terminal Vessel remains in DP using other wind sensors, loss of operatoe terminal has no effect on DP control.	
Failure of I/O card U31, Internal fault	Loss of: Thruster 1 (ready signal) Thruster 5 (ready signal) Generator 1 status Bustie status Gyro 1 (ready signal) Gyro 1 (ready signal) VRS 1 (ready signal) Vessel remains in DP with thruster 2, 3 and 4. With all positioning references, VRS 2 gyro 2 and 3.	
Failure of I/O card U32, Internal fault	Loss of: Thruster 3 (ready signal) Thruster 4 (ready signal) Generator 3 status Tautwire Gyro 2 (ready signal) VRS 2 (ready signal) Vessel remains in DP with thruster 1, 2 and 5. With DGPS, HiPAP and fanbeam references, All positioning references, VRS 1, gyro 1 and 3.	

Failure	**Effect**	**Remarks**
Failure of I/O card U33, Internal fault	Loss of: Thruster 2 (ready signal) Generator 2 status Gyro 3 (ready signal) Vessel remains in DP with thruster 1, 3, 4 and 5. With all positioning references, both VRS, gyro 1 and 2.	
Failure of I/O card U41, Internal fault	Loss of: Tautwire Vessel remains in DP on remaining references.	
Failure of I/O card U42, Internal fault	Loss of: Thruster 1 (command signal) Thruster 5 (command signal) Generator 1 load VRS 1 data Vessel remains in DP with thruster 2, 3 and 4.	
Failure of I/O card U51, Internal fault	Loss of: Thruster 3 (command signal) Thruster 4 (command signal) Generator 3 load VRS 2 data Vessel remains in DP with thruster 1, 2 and 5.	
Failure of I/O card U52, Internal fault	Loss of: Thruster 2 (command signal) Generator 2 load Vessel remains in DP with thruster 1, 3, 4 and 5.	

7.17 Comments

7.17.1 The vessel is fitted with a Simrad SDP 21 dynamic positioning system. This is a duplex DP system. The FMEA research and testing has found no failure that will result in the loss of DP control, this has been verified during the FMEA.

8. DP OPERATIONS

8.1 Machinery Configurations

8.1.1 To configure the vessel for Class 2 DP operations the following criteria have to be met:

Fuel system has to run as split system.
Each side of the switchboard has to be powered by a diesel generator.
Each side of the switchboard has to power a bow thruster.
Both azimuth thrusters running

8.1.2 When operating the vessel in this mode, consider the loss of one switchboard due to a short circuit. The actual result of the failure will depend on the configuration before the failure. Since the switchboard PLC will allow one generator to power only one bow thruster, tripping other connected bow thrusters, in the worst case this will result in the vessel operating in DP with one bow thruster and one stern thruster, with reduced station keeping capability.

8.1.3 To recover from this electrical failure, the operator can reclutch and reselect in DP the failed azimuth thruster. The vessel will now be operating with one bow thruster and both azimuth thrusters. The operator can also connect bow thruster No.2 to the healthy switchboard, by starting and connecting diesel generator No.2. The vessel will now be operating in DP with two bow thrusters and both azimuth thrusters.

8.1.4 In the event of water contamination of one fuel oil service tank, the effect will be the loss of one diesel generator and one azimuth thruster. If the vessel was operating with two generators at the time of the failure, the switchboard PLC will trip all but one of the bow thrusters. The vessel will be operating with one bow thruster and one azimuth thruster. The failed azimuth will not be immediately available, as the engine fuel system will have to be flushed of water contamination. The operator can connect diesel generator No.2 and then bow thruster No.2. The vessel will then be operating in DP with two bow thrusters and one azimuth thruster.

8.2 Comments

8.2.1 For generation of the vessel DP capability plots, the worst case failure is water contamination of the fuel oil service tank. After this failure, the vessel will be able to maintain position with one bow thruster and one stern azimuth. It is recommended that this failure is simulated when the vessel is operational and the actual bow thruster output available is used to generate the capability plot.

8.2.2 Due to the flexible nature of the switchboard and generators, it may be possible to reconfigure the switchboard after a failure, dependant on the initial failure. In this case the engineering operator can start No.2 generator and synchronise it with the "healthy" switchboard. Bow thruster No.2 can then be connected. The vessel will now be able to position with one azimuth thruster and two bow thrusters, powered by two generators. The actual time to complete this operation will depend on the ability and training of the operator. It is recommended that the engineroom watch keepers are fully trained in this change over procedure and clear instructions are posted by the switchboard.

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