



FMEA OF OSV "RELUME"

FOR MENAS

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MARINE, OFFSHORE AND ENGINEERING CONSULTANTS

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1. SUMMARY

In 2004, Global Maritime completed an FMEA of the systems directly and indirectly involved with keeping the vessel on a wanted position or track. The work has been carried out from the study of drawings, specifications and meetings at Imtech with Owners and representatives from vendors, Damen Shipyard and Three Quays, the designers. The report was then updated after the annual trials to correct a few errors and add a third DGPS.

In September 2012, Global Maritime Scotland Ltd was requested to revise and update the FMEA to incorporate any changes since last revision in 2006.

In November 2012, the FMEA was again revised and updated to include the new Fanbeam unit.

The vessel specification is DP class 2 (Lloyds DP AA notation) so that the vessel can carry out offshore work where DP redundancy is required. The DP activities envisaged are ROV and dive support work, where the necessary equipment is provided by a contractor as a complete package on the after deck.

The assumptions made during the study were verified during commissioning and DP Trials held in August and September 2004 and the annual trials carried out between 2006 to 2012.

The FMEA is a living document and, as such, is discussed and reviewed during each annual trial by the Master and DPOs, the DP auditor, Kongsberg Maritime, Rolls Royce and any other attending third parties such as the Class Surveyor.

Based on compliance with IMCA and IMO guidelines, the vessel meets the requirements for a Class 2 Dynamically Positioned vessel with the main switchboard bus tie open and is fit for carrying out DP operations within her design and operational limitations.

2. INTRODUCTION

2.1 Instructions

- 2.1.1 Global Maritime was instructed by MENAS to carry out a full revision of the FMEA. The original report covering all the systems involved directly or indirectly with DP and DP operations and was completed in 2004. The report was updated after the first annual trials in February 2006. This revision was completed in October 2012.
- 2.1.2 This report was originally produced based on drawings and specifications provided during the vessel construction, it was issued as the final report, verified by the commissioning and DP trials held in August and September 2004 and updated in March 2006 and again in October 2012. This report identifies all reasonably likely failure modes and their effects. As more information becomes available, it will be incorporated in the next revision of this report so that it serves as a source of information and DP philosophy for key DP personnel working on the vessel.

2.2 Vessel Particulars

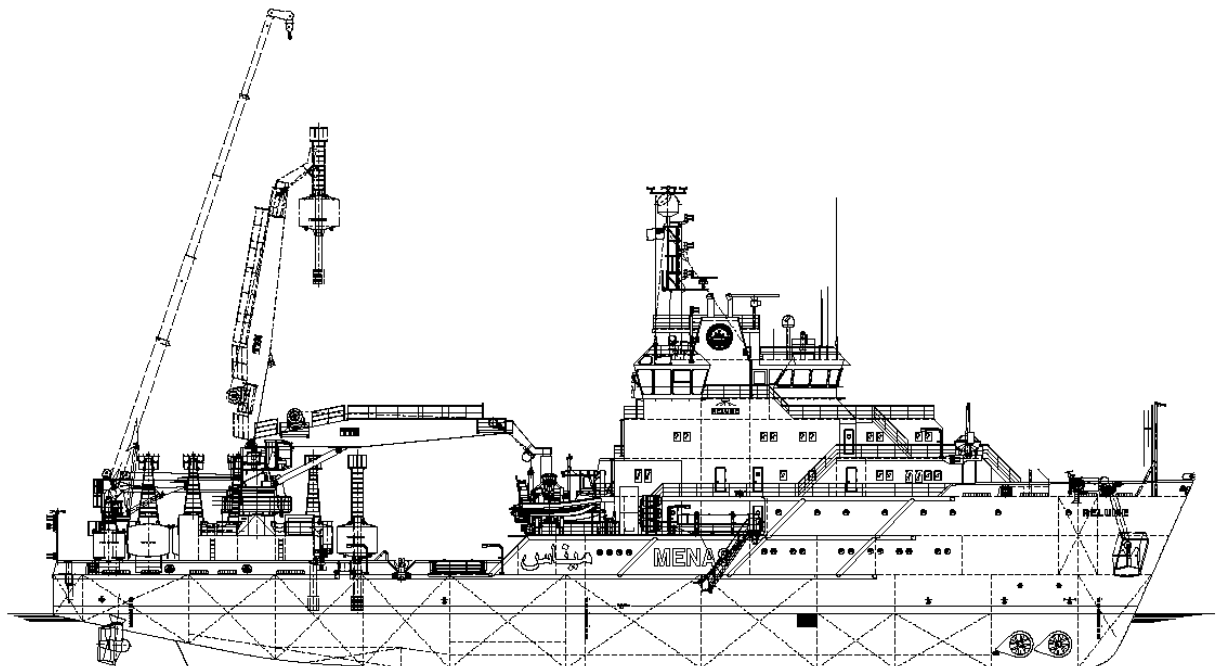


Figure1: OSV Relume Profile

2.2.1 The following are the general particulars of the vessel:

The hull, machinery and electrical installations were built and installed under special survey in accordance with the Rules and Regulations of Lloyd's Register of Shipping for notation:

+100A1, +LMC, UMS, DP (AA), IBS - LIGHT TENDER/ OCCASIONAL OIL RECOVERY DUTIES

The Vessel is registered in the Bahamas, port of registry Nassau and is designed to comply with the requirements of the U.K. Maritime & Coastguard Agency (MCA), the Flag Authority, for a Class VII vessel.

Length Overall	82.6 metres
Length Load Water Line	78.2 metres
Length between Perpendiculars	73.6 metres
Breadth Moulded	16.5 metres
Depth Moulded to Main Deck	6.8 metres
Depth Moulded to Lower Deck	4.0 metres
Depth Moulded to Forecastle Deck	12.4 metres
Design Draft Moulded	4.0 metres
Draft Scantling Moulded	4.5 metres

3. POWER GENERATION

3.1 Fuel Oil Systems

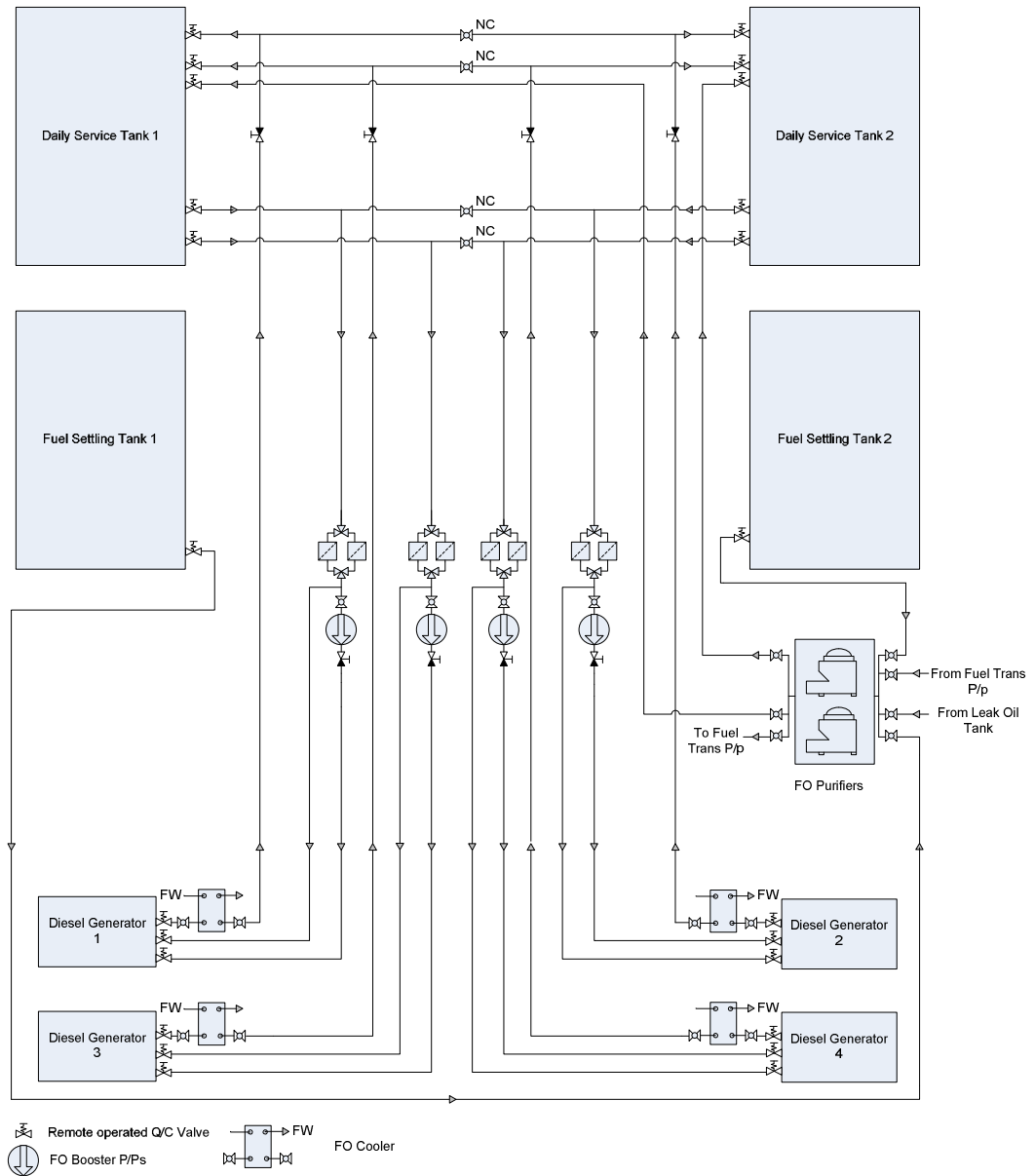


Figure 2: Fuel Oil System (Ref drawing No 320.01)

3.1.1 There are two service fuel oil tanks; each tank supplies two of the four diesel engines via a single quick closing valve. So provided each tank is available DP class 2 can be achieved such that the worst-case failure can only cause the loss of two diesel generators. The effect of this is the loss of one switchboard and two of the four thrusters. This is the design worst-case failure and DP capability for work like dive support is based on this.

3.1.2 The design separation however is not necessarily adequate to ensure that a failure with a greater effect than the design worst case is impossible. Experience shows that it is always possible to blackout:

Failure Mode	Cause(s)	Effects	Mitigation
F.O. Starvation (two DG's)	QCV operate Filter blocked Pumps fail Leakage	Unable to deliver demanded power	Other thruster compensates
F.O. Contamination	Water in fuel Microbiological contamination	Unable to deliver demanded power	Other thruster compensates

3.1.3 In the above circumstances, the power management system and DP control system will not know the reason for the loss in power. If there is under-voltage and under-frequency, the power will be cut back by the azimuth thruster frequency converter and there will be an increase in thrust and power on the healthy side of the switchboard. Thus, blackout and loss of position should be avoided. However, in the worst case there would be blackout on one side followed by a sudden step change in demand on the healthy side of the main switchboard. Provided the engines can deliver the power, negligible position excursion should occur. However if, after many hours of running at low load, they are unable to deliver power as expected, position will be lost. If the contamination is common to both fuel oil systems then blackout is possible even if the azimuth thruster's power is reduced significantly very quickly. The loss of power and thrust in this way is not considered a single point failure provided planned maintenance makes sure fuel oil contamination etc. is very unlikely and the engines are tested regularly so that the chance of them not being able to deliver on demand is very small. In these circumstances blackout would have more than a single point cause.

Fuel flow meters are installed. Care should be exercised so that they cannot fail and cause fuel oil starvation from line blockage. In the event of fuel oil, filter high differential the pressure in the fuel suction main will drop below alarm level. This will result in the fuel boost pump starting automatically to increase the fuel pressure. However if the problem is a blocked filter, the improvement provided by the boost pump will be short-lived.

Should fuel oil starvation take place, operators can quickly change filters or take other appropriate action, but care must be taken to prevent diesel engines tripping on overspeed because the demand is at maximum (fuel rack is fully open). Care must also be taken to vent air out of the fuel oil system as this can cause unexpected tripping just after the situation has been 'saved'.

3.2 Sea Water Cooling

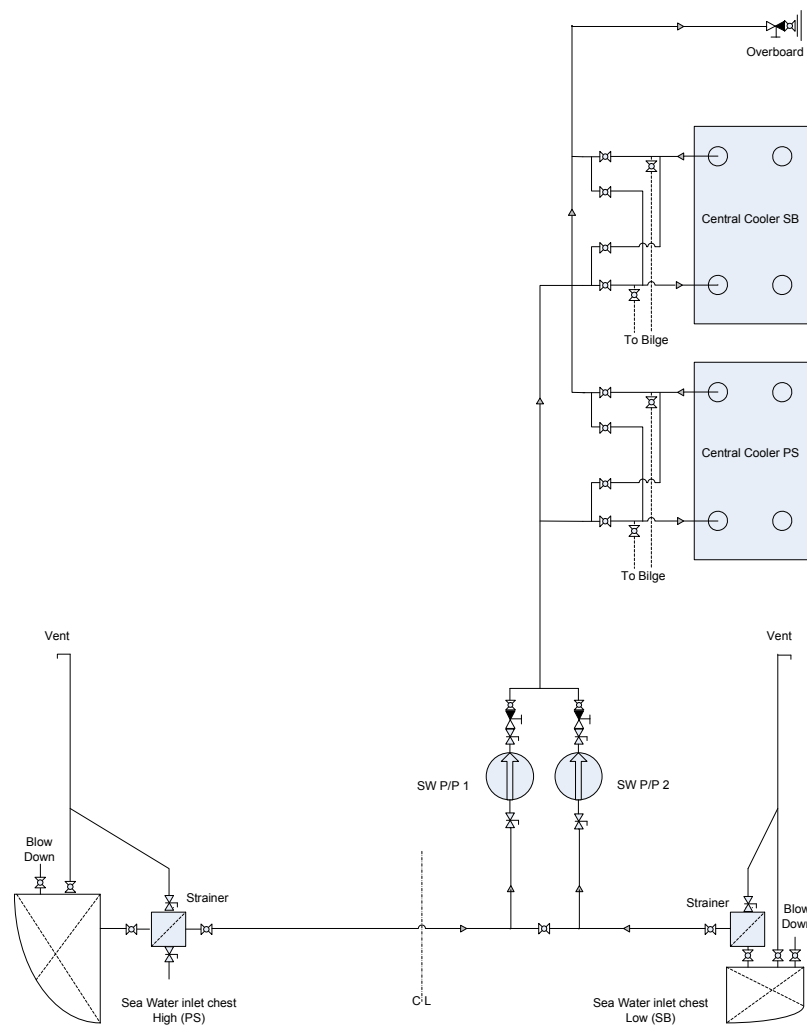


Figure 3: Sea Water Cooling System (Ref drawing 330.01)

3.2.1 There is one common sea water system with two suctions (port and starboard) and two circulating pumps. The vessel will normally operate with one pump on line and one pump on auto-standby. This has been confirmed by tests but relies on the stand by pump being available and not being unavailable due to a hidden failure. The standby pump function is tested frequently and pumps changed over on a regular basis. Seawater is only used for cooling the fresh water systems and provided it is reliable, this is acceptable for DP2. The failure modes that need to be considered are as follows:

Failure Mode	Cause(s)	Effects	Mitigation
Inadequate Flow	Pump failure Air in system Poor maintenance Leakage (Burst Plate Cooler)	High FW Temperature	Standby Pump Can isolate leak
	Blocked intake	Low Flow	Can use other suction

3.2.2 There is a body of opinion that believes that plate coolers should be considered as active components so there is a requirement to make sure they are kept reliable. If the system is reliable then there are only two failure modes that are potentially critical and could cause high temperature shut down of all the diesel engines and hence a loss of position. The first of these is failure of the duty pump when the stand-by is not available. This could happen if only one of the two pumps is on line and the stand-by fails to start. This can be avoided for critical DP work. The second is a build-up of air in the system such that an air lock occurs; however, on this vessel the sea suction is vented to deck in order to prevent air locks in the system.

The sea water system flow is determined by the pumps and the valve setting which is manual. It is anticipated that full flow will be the norm and no active control will be used; temperature control is on the fresh water side. If the seawater inlet becomes blocked (marine growth plus plastic bag for example) operators should have low-pressure alarms and LT temperature alarms before F.W. high temperature so that the other sea suction can be used. During sea trials, it was confirmed that under normal DP operational conditions the engines were able to operate for a considerable time before the engine HT temperature reaches the shutdown setting of 110C. Prior to shutdown, the LT temperature alarm, set at 45C, will activate, providing the watch keepers with adequate time to take preventive measures.

3.3 Fresh Water Cooling

Ref Dwg 330.02 Fresh Water Cooling System

3.3.1 The fresh water system is also common but there is an expansion tank and a buffer tank so that there will be two alarms if there is leakage in the system that might threaten blackout from loss of cooling to all diesel generators. The system has two plate coolers and two 100% circulation pumps so the design philosophy is for one to be on line and one to be on auto-standby. This common cooling system supplies the thruster coolers, the converter cooling system, fuel oil coolers and start air compressor cooling. Again, the loss of one pump could be critical if the standby pump failed to start (hidden failure); however this risk is mitigated, in part, by regular testing and changeover of the running and standby pumps.

If leakage occurs, the header tank low-level alarms will activate before any loss of pump pressure. During trials, with FW cooling system shutdown, the thruster converters ran for 20 mins before the High High Shutdown (55°C) activated. The engines were still running OK.

Failure Mode	Cause(s)	Effects	Mitigation
Inadequate Cooling	Temperature control valve fault Leakage from cooler Air in system	Alarms High D.G Temperatures Risk of blackout	Early warning Isolation possible Temperature rise not instant Standby pump

3.3.2 The system is well designed and reliable. The risk of leakage being excessive so that isolation is not possible in good time is small. The two pumps are powered from the split 440V switchboard. If the stand-by is unavailable then the vessel cannot be considered as working in the safest (Class 2) mode. The most likely cause of the loss of cooling water is the failure of a flexible coupling at one of the four diesel generators. This can happen from excessive engine vibration

perhaps after poor maintenance. Operators must pay close attention to these couplings.

The bow thruster and azimuth thruster motors and azimuth thruster oil coolers are FW cooled but the converter coolers (fan/coil units) are part of the closed system for each converter. The FW system is the cooling medium used in their dedicated plate coolers.

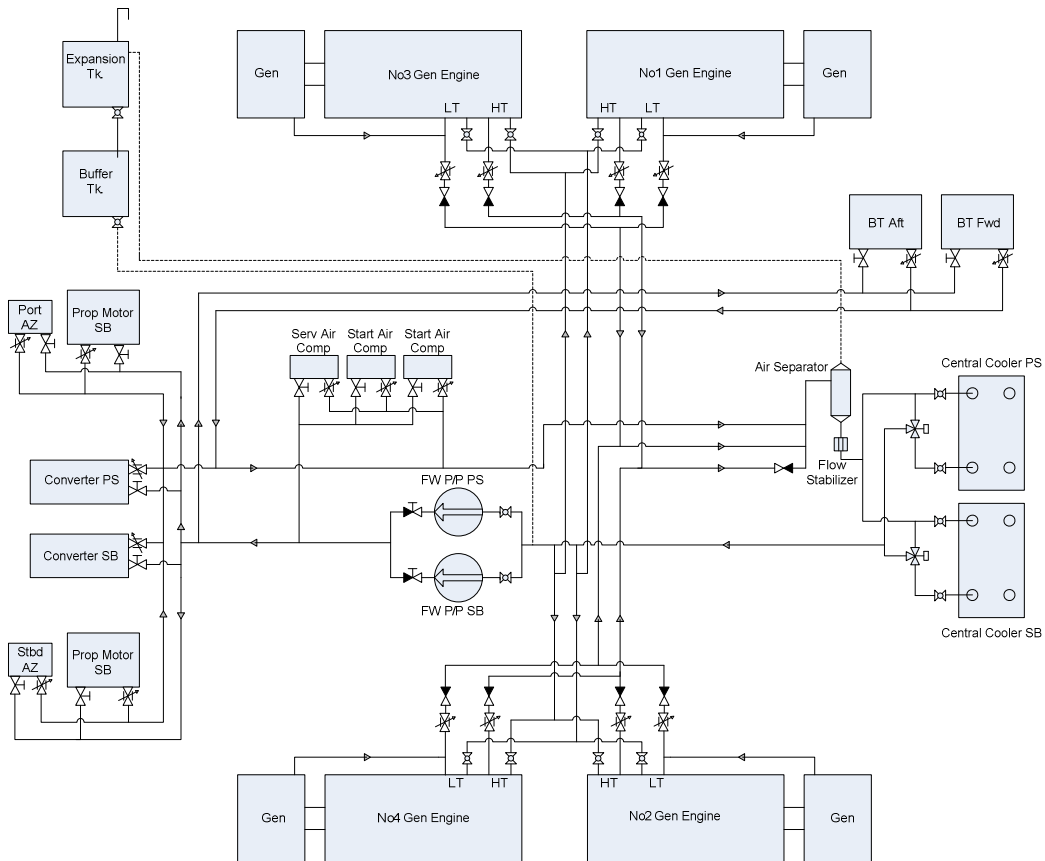


Figure 4: Fresh Water Cooling System

3.3.3 The expansion tank is 1100-L capacity and the buffer tank is 900-L capacity. The operator will know there is a significant leak (Red Alert) if both alarms take place in quick succession.

3.3.4 The fresh water temperature control has two sets of control loops, one for each diesel engine between HT and LT circuits and one for each plate heat exchanger. The temperature control valves are Amot and once set up they should operate adequately. If there is a control problem, manual adjustment of the plate cooler thermostatic valves is possible.

3.4 Lube Oil

3.4.1 There is no common lube oil system for the diesel generators, each is independent with a motor driven pre-lube oil system and an engine driven circulation once the diesel generation is running. The lube oil to any one generator can be changed or

filtered separately by using dedicated pumps, so the failure modes are reasonably limited to one engine.

- 3.4.2 The failure modes that can contribute to an effect greater than the loss of one diesel generator are generally concerned with a standby machine not starting and coming on line when needed because of a lube oil low-pressure sensor fault or the pre-lube logic being faulty. These failure modes were tested during trials. The pre-lube oil pumps should be running on all standby machines. If there is a blackout or partial blackout a healthy diesel generator will be able to start as the pre-lube oil pump of each 1,300 kW engine is powered from the Emergency Switchboard, also if the pump was running before the blackout, lubrication is still present to allow starting.
- 3.4.3 Lube oil contamination microbiological or by fuel, oil is possible but this is unlikely to affect more than one diesel engine at any one time.

3.5 Compressed Air

- 3.5.1 The starting air system is also common with redundant active components and compressors. There are also two receivers. For loss of starting air to be critical there has to be two failures namely, a loss of one or more diesel engines and a loss of starting air so that they cannot be restarted or another brought on line.
- 3.5.2 In addition to the start air compressors, there is a Control/Working air Compressor with a capacity of 66m³/hr. at 12bar. This compressor is fitted with an 800l receiver and filter/drier unit. Air from this system is used to supply the azimuth thruster header tanks and the taut wire unit.
- 3.5.3 Each azimuth thruster has a header tank (gravity tank pressurising) and because there is inadequate height at the stern above the thruster, the tank has to be pressurised by service air that is reduced from 8 bar to 1.5 bar. The air is supplied to the header tanks via non-return valves and therefore loss of air will have no immediate effect. A back-up air supply is available from either the start air system or the secondary service air compressor with integral 250l receiver. The azimuth header tanks and the service air system are alarmed for low air pressure; hence, the operator will be informed should loss of air pressure occur. A safety valve is fitted to the thruster air supply to prevent over-pressure. The pneumatic system is not supplied by Rolls Royce. Control air is also used for the thruster brake but this is only used when thruster maintenance is in progress and the thruster is not available.

3.6 Diesel Generators

- 3.6.1 The vessel has four diesel generator sets, two to port, one behind the other, and two similarly arranged to starboard. They are similar Wärtsilä engines but in each pair one is a six cylinder, 948kW and the other is eight cylinder 1269kW. The engine room is one space from a fire and flood perspective but there is a longitudinal acoustic bulkhead so that there is some acoustic separation. There is one Caterpillar Emergency Diesel generator set of 145kW.
- 3.6.2 For the vessel's AA (DP2) notation the main switchboard will be split with one or two diesel generators on line each side. In these circumstances, the worst-case failure will be blackout on one side, port or starboard. However, there are several failure modes that can cause the loss of one or two diesel engines. The fuel oil

and cooling water failures have already been discussed. The additional failure modes are as follows for cases where two diesel generators are on line each side:

Failure Mode	Cause(s)	Effects	Mitigation
Excessive vibration	Mechanical damage	Reverse power trips Low F.O. pressure Low LO trip High temp. trip	Other engines
Overspeed	Control fault	One D.G. trips Other on reverse power	Other engines
Instability	Control fault	Operator trips faulty machine (risk of stopping healthy one by mistake)	Other engines

- 3.6.3 The risk of mechanical damage is small. If an engine is not performing well this should be evident and the operator should initiate starting of the other engine (if not on line) and shut down prior to the engine tripping. This action should cause an amber alert and cause divers to return to a safe position if the vessel is engaged in diving support work.
- 3.6.4 For this vessel, mechanical damage to one engine is unlikely to physically damage another but instability or overspeed of one could cause both to fail and the vessel to rely on the other engine(s) on the other side of the vessel. When the control of one engine causes instability, it is equally difficult for the operator, as the instrumentation and protection, to identify which is the faulty machine and which machine is following. There have been instances where the operator has tripped the healthy engine and then the unhealthy engine also trips.
- 3.6.5 The limits of operating with just one diesel engine each side depends on which pair of engines is on line and the environmental conditions at the time but with a 1 + 1 arrangement the second DG should be on line as soon as the load reaches 50%, otherwise there will be a loss of position from the failure of one DG.

3.7 Power Management

- 3.7.1 The vessel is fitted with an "Alarm, Monitoring and Control System". This system covers the requirements for an unmanned engine room, the remote monitoring starting and stopping of equipment, the audible and visual alarms and the power management.
- 3.7.2 The whole system is integrated with data being transmitted over a redundant Ethernet network with two independent LAN connections. The main server is located in the engine control room and the back-up server on the bridge.
- 3.7.3 Each engine PMS unit has a direct supply from UPS port or starboard. The supplies are diode protected. A second supply is provided from the generator, via a transformer/rectifier, once the machine is on line.
- 3.7.4 There are Server and Client computers located in the ECR and on the bridge, under normal conditions the ECR Server is in control, in the event of it failing, control is taken by the Bridge Server. Access to the system from the ECR will then be via the client computer. Both servers are supplied from the Praxis UPS. The ECR client is supplied from NLDP4 and the bridge client from NLDP1. All workstations are also protected by a local dedicated UPS.

3.7.5 The system has 11 intelligent I/O cabinets: each has a 24V-dc power supply. The units and their function are shown the following table.

ID	UNIT FUNCTIONS	LOCATION	POWER	MODULES
DPU1	DG1, DG3, BT1, PS PM PS Tanks, Auxiliaries & SWBD	Engine Room PS Tween Deck Fr 71	PRAXIS UPS cct F11	13
DPU2	DG2, DG4, BT2, SB PM SB Tanks, Auxiliaries & SWBD	Engine Room SB Tween Deck Fr 71	PRAXIS UPS cct F12	10
DPU3	Thruster Control PS PM, Drive & Azimuth PS Tanks & Auxiliaries	Carpenters Workshop	PRAXIS UPS cct F13	10
DPU4	SB PM, Drive & Azimuth SB Tanks & Auxiliaries	Hold PS Tween Deck Fr 62	PRAXIS UPS cct F14	7
DPU5 (XS316 XS317)	BT Alarms, ESB Monitoring & Auxiliaries	Bridge FWD Console PS	PRAXIS UPS cct F23	6
DPU5 XS318	BT2 Starting, Bridge Alarms SB PM Indication	Bridge FWD Console PS	MSB1 24V cct Q23	2
DPU7	PS Pumps	Group Starter Panel No. 1	PRAXIS UPS cct F21	3
DPU8	SB Pumps	Group Starter Panel No. 2	PRAXIS UPS cct F22	3

3.7.6 All Server and Client Workstations are inter-connected via a redundant high-speed network and uses two coaxial cables, one for main link and one for back-up link.

The operation of this redundant network is such that either the Main or Backup network can take control in case of any the other failing.

LAN network arrangements can be referred to in drawing 394-440-100-LDS-001 sheet 101 Rev 1.

3.7.7 The system has four dual field bus networks (CAN-bus). Number four is for watch keeping, (unmanned engine room) alarm monitoring and calling. This does not concern operations in DP2 on the basis that the engine control room will be manned during operations. The other three are configured as follows:

FIELD BUS	DPU's	DATA
1	1	DG's 1 & 2 Port
2	2	DGs 3 & 4 Starboard
1	3	Thruster Drive Port
2	4	Thruster Drive
3	5	Starboard Wheelhouse
3	7	Group Starter Panel 1
3	8	Group Starter Panel 2
3	11-14	HVAC

Note: DPU 6, 9 and 10 do not exist, these numbers are reserved for future developments.

This shows that the port diesel engines and port thruster drive are controlled and monitored by No. 1 dual network while the others are on No. 2 dual network. The remainder are on field bus No. 3. Thus, port and starboard separation is achieved.

3.7.8 Each diesel engine has an individual PMS module (PS 3500), which is linked by a dual redundant CAN-bus so that the loss of one link will only cause an alarm but no power management malfunction. If both are lost from one module, however the

PMS can act to control the machine independently of the others. The serial data bus is used for load sharing and data transfer to the AMCS (Alarm, Monitoring and Control System). All four diesel engines will run in droop mode but be adjusted by the PMS system to achieve load sharing. Each PMS module has a 60 Hz reference and it is this that is used for load sharing. Each PMS module is powered by different internal feeders in the 690V main switchboard. They are galvanically isolated by converters capable of withstanding spikes and interference from the main power cables and bus bars.

- 3.7.9 When the main bus tiebreaker is open the port PMS modules and starboard PMS modules are made independent of each other by opening the hard-wired contact from the bus-tie breaker to each PMS module. In this state, there is no communication between the two sides.

Failure Mode	Cause(s)	Effects	Mitigation
One PMS fail	Power loss or over voltage	One DG stops	Other engine Dual power
One PMS link fail	Wire break	None	Use other
Both PMS fail	Non alarm on other Operator error	DG independent	Alarm Other side OK
Loss of DPU 3 or DPU 4	Internal short	Loss of azimuth thruster indication	Other OK
Loss of DPU 1 or DPU 2	Internal short	Loss of diesel Engines indication	Other OK
Loss of DPU 5	Internal short		Information only
False bustie breaker status to OMS	Wire break Breaker fault	All engines still run	Should not cause tripping

3.8 Power Balance

- 3.8.1 Generated power with all four-diesel generators on line there is 2,217kW of power available for each side of the main switchboard. Each bow thruster consumes 515kW at full power while each stern azimuth thruster can consume 1590kW. Thus if one side of the switchboard is lost and the thrusters were at 50% there is not enough power for one side, with both DG's on line to supply the full DP load if allowances are made for the domestic load. This assumes that on the worst case failure the two remaining thrusters have to supply 100% thrust.
- 3.8.2 In practice, the thrust of the stern azimuth thrusters has to be limited so that overload is avoided. Calculations from the builders show that about 90% power would be available and that with an open bus-tie breaker it is quite straightforward to limit the power (DP control system) and cut back the power of the azimuth thrusters because they have frequency drives.
- 3.8.3 These arrangements are satisfactory provided there is no risk of incorrect or missing data that can:
- Prevent a cut when one is needed
 - Cause a cut when one is not needed
- 3.8.4 If operating with two DGs on line (1 + 1 open) and one thruster went to full power, there is a chance of overload and blackout on that side. The other side would have to recover the position and heading excursion, which would not be possible until the second DG, started and came on line and then it might be too late.

3.9 Engine Room Fire

- 3.9.1 DP Class 2 does not require separate engine rooms but the risk of an engine room fire is much higher than the risk of fire in other spaces and close attention is needed to ensure prevention, and prompt detection and extinguishing a fire in the event that one occurs.
- 3.9.2 The system on this vessel is designed so that no single fault can cause a false shutdown. The CO2 relay box has two independent power supplies and additional switches added to the release boxes power distribution.

3.10 Main Switchboard

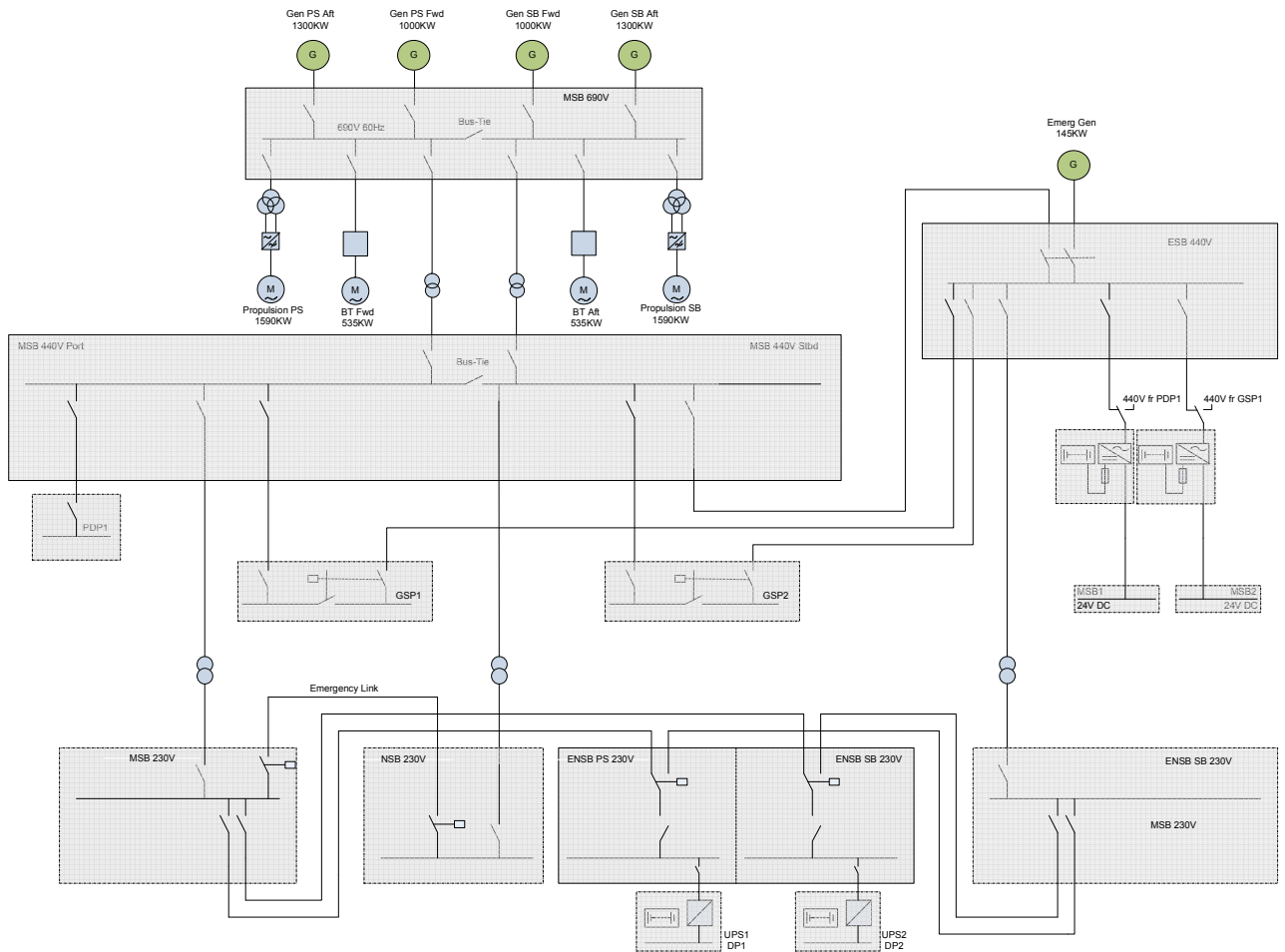


Figure 5: Electrical Distribution System (Ref drawing 300144-400_000-GRS-001 Single Line)

3.10.1 The main switchboard is 690V 60Hz and can be split by a single bus-tie breaker. This will be normally open for DP2 work so that any fault should be restricted to the failure of just the port or starboard side of the switchboard. There are many faults that can cause the loss of the switchboard and these are listed below:

- short circuit
- loss of excitation on one diesel generator
- trip of one diesel generator and overload of second
- trip of both diesel generators (fuel oil)
- AVR fault with one diesel generator that causes loss of both
- PMS fault with one diesel generator that causes loss of both.

3.10.2 The number of causes is not as important as the frequency of their occurrence. All of the above have taken place in the past on other vessels. Only the first is an unavoidable blackout, the others should not occur even though the effect should only be the loss of half the power and thrust.

3.11 440V Switchboard

- 3.11.1 The main 440V switchboard is also in two sections with a single bus-tie breaker that is normally open whether the main switchboard is open or closed. Each side is powered via 1400kVA transformers. The consumers of each side of these two switchboard sections are primarily related to the port side or starboard side as appropriate. Exceptions occur for the air conditioning units and the third pump where a common stand-by is available for both port and starboard sides. The three seawater pumps are cross-connected with manual valves in between. This arrangement is satisfactory provided the common stand-by is used when DP is not required (for example) so that the running hours and planned maintenance can function and leave the port and starboard units available for important DP operations. AC1 is only for the Wheelhouse and the Bridge Void as the ECR has its own AC-unit.
- 3.11.2 The engine room is supplied by two, two speed fans. In normal operation, they are run at slow speed. In the event of failure of one, the speed of the remaining fan is increased to high speed, which has been proven to provide ample air for the engines. Failure of one side of the 440V board will also fail half the ventilation to the engine room, the azimuth thruster room and the bow thruster rooms. If the engines are still running then a temperature, rise may occur but the rise will be slow and there will be enough time to cease the work and reach a safe situation.
- 3.11.3 The air conditioning systems critical to DP function, are located on the bridge and ECR. The air-handling units for these systems are cooled by the three chiller plants located in the ER. Any one of the three chiller plants can be used for the bridge or ECR AC systems. Both units are fitted with spare fan motors and if the control system fails, manual operation of the control valves is possible. Disintegration of the fan would be a problem until it was replaced. To keep working a portable fan could be employed otherwise the work could be terminated until the repairs were made. There should always be time to safely terminate the work. The particular failure mode that has been experienced is loss of AC followed by condensation on cold surfaces of the DP control systems and failure. Failure of the AC is alarmed and the motors for the system are supplied from both switchboards.
- 3.11.4 On failure of the port 440V switchboard, the AC1 air handling motors can be switched over to be powered by the starboard switchboard but there would then be inadequate power to continue to run AC2 and AC3. The cooling unit in the ECR is powered from the starboard board normally so that would continue.
- 3.11.5 Should the starboard 440V switchboard fail the cooling unit in the ECR can be switched over to the Emergency Switchboard. However, as this is normally supplied by the starboard main switchboard it will rely on the Emergency Diesel Generator starting and running to remain operational. AC2 and AC3 units will fail anyway in this case because they are powered from this switchboard. These units supply the main deck and accommodation.
- 3.11.6 The Emergency generator is independent and supplies the emergency 440V switchboard when the normal supply from the starboard 440V board fails or is unavailable. The 440V Emergency Switchboard supplies the following consumers:
- Port & Starboard azimuth No. 2 steering motors
 - PS propulsion converter aux. supply
 - Emergency fire pump
 - Bilge/ballast pump
 - 440V Supply to 24V MSB1

- HiPAP hoist motor
- Back-up supply to GSP Nos 1 & 2
- HVAC CP ventilation

3.11.7 The Emergency 230V board is supplied from the Emergency 440V via transformer and supplies the following consumers:

- Lighting circuits
- PA System
- Praxis UPS
- HiFog detection panel
- Ku band UPS
- Fire Dampers
- CO2 relay boxes
- Speed log
- Fuel/Ballast control systems
- Service air system & drier
- DP Traffic Lights

3.11.8 There are also two supplies to back up the port and starboard main switchboard supplies for DP, (see below).

3.12 230V Switchboards

3.12.1 The 230V switchboards are separated and normally not joined when the thrusters are in use. They are supplied via transformers from the port and starboard 440V switchboards. In principle, the consumers are split in line with the port and starboard separation for engines, thrusters and DP in general. The distribution panels of interest are listed below:

DISTRIBUTION BOARD	SOURCE(S)	CONSUMERS
NLPD 1	230V Starboard	Single beam echosounder Multibeam echosounder Praxis AMCS Client 2 PC
NLPD 2	230V Starboard	Ships LAN
NLPD 3	230V Port	Single beam Than A unit Elec cab fwd bow th* Elec cab aft bow th*
NLPD4	230V Port	Praxis AMCS client 1 PC
ENSB PS	230V Port or 230V Emcy. (change over)	DP1 UPS charger DP1 Gyro1* Wind sensor 1 JSO 1 GYRO 3* Fire detection panel Echosounder

ENSB SB	230V Port or 230V Emcy. (change over)	DP2 UPS charger DP2 Gyro 2* Wind sensor 2
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* ALSO 24V DC BACKUP.

- 3.12.2 Both DP1 and DP2 systems have dual supplies from the port 230V DB and the Emergency 230V DB. Normally, DP1 is supplied from port 230V supply and DP2 from the Emergency 230V supply. In order to avoid the possibility of both DP UPSs being supplied from a common source, the DP checklist should include the correct configuration of the supplies to the DP consumers.

Failure Mode	Cause(s)	Effects	Comment
Loss of 230V ESB	440V/230V transformer 440V ESB power 690/440V transformer short circuit 440V short	UPS to batteries Alarms Both wind sensors lost JSO 1 & 2	Emergency generator will take too long Changeover will not prevent loss of equipment

- 3.12.3 Several of the critical items of equipment not only have UPS supplies but also have separate 24V back up supplies so if the UPS batteries are found to be inadequate when the charger fails power will not be lost.

3.13 24V Systems

- 3.13.1 There are two separate 24V DC supply systems, MSB1 located in the bridge void space and MSB2 located in the engine room. These supply two further 24V distribution panels. Both switchboards have a manual changeover switch allowing supply to be taken from either the port or starboard 440V MSB. These switches are clearly marked to avoid the possibility of the two systems being supplied from the same switchboard.

The PMS units however are also supplied by local transformer rectifier units from the diesel generator, once it is running, via a 690/230V transformer. This also supplies the Woodward 723 digital controller for the generator. When the generator is not running, the system is powered from the 24V board. The board is diode protected from the generator supply. The board is normally powered from the bridge charger rectifier and/or batteries located on the bridge. The charger is powered by the Emergency 440V switchboard with a changeover to port.

24V Switchboard	Supply	Distribution Panels
MSB1 (bridge)	PDP1 Q1 (normal)	DP24V (engine room)
	ESB 440V	TLDP1 (bridge void)
MSB2 (engine room)	GSP1	TLDP2 (O/S Galley)
	ESB 440V (normal)	TLDP3 (hold fwd.)

- 3.13.2 There is adequate redundancy in supply but nevertheless a risk of a mistake exists because both systems could be powered from the same switchboard (port or emergency) so that if the switchboard fails it would leave much equipment on batteries. The use of DP checklists prior to commencing operations will ensure that the systems are properly configured.

3.13.3 The following is a list of 24V consumers and their associated power supplies:

EQUIPMENT	SUPPLY 1	SUPPLY 2
Gyro No. 1	MSB1 24V	DP UPS No. 1
Gyro No. 2	MSB1 24V	DP UPS No. 2
Gyro No. 3	MSB1 24V	ENSB SB
DPC 21 A	DP UPS No. 1	
DPC 21 B	DP UPS No. 2	
DG1 PMS (PS FWD)	DP24V	Local when DG Running
DG2 PMS (SB FWD)	MSB2 24V	Local when DG Running
DG3 PMS (PS AFT)	DP24V	Local when DG Running
DG4 PMS (SB AFT)	MSB2 24V	Local when DG Running
BT1 Electronic Cabinet	NLDP3	DP 24V
BT1 Alarm Unit	DP 24V	
BT2 Electronic Cabinet	NLDP3	TLDP2
BT2 Alarm Unit	TLDP2	
Azimuth Thruster BCU Master	TLDP1	
Azimuth Thruster BCU Slave	TLDP2	
PS Azimuth Thruster ACU	MSB1 24V	
SB Azimuth Thruster ACU	TLDP3	
ECR Azimuth Control Unit	TLDP2	

4. THRUSTERS

4.1 DP Capability

- 4.1.1 The generator capacity shows that the stern azimuth thrusters might not be able to work at full power when one side of the power plant fails. This limitation however may have very little impact on the DP capability because the vessel is unlikely to work in weather conditions that require full thrust on one stern azimuth thruster. The DP capability will be controlled by the bow thrusters. If the vessel is working head to weather then the loss of the forward bow thruster will be very limiting. The vessel will have a better DP capability stern on to the weather but this might make the after deck too wet. When the weather is from more than 30° on the bow the power in the thrusters aft cannot be used. However, significant project equipment on the after deck is also unlikely to reduce DP capability significantly.

4.2 Bow Thrusters

- 4.2.1 The bow thrusters are supplied by Rolls Royce (type TT1660 DPNCP) and are driven by 690V AC motors at 1800 rpm. They are controllable pitch with hydraulic power packs to change the angle of the blades from full starboard to full port in 18 seconds. The propeller speed is 374 rpm and the calculated thrust is 85kN each. They have radial lip seals of the 3-ring type, which enables pressure control, and drain connection/leakage detection, which is very important for thruster management. The seal material is 'Viton Super lip' running on a ceramic-coated stainless steel liner. A rope guard is mounted on the gear housing to protect the seal.
- 4.2.2 The hydraulic power pack comprises a tank, filter; cooler and two pumps; one duty and one stand by with an automatic change over if one fails or if there is low pressure. Loss of pressure will cause loss of control and the drive motor should trip. There is also a gravity tank that provides the positive pressure against the seawater the other side of the propeller seal. This pressure should account for static head at the maximum plus a margin for motion. The filling of the system is important so that air is not trapped in the system and the head as a result is inadequate. Failure of bow thrusters from seal failure is however unlikely to cause a thruster to trip before other warning signs and it is unlikely that both fail at the same time.
- 4.2.3 One bow thruster can fail from a number of causes as shown below but the effect should always be acceptable if the vessel's capability was not being exceeded. The assessment of the safe working limit will always be for the operator to decide because the consequence analysis warning may well come several minutes after the limit has been exceeded. The normal feature of DP control systems for mono-hulled vessels is for the bow thrusters to be used together and for high levels of pitch to be used for short periods to counter the effect waves have on heading. This feature called 'heading priority' is very necessary so heading is not lost say 10° and is then not recoverable because of the sequence of waters experienced. Therefore, the thrust demands of the two bow thrusters could be at 100% for brief and isolated periods and at 20-30%

otherwise. In these circumstances, it is difficult to assess whether it is safe to continue operations, however normal DP practice would be to alter the heading to reduce thruster demand or consider stopping DP operations when the thrust demand from the bow thrusters exceeds 80% for more than brief or isolated periods.

Failure Mode	Cause(s)	Effects	Comment
Loss of one BT	Electrical fault Hydraulic fault Overcurrent (motor) Low oil pressure Wire rope in tunnel Mechanical damage Control fault	stop	Other BT
Bow thruster to full pitch	Feedback fault Valve stick Control fault	Operator must stop if no overcurrent	Critical to DP
Unstable pitch	Control fault - pot - amp - earth	Degraded performance	Difficult to detect

- 4.2.4 The worst failure mode is failure to full pitch especially if this happens on the forward of the two bow thrusters because all the thrust of the after unit will be consumed to counter the turning moment unsuccessfully. The causes are electronic, mechanical or hydraulic. Some vessels use two feedback potentiometers and freeze pitch if there is a difference. Pitch can also be frozen if the pitch movement does not follow as expected but there is always a delay in such checks and it is better to have no thrust than unwanted thrust.
- 4.2.5 In a 1 + 1 DG arrangement, one bow thruster moving to full power risks overload to the one diesel generator unless reduction can be made on the stern azimuth thruster fast enough. This may release enough power to trip the bowthruster on overcurrent. However, the remaining healthy bowthruster will then be at full pitch to recover the loss in heading.
- 4.2.6 If the feedback linkage breaks or a hydraulic valve sticks that, the resultant full pitch will cause overcurrent and the tripping of the drive motor. This is satisfactory. If the pitch freezes and the alarm is given on the DP, the operator should stop the thruster motor completely and not just deselect it from DP. This is because the thruster, even though deselected from the DP, continues to run, resulting in loss of heading even when the command signal is zero
- 4.2.7 Unstable pitch can occur from worn parts or maladjusted potentiometers. Similarly, poor adjustment of the zero pitch can make starting currents much higher. The start system is interlocked so that two generators must be running and fans running on high speed before the bowthruster can be started. As mentioned previously, the DP capability is not degraded much (in practical working terms) from the loss of one azimuth thruster but is from the loss of one bow thruster.

4.3 Azimuth Thrusters

- 4.3.1 The stern thrusters are not CPP but fixed pitch with variable speed frequency drives. The propeller and azimuth controls are supplied by Rolls Royce, as are the bridge and engine room panels. A 440V mounted steering motor (independently fan-cooled) provides azimuth control. The steering motor serves to rotate the azimuth thruster to the required heading. Failure of the feedback signals can be detected and alarmed before serious misalignment takes place however, a misalignment of up to 45deg is possible which causes a position excursion until the thruster is stopped or the error is compensated for by the integral term of the DP controller. There is only one feedback to the DP control system and a separate feedback to the Aquamaster control unit. The feedbacks are sin and cos.
- 4.3.2 The azimuth thrusters can be used for steering (auto track and autopilot) either together or individually. When in DP there should be restricted zones so that they are efficient and do not interface with each other. Maladjustment of these zones can cause position instability particularly in rough weather. The DP control system will generally always rotate these thrusters to use ahead thrust but when a rapid change of thrust direction is needed, they may rotate astern. The logic used was tested on trials to show that it is optimised for DP and crash stops and found to be satisfactory.
- 4.3.3 Failure of one azimuth thruster when on DP is not critical. There are alarms for all the parameters of interest like water temperature for the water/water heat exchangers (from the vessel's fresh water cooling system) and water leakage within the converter cooling system and water flow and pressure. There are indications and alarms for winding temperatures, motor current, power and control system faults. However, the items that are important to DP control are those used for control because it is essential that unwanted thrust is not developed.
- 4.3.4 The speed demand from the DP (or RR panel) is sent to the azimuth thruster converter's PLC, which executes the command and receives the feedback from the motor from the incremental pulse tacho. This comprises 2HTL encoder signals shifted 90deg so the direction can also be known. There are 1024 pulses per revolution and it is essential that this feedback does not fail or give incorrect data. If this happens unwanted thrust and a position excursion will occur.
- 4.3.5 The other failure mode that is potentially critical is the power chop to prevent blackout should a diesel generator trip for example. The PMS has serial communications with the drive converter PLC but the critical speed signal is hardwired and there is an analogue back up. When power chop is calculated to be necessary (true or false diesel generator trip signal) a single contact opens and the output power of the thruster drive is reduced to 200kW irrespective of speed. After the chop has lasted 3 seconds, the contact is closed and the analogue (4-20mA) signal should give the drive the appropriate amount of chop.

Failure Mode	Cause(s)	Effects	Comment
Drive motor trip	Mechanical fault Electrical fault Lack of cooling	Reduced DP capability	
Converter fault	Mechanical fault Electrical fault Lack of cooling	Reduced DP capability	
Speed control fault	Wire break	Unwanted thrust	Small position excursion if stopped quickly
Lube oil pump fail	Electrical fault Mechanical fault	Alarm only	
Hydraulic motor fail	Electrical fault Mechanical fault	Reduction rotation speed	Azimuth feedback difference alarm
Azimuth feedback fault	Wire break	Thrust in unwanted direction	Alarm and operator can decide
Unwanted power drop	Wire break	Small position excursion	Alarm and operator can decide
Loss of control air	Leak or reducer fault	Reduced seal pressure	Water ingress and costly damage
Power chop too late	Hardware or software fault	Blackout one 690V board	Small position excursion if safe Limits not exceeded

4.3.6 The azimuth thrusters have several control locations. They each have local controls, there is a control board in the engine control room plus aquapilot control panels and there are control units, interface units and three control lever panels on the bridge plus the DP and autopilot. The independence of these units was verified on trials, confirming that when in DP none of them should be active and no single fault or act of maloperation should make them so. The interpretation of the latter point has to be reasonable. This means that maloperation has to be a mistake rather than an action to cause a problem deliberately and this is unlikely, as the permit to work system does not allow any work to be undertaken on critical systems during DP operations. Simple faults can include wire break, shorts and earth faults.

5. DP CONTROL SYSTEMS

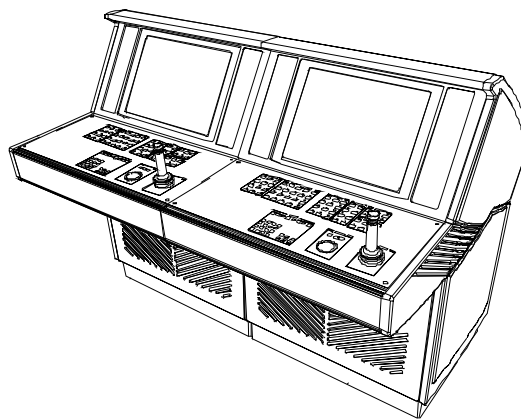
5.1 DP21 Computers

- 5.1.1 There are two independent but linked microprocessors (Single Board Computer – SBC based on Intel 960 RISC processor) which take the input data received from a range of sensors using a master/slave relationship and generate the signals to the thrusters required for position and heading control. The system for the console computers is a Windows TM NT – 32-bit operating system but this is just used for display purposes. The actual control is executed by the computers (SBC's) in the Kongsberg computer cabinet located in the void space beneath the bridge.
- 5.1.2 The two (DPC) computers operate in parallel each individually receiving input from sensors, reference systems, thrusters and the operator and performing the necessary calculations. However, only the on-line computer (master) controls the thrusters. Switchover between the computers (master/slave) may be either automatic or manual. It is automatic if failure is detected in the on-line computer. Continuous comparison tests are performed to check that the two computers read the same inputs and give the same outputs. If a difference occurs, warnings and alarms are reported from each computer. The weak point in a dual redundant system is the ability to determine which computer is wrong. The operator therefore could choose the wrong one. In practice, this difference is rare.
- 5.1.3 To meet DP Equipment class 2 at least three position references must be available, whereby the system can exclude a failed or degraded position reference and still keep position. This vessel is configured with four different position references i.e. DGPS, HPR (Simrad HiPAP), a taut wire and an MDL Fan Beam. During the DP trials, the fan beam was not available, but it had been commissioned earlier during customer acceptance trials. It will only be hired on a project basis. The Consequence Analysis warning does not take position references or sensors into account but reacts purely on low power availability or insufficient thrust (thrusters and generators).
- 5.1.4 Both computers and all interface boards are located in the upper cabinet whereas power supplies are sited in the lower cabinet. Although the CPU's and the power supplies are separated, the interface boards are serial linked with both computers connected to each board. There are analogue boards for the thruster, MRU signals and digital boards for other data. There are two separate cards, one to handle all inputs and one to handle all outputs. Each will have galvanic isolation so no single fault can degrade more than one system.
- 5.1.5 All the above mentioned boards are connected to both power supplies with failure detection on each interface board. In case one board detects a problem with the power supply, all boards switch to the standby power supply. The downside of this arrangement is that a fault on one could fail both.

Two Power Supply Units (PSU) are mounted to the computer cabinet. Their function is to generate a stable reference voltage for the potentiometers used for the feedback signals.

- 5.1.6 A 'redundant' Ethernet is installed between both computers and the operator stations. In case network A fails, B will take over and vice versa. However, each has the same data and same software so if the on-line net is overloaded so too will be the backup. It is important that this cannot happen.
- 5.1.7 The SDP system has only very basic features for hardware error detection of the interface and the network hardware. The operator has to be extremely experienced in order to identify the problem when an error occurs and take the necessary corrective actions in time.
- 5.1.8 To take command of the thruster in DP a changeover switch is located on the forward bridge. It is directly hardwired to each thruster controller and a single failure of the switch should not be able to disconnect more than one thruster from DP.

5.2 Operator Consoles



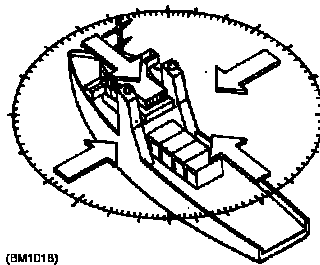
Courtesy: Kongsberg Simrad

- 5.2.1 Three operator stations (OS) with similar consoles are installed on the bridge and they all have the same functionality including a joystick. OS1 is located on the bridge forward midships, while the other units are located on the bridge aft, to port and starboard.
- 5.2.2 The 230V power supply to the consoles OS #1 and OS #2 comes from UPS 1 and UPS 2 respectively. Each OS is also supplied with 24V. The 24V is fed from the 230V via a 230V /24V converter. The screen of each console is divided into one large area on the right and two smaller areas on the left and the size of these areas cannot be changed. Each of the areas can display a separate page of information, which can be selected by the operator.
- 5.2.3 Alarms are displayed when the "Alarm" button on the keypad is pushed. All the alarms are presented on an overlapping window on the screen of the console where the button is pushed. When an operator has to input information this is also done using overlapping windows, which always show up at the same location on the screen. The cursor is positioned directly on the input window. The pointer can be

moved using a trackball and selections are made using one of the three buttons in front of the trackball.

- 5.2.4 Colours can be selected from different palettes (e.g. Daylight, Dusk and Night). The 'Night' palette has different colours and easy to split information and commands can also be made using the push buttons but they all look alike. No colours are used to distinguish functions but they do have text and when a button is pushed an indicator light will illuminate showing the function has been selected. Critical buttons are double push non-critical buttons are single push. Therefore, surge, sway and yaw for example are double push.

5.3 DP Control Modes Functions



Courtesy: Kongsberg Simrad

- 5.3.1 The standard DP control modes are implemented which are standby, manual (joystick) and auto position. Mixed modes between manual and auto give automatic control of heading, X-axis and Y-axis either separately or combined. When all three are selected an automatic switch to auto mode is made. The system has in addition 'High Precision Control', 'Relaxed Control' and 'Green Control'.
- 5.3.2 In principle, these modes are promoted to reduce thruster wear and use less fuel. Generally, operators experiment with modes and gains and then use only a few combinations. Other modes include Auto track (low speed) Waypoint Table Management linked to ECDIS and fixed and variable azimuth mode.
- 5.3.3 The wind, gyro and VRS/MRU sensors used by the DP system cannot be directly selected from the keypad. Instead, a dialogue box on the screen is used where the sensors have to be enabled and the preferred sensor has to be selected. On the keypad, a button only controls whether the gyro, VRS/MRU and wind inputs are made available to the DP control system.
- 5.3.4 The management of position references is of primary importance because the DP control system acts immediately on position error and, for good position performance, needs new data at one-second intervals. Clearly, there is a need to:
- filter noise
 - determine the relative weight of each
 - correct for vessel motion (roll and pitch)

- 5.3.5 To help the above process a Kalman Filter uses the mathematical model of the vessel to predict the position excursions of the vessel that are reasonably possible in the conditions sensed over the last 10 or 20 minutes. It is self-adaptive so reducing the noise of the position (and heading) inputs. It can increase reliance on the model when the position references are poor. It can also provide 'dead reckoning' when there are no position references accepted and calibrated thus providing a "fill-in" while another position reference is made available. It is essential that the tuning of the Kalman filter is correct so that it improves performance in all conditions not just some environmental conditions. It is most useful when the conditions are marginal and these conditions are really needed for the trials.
- 5.3.6 DP consequence analysis must be selected when undertaking DP 2 work. The analysis provides a warning to the DPO. Checklists should be used to ensure the analysis is running when undertaking DP critical work. The analysis however should not be relied upon because it takes three consecutive calculations over three minutes all to say 'failed' before a warning is given. So safe working limits can be exceeded for some time, even 15 minutes before the operator is warned; a good operator is therefore better than this analysis. The facility works well when there is a steady increase of environmental load from current. It does not work well in squalls.

5.4 Motion Sensors

- 5.4.1 There are two motion sensors of the type Seatex on board, one MRU-H (MRU1) and one MRU-5 (MRU2). Both MRUs are used as sensors to the SDP. MRU 2 is also directly used for the HiPAP and both are used for MBES. The MRU system uses solid-state device to measure the roll, pitch and heave rate. Integrating these signals gives the roll, pitch and heave measurements.
- 5.4.2 The MRUs are powered from the DP system. MRU1 is supplied from the DPC and MRU2 is supplied from UPS2. The MRU data is fed as $\pm 10V$ dc signals. Loss of these signals from these inputs will cause an alarm in the DP consoles once failure is detected but this is difficult if there is little motion and the vessel is not inclined.
- 5.4.3 When the measured antenna or transponder position is corrected erroneously with wrong inclination data, the DP system will react and degrade the station keeping. A slow drift of the input is dangerous because it will not be immediately detected. When the difference between the two units exceeds a pre-set limit (1deg), an alarm is given and it is up to the operator which VRS to select as input to the DP system.
- 5.4.4 The HPR default setting is MRU 2 so if this unit has a fault so does the position data from the HPR. If MRU 2 is also selected as "preferred" then all position references will have a fault: the effect of this is a degraded position performance at best and a drive off position at worse. However, there is a way of switching over to MRU 1 in the software by means of manual selection. It is still advisable the Checklist should make MRU1 preferred so that the DGPS and Fanbeam (when fitted) are corrected by a different MRU (MRU1) to HPR (MRU2).

5.5 Gyro Compasses

- 5.5.1 The vessel is equipped with three gyros; all three are the same type (Navigat X MK1, Mod 10-4914). The gyros are located in the void space beneath the bridge. All of the gyros are interfaced to the SDP 21 and the operator must select the preferred gyro. No.1 gyro is used by the HPR. In this case, another gyro must be selected as preferred because the fan beam and DGPS may not be given a unique gyro input and will provide relative fixes to the DP control system.
- 5.5.2 The gyros are treated in a similar way to the position references but because they are the same their characteristics will be similar and the identification of a rogue gyro more easy. The chances of a common fault failing all three gyros is negligible: they all have separate power supplies.
- 5.5.3 The difference alarm should be set at 2 deg. The output from these gyros is also quite secure (serial line NMEA-0183) and loss of this connection is immediately alarmed. Only the slow drifting of the preferred gyro when only two are available presents a DP hazard but the vessel is no longer DP2 in this condition.

5.6 Wind Sensors

- 5.6.1 Both wind sensors measure the wind speed and direction, which is used in the DP mathematical model to calculate the thrust needed to balance this force. This is added to the thruster allocation logic immediately to compensate for the calculated wind force (wind feed forward). Both wind sensors are placed on the navigation mast (forward & aft positions) above the main bridge. Both units are supplied from UPSs (wind sensor 1 UPS2 F8 and wind sensor 2 UPS1 F9) and both should be enabled whenever possible. When both units are enabled difference, alarms are generated for wind speed and direction to alert the operator of a mismatch. This feature can be a nuisance at times but it is better than having just one selected because a failure in speed or direction can cause a position excursion and degrade the DP mathematical model. Complete loss of the wind speed signal (RM Young wind sensors) when there is some wind, > 5 knots will cause an alarm. However, loss of the direction feedback can cause an acceptable (to the DP) shift and a sudden unwanted increase in thrust.

5.7 Hydro Acoustic Position Reference (HPR)

- 5.7.1 The HPR system is named "HiPAP" ("High Precision Acoustic Positioning") and is designed for water depths from very shallow to deep-water (2000m) looking straight down with a standard unit. The transducer extends below the hull through a gate valve and comprises a semi-spherical transducer with over 220 elements. Electronic controls nearby within the vessel enable beam directional transmission and focused reception in the direction of the transponder, thus improving the signal to noise ratio. This is important because the base line is very short (only the distance of the head itself).
- 5.7.2 The system calculates the subsea position of a transponder relative to the vessel mounted transducer unit. The directional stability of the unit is obtained by firstly fixing the transponder location by a wide beam and subsequently narrowing the reception

beam towards the transponder. The system uses a digital beam form, which takes its input from all the transducer elements. The system controls the beam dynamically so it is always pointing towards the target, 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.

- 5.7.3 The system calculates a variance for its measurements, determines the system accuracy and standard deviation. The HiPAP has a built-in Kalman filter, which improves the stability and accuracy of the initial narrow beam optimisation but does not interfere with raw data being sent to the DP control computers. Raw data should be used because filtering causes a lag, which can cause instability.
- 5.7.4 The transducer is directly hardwired to the HiPAP OS. The system is supplied 230V from UPS-2 and the transducer hoist system is powered by 440V AC from EDDP1 for safe recovery in blackout scenarios and is supported by emergency generator changeover.
- 5.7.5 The performance of HiPAP is also dependent on the gyrocompass and the MRU. This is a weak point, as the reference is dependent on both the MRU and gyro. The HiPAP is, however, a single reference in a vessel with four position references and a backup DGPS. There are many failure modes of this system but the majority are detectable either by the system itself or by the DP control system. Failure Modes that are a risk because they are not detected are:
- reduced performance (failure of some of the heads)
 - lost transponder(s)
 - dragged transponders when tethered on wire or rope loss of signal and/or refraction
 - noise from thrusters and/or other vessels.

The performance was bench marked on trials so that an initial value was established and can be verified several times on an opportunity basis so that any reduction in performance can be quantified.

All vessels approaching should be warned if acoustics are being used. They should switch off echo sounders if they operate close to the frequency being used by deployed transponders.

- 5.7.6 Noise interference is also a problem when working in heavy weather; noise turbulence and vibrations will cause occasional signal loss. The extent to which this is a problem will depend on the machinery noise and current. If operating with only DGPS and acoustics, failure of the DGPS can cause increased thruster activity that in turn causes loss of the acoustics and a loss of position to take place.
- 5.7.7 Transponder battery failure can also be experienced at any moment. If only one transponder is deployed, a single failure will disable the HiPAP. Again, on this class of vessel, this failure is not dramatic assuming good quality satellite reference and fan beam data are available. A log of transponder battery use should be carefully kept.
- 5.7.8 Online help is provided within the HiPAP software and the Operator can access this valuable feature whilst in operation. The help format follows similarly from that provided

in the SDP software, being indexed alphabetically or in groups. Help for both HiPAP and SDP follows the Microsoft Windows conventional interface and is simple to operate.

5.8 DGPS

- 5.8.1 The vessel is fitted with four DGPS, three of which are dedicated for DP use only. DP DGPS No.1 is a Subsea 7 Veripos system receiving differential corrections simultaneously from Spotbeam and Inmarsat communications satellite. DP DGPS No.2 is a Litton MX420/8 receiving differential corrections from coastal MF stations. DP DGPS No.3 is a C-NAV 3050 receiving differential corrections from Spotbeam. All these three DGPS are interfaced with SDP21 system using NMEA-0183 serial line. The fourth DGPS is a Litton LMX420/AIS and is used for navigation systems and not connected to the DP.
- 5.8.2 The Global Positioning System (GPS) is a highly accurate, satellite based navigational system, which permits a land based object to fix its geographic position using Doppler phase shift techniques. In order for the Earth station to calculate the fix position, a minimum of three transmitting satellites (above its radio horizon) is required.
- 5.8.3 By calculating the naturally occurring error at a known location, it is possible to obtain a differential correction figure, which can be applied to mobile offshore stations using the GPS system. This technique, known as Differential GPS (DGPS), enables the precise fixing of a vessel's position with sufficient frequency for it to be used as a position reference for DP operations. This technique improves the position accuracy of the GPS system to within metre accuracy.
- 5.8.4 The antennas for the GPS system and the differential corrections are distributed to different locations on the wheelhouse roof. The difference in antenna locations is to ensure that they will operate with different satellite constellations. The DP operator will need to ensure that they operate with different correction signals. The differential signals should be input into the DGPS from two different sources.

5.9 DGPS Failure Modes

- 5.9.1 Possible failure modes for the DGPS are:
- GPS signals blocked by structure
 - Reception of reflected signals causing range jump
 - Reflected signals may combine with direct signals and cause fading or signal loss
 - Loss of correction signal.

The performance was bench marked on trials and it was confirmed that no shadow areas existed. When the vessel is operating within the 500m zone of a large installation this will need to be verified.

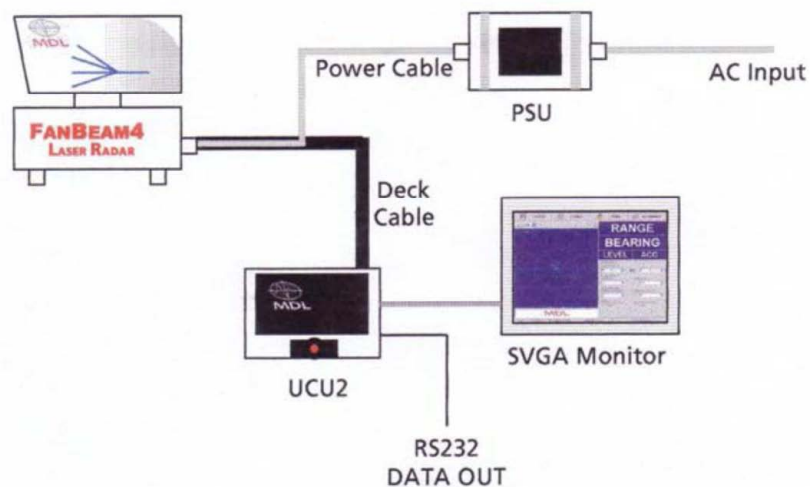
5.10 Fan Beam

- 5.10.1 The vessel has an interface for an MDL fan beam. A Fanbeam Mk4 was fitted and commissioned in Nov 2012 for a new vessel contract. The Fanbeam is a laser based position reference system, which can input the vessel's relative position from a fixed structure, into the DP system, to be used in conjunction with other position reference systems. This system is fed directly from 230VAC UPS 2 (PDU 2).
- 5.10.2 The system uses the principle of laser range finding by measuring the time taken for a pulse of laser light to travel from the laser source to a target and back to the detector. The requirement to have an accurately pointed laser transmitted from a moving platform to a stationary target is achieved by using special laser optics, which transmits a laser beam in a 20° vertical fan. By scanning this fan horizontally, the target can be accurately tracked and have its bearing relative to the vessel's heading and range determined. This information is then inputted into the DP system.
- 5.10.3 A pulse generator drives the infrared semiconductor laser diode at a rate of 7500Hz to produce the 20° laser fan. These light impulses are adjusted for the line of sight and emitted by the transmitting lens to produce a vertically diverging and horizontally parallel beam. The reflected beam is picked up by the receiving lens and converted to an electrical signal by a photo diode. The time interval measured between the transmitting and receiving of the beam is used to compute the range.
- 5.10.4 The accuracy of the horizontal angle is achieved by detecting every echo from the laser and reading the echo for each echo. Once the laser has passed over the target, the angles are averaged, providing an angle to the centre of the target. Therefore, accuracy is not dependant on target size. The echo signals are averaged to increase the range accuracy. To achieve a range accuracy of +/-20cm at least five echoes are required from the target.
- 5.10.5 The scanner is mounted on a rotating table which is driven by a stepper motor and a precision worm and wheel that results in a resolution of 0.01°. A high accuracy optical encoder mounted directly on the laser shaft measures the angular position of the laser.
- 5.10.6 The scan speed is automatically controlled by the system software according to the target range with parameters seen in the table below:

Target range (m)	Fanbeam Speed (°/sec)
<100	50
100>250	30
250>500	15

Fanbeam Scan Speed

- 5.10.7 The Fanbeam is only effective as a position reference system within approx. 250 metres range of the target.
- 5.10.8 The equipment configuration can be seen below.



Fanbeam configuration

- 5.10.9 The scanner is located in such a position that it allows a clear line of sight in all directions where the targets are to be installed.
- 5.10.10 The scanner head can rotate through 360° and has vertical adjustment of +/- 15° in 5° steps, which allows for large variations between the height of the vessel and target.
- 5.10.11 The quality and type of material used for reflectors are critical to the reliable operation of the Fanbeam. Good quality reflective tape can be used on a cylindrical mounting of no less than 150mm and no more than 250mm diameter and 100mm in length. This will give a good target up to 150m, (depending on conditions). Retro Prism will give good accuracy between 150 and 1000metres, (depending on conditions), as they can reflect the laser beam +/- 30° from the prism centre line. For accuracy between 1000 and 2000m, a stack of six prisms is required.
- 5.10.12 It is essential that the targets are mounted in areas that are clear of obstructions and away from lights and other surfaces containing reflective material, (e.g. life rafts or lifeboats). They should also not be located close to walkways where reflective strips on coveralls or jackets may cause confusion regarding which target the Fanbeam is tracking.
- 5.10.13 The system is interfaced to the SDP-21 via the universal control unit (UCU); the data is also displayed on a monitor. The target is passive, consisting of a simple reflective item installed on a nearby installation.
- 5.10.14 Disadvantages are inoperability in bright sunshine or with heavy rain and fog, bright lights near the target or other reflective items. Power loss will require resetting of the system. The assembly has to be installed in a protected location as rain and salt spray might obscure the lenses and affect the operations (see IMCA report M 131, "Review of the use of the Fanbeam laser system for dynamic positioning"). As the maximum range of the system is, 2000 meters it can be used only when operating near an installation.

5.11 Failure modes of the Fanbeam

5.11.1 The possible failure modes of the Fanbeam are:

- Signals can be blocked by dirty transmitting, receiving lenses or physical obstacle.
- The acquisition of false targets, e.g. reflective tape on working gear, lifeboats etc.
- Signals can be distorted by a low rising or setting sun.
- Inclement weather, e.g. heavy rain, snow or fog can reduce system efficiency.
- Frozen range or bearing.
- Jump in range or bearing.
- Intermittent signal.
- Loss of power supply.
- Loss of serial line to DP control system or Fanbeam processor failure.
- Loss of encoder feedback.
- Seizure or malfunction of scanner head.

5.11.2 Signal blocking will not occur due to a dirty lens provided the Fanbeam recommendations for regular cleaning are followed. Signal blocking by other means must be avoided by careful placement of the reflector and following operational procedures. However if blocking occurs, the Fanbeam will be rejected by the DP control system and an alarm given.

5.11.3 Intermittent signal blocking might occur during heavy precipitation or fog. This would affect the DP if there is not a clear failure, however, the Fanbeam's range checks will detect this and reject the target. Also the target can be lost if it is obscured by dust, fog or smoke.

5.11.4 Fanbeams have been known to lock onto false targets such as reflective jackets, etc. on personnel. The DP control system's median check will reject a false target, as it will cause the Fanbeam to diverge from the other reference systems.

5.11.5 Low sun or bright lights can affect the Fanbeam; their effects though will be noticed by the level checks of the Fanbeam and the target rejected. Alongside a platform, low sun is unlikely to be a problem as the target will be masked from the sun by the platform and the vessel. Bright lights on the platform could present a problem and the operator will be aware of this.

5.11.6 Loss of power to the Fanbeam, loss of the serial line to DP control system or Fanbeam processor failure, will result in the DP timing out the Fanbeam, alarming and rejecting it.

5.11.7 Loss of control of the scanner will mean that the target will be lost or at least move outside the Fanbeam window check. It will therefore be rejected by the DP system and alarmed. The Fanbeam can be affected by a number of factors, but as long as it is carefully monitored by the operator, it can provide an invaluable and highly accurate reference.

5.11.8 It is very difficult to find an ideal location for the scanner unit, as there are always competing claims for the highest, clearest position. The scanner is likely to have a number of blind spots caused by aials and the mast itself.

5.12 Taut Wire

- 5.12.1 The vessel has a Bandak LWTW (light weight taut wire) Mk 14B installed as a position reference for shallow water. This system is an electro-hydraulic-pneumatic system that requires a 440V, three phase power supply and compressed air between 6 and 10 bars. The instrumentation uses a 230V single-phase supply. The taut wire is, as the name suggests a tensioned wire that in this case is held in constant tension by a weight on the seabed and a winch and servo system on the surface. The tension compensating system is pneumatic with air cylinders controlled by a pressure regulator. The length of the wire and the alongships and athwartships angles are measured and used for the calculation of position. Therefore, the position of the seabed weight is the position of the wire suspension point adjusted for by the wire angle and the vessel motion. The position of the vessel is determined from this after allowing for the offsets of the taut wire head position.
- 5.12.2 The taut wire has its own control system (Telemecanique TSX Micro PLC system) and local and remote control panels. The weight should initially be deployed locally but one deployed and the “mooring” is on operations of re plumbing can be executed from the bridge.
- 5.12.3 The failure modes of the taut wire are therefore as follows:
- Drag of the weight from poor tension control or operator error
 - Tension too low and poor position data
 - Air failure
 - 440V failure
 - 230V failure
 - PLC fault
 - Wire against ship’s hull and no change in position given when position is being lost
 - Broken wire and loss of data
 - Error in one pot meter or broken wire of one
 - No or wrong motion corrections
 - Incorrect wire length (water depth) giving wrong position change data.

All the above failure modes are detectable if three different position references are on line but if only two are in use a drive off is possible from a single taut wire failure. The hardest for the DP control system to detect is the failure or fault in one potentiometer as the position itself will show change but the failure in one axis might be missed and the weighting kept high. Zero change in both pots will cause immediate rejection as will a wire break. The set-up of the taut wire should always give an alarm before the ship’s side is touched but sometimes this alarm is not adjusted for a list angle.

5.13 Position References & Weighting

- 5.13.1 The vessel is provided with a wide range of position references to provide the operator with various options to ensure accurate tracking of position, regardless of exterior factors. When preparing to operate on DP it is essential, that due regard is taken of factors, which can influence the different systems.
- 5.13.2 The weighting assigned to each sensor within the DP system is determined by the operator. It is essential that three separate systems operating on different principles are employed, such as LTW, DGPS and HPR. In this way, failure of any one system will leave the two remaining units uninterrupted and the system in error will be outvoted.
- 5.13.3 When multiple units of sensor types are available, it is important that they are not given a disproportionate weighting, which could lead to a drive off.

6. COMMUNICATIONS

6.1 Bridge

- 6.1.1 The bridge is fitted with the following shipboard communication systems:
- Auto telephone
 - Talkback
 - Dive Alert System
 - VHF
 - PA.
- 6.1.2 The telephone system communicates with the engine room, all offices, cabins and internal work areas of the vessel.
- 6.1.3 The talkback system allows communication from the bridge to the engine control room and thruster rooms.
- 6.1.4 The dive alert system is fitted to the bridge, engine control room and the cabins of the Master, Chief Engineer and Dive Supervisor. In addition, a portable alarm panel, on a 20-metre cable is provided in the Buoy Workshop.
- 6.1.5 The VHF system communicates with the handsets provided to all duty officers.
- 6.1.6 The PA system has two operational settings, either public areas or all areas throughout the ship.

7. CONCLUSIONS

7.1 General

7.1.1 The vessel meets DP Class 2 requirements with no exceptions.

8. TABULATED FAILURE MODES

Power Generation Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Loss of one pair of engines	Fuel failure due to Fuel starvation Fuel contamination	Low	Engine stoppage	Loss of 50% of generation capacity	Minor	Other two engines supplied from separate fuel tanks, will provide adequate power to maintain DP and position.
	Catastrophic engine failure	Very low	Two engines shut down			
Mechanical Failure	Failure of engine (piston, piston rod, cylinder relief v/v, crankcase explosion, governor failure)	Low	Loss of power from one engine	Increased load on remaining generators, vessel maintains position	Minor	Minimised by good maintenance & procedures. Catastrophic engine failure could cause loss of whole engine room
	Mechanical failure of shaft between engine and generator	Low				

Power Generation Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Electrical Failure	Generator failure (windings, stators etc.)	Low	Loss of power from one engine	Possible failure of other engine on the same switchboard on reverse power	Minor	Alternate engine room will provide adequate power to maintain DP and allow the vessel reach a safe situation.
	Generator failure (AVR)	Low	Defective generator will be tripped	Running generator take additional load	Minor	Alternate engine room will provide adequate power to maintain DP and allow the vessel reach a safe situation. (see also power management)
	Loss of power to fuel injection system	Low	Engine shuts down	Possible loss of other engine if it is unable to take sudden load		

Power Generation Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Inadequate flow of sea water	Pump failure	Low	High FW temperature	Loss of one central cooler	Minor	Remaining central cooler has 100% capacity for all engines Remaining cooler takes suction from the other side of the vessel
	Air in the system					
	Poor maintenance					
	Leakage					
	Blocked intake					
Inadequate cooling	Pump Failure	Medium	Low pressure alarm start stand-by	None	Minor	Relies on stand-by starting
	Faulty control valve	Low	High diesel generator temperature	Engine S/D	Minor if problem isolated	Early warning possible Temperature rise is not sudden
	Leakage from cooler					
	Air in system					
	Failure of flexible coupling					
Loss of start air	Compressor failure	Low	Loss of engine start capability	None	Minor	Standby compressor available
	Leakage	Low		Partial loss of engine start capability	Minor	Split system

Power Generation Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Loss of service air	Compressor failure	Low	Reduction in air pressure	Loss of air to header tank	Minor	Back-up supply available from main starting air system via reducer
	Drier failure	Low	Moisture in system	Erratic operation of pneumatics	Minor	

Diesel Generator Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Excessive vibration	Mechanical damage	Low	Generator S/D	Reverse power trip	Minor	Other engine Split switchboard Engines running on low load
				Low FO pressure		
				Low LO pressure		
Overspeed	Control Fault	Low	Generator S/D	Second generator s/d on reverse power	Minor	Other engine Split switchboard Engines running on low load
Instability				Operator may shut down healthy machine in error		
PMS Failure	Power loss	Low	Loss of voltage control on generator	Generator S/D	Minor	Other engine Split switchboard
	Voltage loss	Low				
Faulty bus tie status to PMS	Wire break	Low	Tripping of breaker	Loss of one engine	Minor	Engines running on low load
	Defective breaker	Low				

Diesel Generator Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Drive motor trip	Mechanical fault	Low	Loss of thruster	Reduced DP capability	Minor	Other thrusters Low load
	Electrical fault					
	Loss of cooling					
Converter fault	Electrical fault	Low	Generator S/D	Reduced DP capability	Minor	Other thrusters Low load
	Loss of cooling					
Speed control fault	Wire break	Low	Overspeed	Unwanted thrust	Minor	Small position excursion if stopped
Lube oil pump failure	Mechanical	Low	Auto start of standby pump	Alarm	Minor	
	Electrical	Low				
Electric motor fail	Mechanical	Low	Loss of thruster	Reduced DP capability	Minor	Other thrusters Low load
	Electrical	Low				
Azimuth feedback failure	Wire break	Low	Loss of control	Thrust in an unwanted direction	Minor	Alarm & operator to decide shut down
Unwanted power chop	Wire break	Low	Reduction in thrust	Reduced DP capability	Minor	Other thrusters available
Power chop too late	Hardware fault	Low	Excessive thrust	Blackout of one 690V board	Major	Split switchboard
	Software fault	Low				Thrusters on 50%

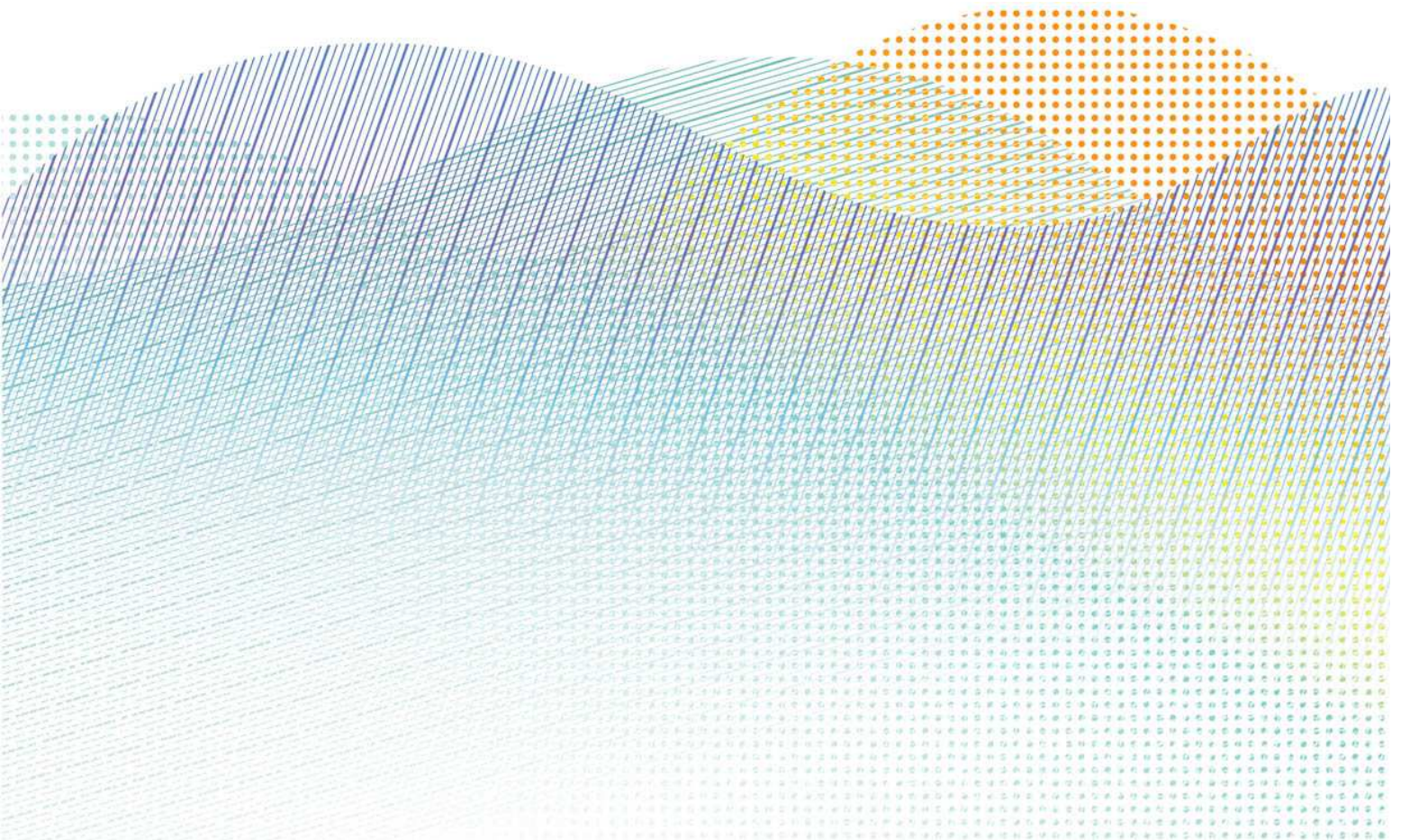
Network Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
One PMS fail	Power loss or overvoltage	Low	Generator S/D	Possible reverse power trip of other engine	Minor	Split switchboard Engines running on low load
One PMS link fail	Wire break	Low	None			
Both PMS link fail	Wire break	Low	DG operate independently	Alarm	Minor	
Failure of U42 analogue board	Internal short circuit	Low	Loss of board and feedback	Loss of T1 and T3	Major	Vessel remains on DP Position loss possible depending on weather conditions
Failure of U51 analogue board	Internal short circuit	Low	Loss of T2 & T4		Major	Vessel remains on DP Position loss possible depending on weather conditions
Loss of DPU 3 or DPU 4	Internal short circuit	Low	Loss of one DG	Loss of one engine	Minor	Split switchboard
Loss of DPU 1 or DPU 2	Internal short circuit	Low	Loss of info on 2 DG	No effect	Minor	Others only

Network Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Loss of DPU 5	Internal short circuit		Loss of info on bow thrusters	Thrusters continue to operate	Minor	

DP Control System Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Loss of UPS 1	Failure of unit	Low	Loss of output	Loss of: DPC – 21 A(PU1) SPP OS1 Fan Beam	Minor	Other DPC – 21 B takes control
Loss of UPS 2	Failure of unit	Low	Loss of output	Loss of: DPC – 21 B (PU 2) SDP OS2 HIPAP Wind sensor display	Minor	
Loss of HPR	Input failure	Medium	Prediction error, HPR deselects	Other HPR(s) functioning	Minor	
	Power failure	Low				
Loss of wind sensor	Input failure	Medium	Prediction error, wind sensor manually deselected	Other wind sensor(s) functioning	Minor	
	Power failure	Low				
Inadequate satellite coverage	Poor geometry and shielding from platform	Medium	DGPS rejected if other position references	Loss or degradation of position if only DGPS on line	Minor (Major if only DGPS used)	Relies on good procedures

DP Control System Failure Modes						
Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
DGPS 1 failure	Power failure	Medium	No/failed input to DP, DGPS rejected	Other reference systems available	Minor	
	Correction signal failure					
	Masking					
	Configuration					
DGPS 2 failure	Power failure	Medium	No/failed input to DP, DGPS rejected	Other reference systems available	Minor	
	Correction signal failure					
	Masking					
	Configuration					
Fan Beam Failure	Loss of vertical reference	Medium	Sensor out of range	Sensor deselected	Minor	At least two other sensor types should be in use
	Loss of target / false target					
	Loss of serial link to DP					
	Loss of 24V					
Taut Wire failure	Potentiometer meter fault (see others in report)	Low	No data or wrong data in one axis	Rejection by DP control	Minor	Major if not detected or wrong weight

APPENDICES



TYPE APPENDIX NAME

TYPE APPENDIX DESCRIPTION

TYPE APPENDIX NAME - TYPE APPENDIX DESCRIPTION
FMEA OF OSV "RELUME"
GLOBAL MARITIME | 24025-0912-16117 | REVISION 7
ISSUED FOR MENAS