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# MENAS

## FMEA OF CLASS 2
## OFFSHORE SUPPORT VESSEL
## "RELUME"

**Report No: GM-44514-0404-47837 Rev5**

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## SUMMARY

Global Maritime has 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 and specifications and meetings at Imtech with Owners and representatives from vendors, Damen Shipyard and Three Quays, the designers. The report was then updated again after the annual trials to correct a few errors and add a third DGPS.

The vessel specification is DP class 2 (Lloyds 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 in February 2006.

On the basis of 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.

# 1. INTRODUCTION

## 1.1 Instructions

1.1.1 Global Maritime was instructed by MENAS to carry out FMEA studies when the decision to upgrade the vessel to DP class 2 (AA notation) was made. Two earlier brief reports were made in 2003. This report covering all the systems involved directly or indirectly with DP and DP operations was completed in 2004. The report was updated after the first annual trials in February 2006.

1.1.2 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. 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 in the offshore industry.

## 1.2 Vessel Particulars

1.2.1 The following are the general particulars of the vessel:

1. 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), NAV, IBS - LIGHT TENDER/
   OCCASIONAL OIL RECOVERY DUTIES

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

3.

| | |
|---|---|
| Length Overall | 82.62 metres |
| Length Load Water Line | 78.29 metres |
| Length between Perpendiculars | 73.62 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 |

# 2. POWER GENERATION

## 2.1 Fuel Oil Systems

2.1.1 There are two service fuel oil tanks; each tank supplies two of the four diesel engines via a single quick close 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.

2.1.2 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<br>(two DG's) | QVC operate<br>Filter blocked<br>Pumps fail<br>Leakage | Unable to deliver demanded power | Other thruster compensate |
| F.O. Contamination | Water in fuel<br>Microbiological contamination | Unable to deliver demanded power | Other thruster compensate |

2.1.3 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 to be 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.

2.1.4 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 Δp 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'.

## 2.2 Sea Water Cooling

2.2.1 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 common spare on the basis that there is always time to start the stand by pump. This has been confirmed by tests but this relies on the stand by pump being available and not being a hidden failure. 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<br>Air in system<br>Poor maintenance<br>Leakage (Burst Plate Cooler) | High FW Temperature | Standby Pump<br>Can isolate leak |
| | Blocked intake | Low Flow | Can use other suction |

2.2.2 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 suctions are vented to deck in order to prevent air locks in the system.

2.2.3 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 sea water inlet becomes blocked (marine growth plus plastic bag for example) operators should have low-pressure 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 four minutes after to loss of seawater cooling before the activation of high temperature alarms, which is ample time for the ship’s engineers to deal with the problem.

## 2.3 Fresh Water Cooling

2.3.1 The fresh water system is also common but there is an expansion tank and a buffer tank so that there are 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 stand by spare. This common cooling system also supplies the air conditioning units, the thruster coolers and the converter cooling system. Again the loss of one pump could be critical if the stand by failed to start and it is recommended that both are run for critical DP work. The other problem with operating on one pump is that any low pressure alarm will be assumed to be a pump problem and time for successful leak isolation might be lost. In tests with no pump running there was only a 2° temperature rise over 6 minutes. This proves the pump failure mode effects but not the leakage effects.

| **Failure Mode** | **Cause(s)** | **Effects** | **Mitigation** |
|---|---|---|---|
| Inadequate Cooling | Temperature control valve fault<br>Leakage from cooler<br>Air in system<br>Pump failure<br>Flexible coupling fail | Alarms<br>High D.G Temperatures<br>Risk of blackout | Early warning<br>Isolation possible<br>Temperature rise not instant<br>Standby pump |

2.3.2 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 oils 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. The loss of cooling water to the thrusters will not cause high temperatures as quickly as for the diesel generators. The most important point for operators to remember is that the system is common and working on a remote part of the system can quickly cause the loss of the whole system if a mistake is made. The permit to work system for offshore DP work should help avoid mistakes like this.

2.3.3 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.

2.3.4 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 is possible.

### 2.4 Lub Oil

2.4.1 There is no common lub oil system for the diesel generators, each is independent with a motor driven pre-lub oil system and an engine driven circulation once the diesel generation is running. The lub 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.

2.4.2 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 lub oil low pressure sensor fault or the pre-lub logic being faulty. These failure modes were tested during trials. The pre-lub 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-lub oil pump of each 1,300 kW engine is powered from the Emergency Switchboard, also if the pump was running before the blackoput, lubrication is still present to allow starting.

2.4.3 Lub oil contamination microbiological or by fuel oil is possible but this is unlikely to affect more than one diesel engine at any one time.

## 2.5 Compressed Air

2.5.1 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.

2.5.2 There is also a single service air system, which does not supply any DP related equipment.

2.5.3 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 control air that is reduced to 1.5 bar. A back-up supply is available from the start air system. There are no accumulators, total hence loss of air would result in water ingress in each azimuth thruster at the same time, but as the system is alarmed, the operator will be informed to take the necessary action. Over pressure is also possible but this will give an alarm unless there is loss of oil before 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.

## 2.6 Diesel Generators

2.6.1 The vessel has four diesel generator sets, two to port, one behind the other, and two similarly arranged to starboard. They are similar Wartsila engines but in each pair one is 6 cylinder, 948kW and the other is 8 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.

2.6.2 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<br>Low F.O. pressure<br>Low LO trip<br>High temp. trip | Other engines |
| Overspeed | Control fault | One D.G. trips<br>Other on reverse power | Other engines |
| Instability | Control fault | Operator trips faulty machine (risk of stopping healthy one by mistake) | Other engines |

2.6.3 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.

2.6.4 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.

2.6.5 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.

## 2.7 Power Management

2.7.1 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.

The whole system is integrated with data transmitted over two independent field buses (Phillips CAN bus) with the main server in the engine control room and the back up server on the bridge.

2.7.2 There are two separate 24V dc supply systems and two separate 230V ac supply systems (port and starboard). In addition there is a cross connection of the 24V-dc systems so there are in effect two supplies. These supplies are both independently alarmed. For the PMS units, there is one to each diesel generator, dual supplies are achieved by one coming from the UPS port or starboard as appropriate and the second coming from the generator itself once it is on line via a transformer and rectifier. The UPS supply has diode protection. Dual supplies arranged in this way to each diesel generator’s PMS units are satisfactory. The dual supplies to other important suppliers are more problematical firstly because the risk of a common fault failing both and secondly because of the risk of all redundant critical DP equipment being powered by one supply by default and/or operator error.

2.7.3 There are two monitors on the bridge and two in the engine control room so there is redundancy at each location. It is assumed that each has a separate 230V supply with one from port and one from starboard in each location.

2.7.4 The system has 11 intelligent I/O cabinets: each has a 24V-dc power supply. These are split port and starboard according to the equipment they serve which is shown below:

| ID | UNIT FUNCTION | LOCATION | POWER | MODULES |
|---|---|---|---|---|
| DPU-3 | • Thruster control<br>• Port Azimuth drive | Carpenters store | 24V<br>Port | 12 |
| DPU1 | DG#1<br>DG#2 | Engine Room<br>Tank Top FR71 | 24V<br>Port | 16 |
| DPU2 | DG#3<br>DG#4 | Engine Room<br>Tank Top FR71 | 24V<br>Starboard | 16 |

| | | | | |
|---|---|---|---|---|
| DPU5 | Alarm & Monitoring Control of Thrusters | Wheelhouse | 24V | 12 |
| DPU6 | Port Pump Control | Group Starter Panel | 24V Port | 4 |
| DPU7 | Starboard Pump Control | Group Starter Panel | 24V Starboard | 4 |
| DPU4 | Starboard Azimuth drive | Hold | 24V Starboard | 12 |

2.7.5 There are 4 DPUs for the HVAC controls. From the above it can be seen that the split, even for power supplies, is not clear between port and starboard systems. For example DPU5 stands alone and DPU3 has thruster control but DPU4 does not. It is therefore necessary to take the analysis down another level and study the I/O of each DPU.

In drawing 394-440-100-LDS-001 sheet 101 Rev 1 only one UPS is shown that supplies 230V to both the main and back up servers. These supplies are backed up by supplies from LDP4 and LDP1 for the ECR and Bridge respectively

2.7.6 There are dual Ethernet LAN network (coax) cables between the main server and the main MCR console. There are also dual network cables between the backup server and the MCR console. The third pair passes from the back up server to the back up console on the bridge. On the drawing showing this arrangement (394-440-100-LDS-001 sheet 101 Rev 1) the MCR is called the combined propulsion control and steering.

2.7.7 On the basis that each is stand alone then the ethernet between the two consoles is not critical as it is provided only so the MCR can remain operational if the MCR server has failed.

2.7.8 The system has four dual field bus networks (CAN-bus). Number four is for the 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 | DPUs | DATA |
|---|---|---|
| 1 | 1 | DG’s 1 & 2 Port |
| 2 | 2 | DGs 3 & 4 Starboard |
| 1 | 3 | Thruster Drive Port |
| 2 | 4 | Thruster Drive Starboard |
| 3 | 5 | 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.

2.7.9 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.

2.7.10 When the main bus tiebreaker is open the PMS modules and starboard PMS modules are made independent of each other by 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<br>Dual power |
| One PMS link fail | Wire break | None | Use other |
| Both PMS fail | Non alarm on other<br>Operator error | DG independent | Alarm<br>Other side OK |
| Loss of DPU 3 or DPU 4 | Internal short | Loss of one azimuth thruster | Other OK |
| Loss of DPU 1 or DPU 2 | Internal short | Loss of 2 diesel engines | Other OK |
| Loss of DPU 5 | Internal short | | Information only |
| False bustie breaker status to OMS | Wire break<br>Breaker fault | All engines still run | Should not cause tripping |

## 2.8 Power Balance

2.8.1 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.

2.8.2 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 straight forward to limit the power (DP control system) and cut back the power of the azimuth thrusters because they have frequency drives.

2.8.3 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.

2.8.4 If operating with two DG's 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.

## 2.9 Engine Room Fire

2.9.1 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 prevention detection and extinguishing a fire.

2.9.2 The system on this vessel is been designed so that no single fault can cause a false shutdown. The $CO_2$ relay box has two independent power supplies and additional switches added to the release boxes power distribution

## 2.10 Main Switchboard

2.10.1 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.

2.10.2 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.

## 2.11 440V Switchboard

2.11.1 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 sea water 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.

2.11.2 The engine room is supplies by 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.

2.11.3 The air conditioning units however are different; the heart of the system is the single chiller plant in the engine room that supplies the air handling units. So the cooling for the wheelhouse and ECR, the critical areas for DP, are on the same system (AC1) and failure of the system in hot weather would soon cause problems. However locally both are fitted with spare fan motors and if the control system fails manual operation of the control valves is possible. Disintegation 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 will be alarmed and the motors for the system are supplied from both switchboards.

2.11.4 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.

2.11.5 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.

2.11.6 The Emergency generator is independent and supplies the emergency 440V switchboard when the normal supply from the starboard 440V board fails or is unavoidable. Consumers on this and the emergency 230V board are mostly lighting but there are also two supplies to back up the port and starboard main switchboard supplies for DP. (See below).

## 2.12 230V Switchboards

2.12.1 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 |
|---|---|---|
| LPD 1 | 230V STARBOARD | • SINGLE BEAM ECHO S |
| LPD 2 | _______”_______ | • SEATEX MOTION SENSOR |
| LPD 3 | 230V PORT | • MULTI BEAM ECHO S<br>• SINGLE BEAM THAN A UNIT<br>• *ELEC CAB FWD BOW TH<br>• *ELEC CAB AFT BOW TH<br>• TAUT WIRE |

| | | |
|---|---|---|
| EMCY PORT | 230V PORT<br>OR<br>230V emcy<br>(change over) | • DP1 UPS CHARGER<br>- DP1*<br>- GYRO1*<br>• WIND SENSOR 1<br>• JSO 1<br>• *GYRO 3 |
| EMCY STARBOARD | 230V PORT<br>OR<br>230V emcy<br>(change over) | • DP2 UPS CHARGER<br>- DP2*<br>- GYRO 2*<br>• WIND SENSOR 2<br>• DP JSO2<br>• SPEEDLOG |

* ALSO 24V DC BACKUP.

2.12.2 The arrangement enables adequate power separation to be achieved. What is surprising is that there are dual 230V supplies to redundant equipment. This is not essential for DP2. The emergency 230V switchboard does not have to supply both the DP1 and DP2 systems. The emergency switchboard is used as if it were the starboard 230V board when in failure terms this is a less reliable source of continuous power even though there is an emergency generator. The other possibility this arrangement makes is for a total loss of DP because both DP UPS 1 and DP UPS 2 could be powered along with the other consumers on these boards from the emergency 230V board. With alarms for change over and check lists this critical single failure should be avoidable but in principle it is an unnecessary hazard. Loss of the 230V Emergency board can be caused by several faults:

| **Failure Mode** | **Cause(s)** | **Effects** | **Comment** |
|---|---|---|---|
| Loss of 230 ESB | 440/230V transformer<br>440V ESB power<br>690/440V transformer<br>short circuit 440V<br>short circuit 230V<br>operator error | UPS to batteries<br>Alarms<br>Both wind sensors lost<br>JSO 1 & 2 | Emergency generator will take too long<br>Change over<br>Will not prevent loss of equipment |

2.12.3 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. However, the redundancy is in the equipment already and it can be confusing when there are multiple supplies especially if they are simultaneously active such that one fault could fail both and may activate higher protection. Multiple supplies also mean that each has to be monitored so that failure of the back up is alarmed.

## 2.13 24V Systems

2.13.1 There are two 24V-dc systems both in the engine room one port and one starboard. The port one or MSB 1 system supplies the two port diesel generator's PMS units and supplies the bridge. 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 change over to port.

2.13.2 The starboard system is similar but the batteries and 440V charger are in the engine room. So there is plenty of redundancy in supply but nevertheless a risk of a mistake 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.

| **EQUIPMENT** | **SUPPLY 1** | **SUPPLY 2** |
|---|---|---|
| GYRO 1 | MSB1 24V | DP UPS 1 |
| GYRO 2 | MSB1 24V | DP UPS 2 |
| GYRO 3 | MSB1 24V | 230V AC |
| DP 1 | MSB1 24V | UPS 1 |
| DP 2 | MSB1 24V | UPS 2 |
| DG JB (PA) | ER MSB1 24V | MSB 2 ER |
| DG JB (PF) | ER MSB1 24V | MSB 2 ER |
| DG JB (SF) | ER MSB1 24V | MSB 2 ER |
| **EQUIPMENT** | **SUPPLY 1** | **SUPPLY 2** |
| DG JB (SA) | ER MSB1 24V | MSB 2 ER |
| PMG GEN PA | ER MSB1 24V | MSB 2 ER |
| PMS GEN SF | ER MSB1 24V | MSB 2 ER |
| ALARM UNIT BT | ER MSB1 24V | TLD P2 |
| E C FORD BT | ER MSB1 24V | LDP3 230V |
| E C AFT BT | ER MSB1 24V | LDP3 230V |
| THRUSTER CONTROL P | ER MSB1 24V | TLDP3 |
| THRUSTER CONTROL S | ER MSB1 24V | TLDP3 |
| ER CONTROL UNIT THRUSTERS | ER MSB1 24V | TLDP2 |

# 3. THRUSTERS

## 3.1 DP Capability

3.1.1 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 $30^0$ 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.

## 3.2 Bow Thrusters

3.2.1 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.

3.2.2 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.

3.2.3 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 $10^0$ and is then not recoverable because of the sequence of waters experienced. So 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.

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

3.2.4 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.

3.2.5 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.

3.2.6 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 given on the DP the thruster should still be stopped. The operator must not deselect the thruster from DP because although the command will go to zero the thruster that is still running will not and a loss of heading will continue.

3.2.7 Unstable pitch can occur from worn parts or maladjusted potentiometers. Similarly poor adjustment of the zero pitch can make starting currents much higher. Under normal circumstances it requires only one diesel generator to start a bow thruster, providing there is not a high hotel load. As mentioned before 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.

### 3.3 Azimuth Thrusters

3.3.1 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 cooler) 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 $45^0$ 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.

3.3.2 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.

3.3.3 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.

3.3.4 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 $90^0$ 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.

3.3.5 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.

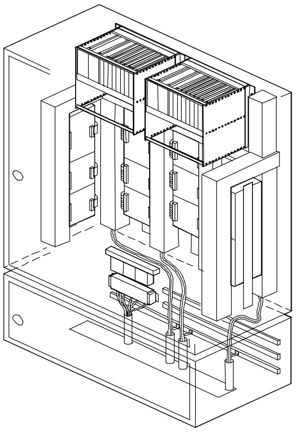
| **Failure Mode** | **Cause(s)** | **Effects** | **Comment** |
|---|---|---|---|
| Drive motor trip | Mechanical fault<br>Electrical fault<br>Lack of cooling | Reduced DP capability | |
| Converter fault | Mechanical fault<br>Electrical fault<br>Lack of cooling | Reduced DP capability | |
| Speed control fault | Wire break | Unwanted thrust | Small position excursion if stopped quickly |
| Lub oil pump fail | Electrical fault<br>Mechanical fault | Alarm only | |
| Hydraulic motor fail | Electrical fault<br>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 |

| Failure Mode | Cause(s) | Effects | Comment |
|---|---|---|---|
| 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<br>Limits not exceeded |

3.3.6 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 the maloperation has to be a mistake rather than an action to cause a problem deliberately. Simple faults can include wire break, shorts and earth faults.

# 4. DP CONTROL SYSTEMS

## 4.1 DP21 Computers



**Courtesy: Kongsberg Simrad**

4.1.1 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.

4.1.2 The two (DPC) computers operate in parallel each individually receiving inputs 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.

4.1.3 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).

4.1.4 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.

4.1.5 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.

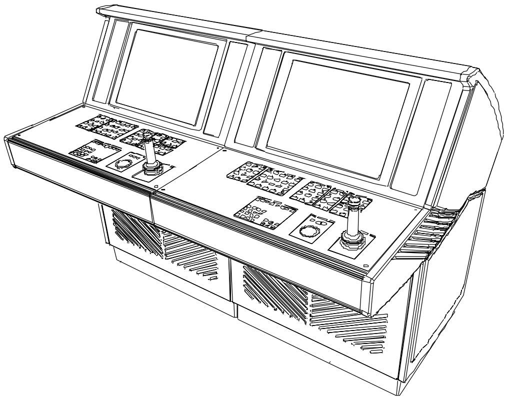
Two Power Supply Units (PSU) are mounted to the computer cabinet. Their function is to generate a stable reference voltage for the potentiometers used for the feedback signals.

4.1.6 A ‘redundant’ ethernet is installed between both computers and the operator stations. In case network A fails, B will take over and visa versa. However, each has the same data and same software so if the on-line net is overloaded so too will be the back-up. It is important that this cannot happen.

4.1.7 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.

4.1.8 To take command of the thruster in DP a change over 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.

## 4.2 Operator Consoles



**Courtesy: Kongsberg Simrad**

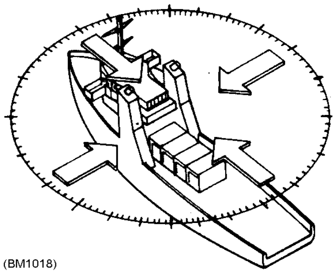
4.2.1 Three operator stations (OS) with similar consoles are installed on the bridge and they all have the same functionality including a joystick. OS1 is located on the bridge forward midships, while the other units are located on the bridge aft, to port and starboard.

4.2.2 The 220V 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 220V via a 220V /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.

4.2.3 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.

4.2.4 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. So surge, sway and yaw for example are double push.

## 4.3 DP Control Modes Functions



**Courtesy: Kongsberg Simrad**

4.3.1 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’. 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.

4.3.2 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.

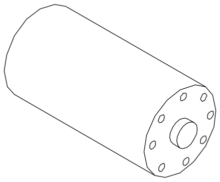
4.3.3 The management of position references is of primary importance because the DP control system acts immediately on position error and, for good position performance, needs new data at one second intervals. Clearly there is a need to:

- filter noise
- determine the relative weight of each
- correct for vessel motion (roll and pitch).

To help the above process a Kalmam 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.

4.3.4 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 sometime, 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.

## 4.4 Motion Sensors



**Courtesy: Kongsberg Simrad**

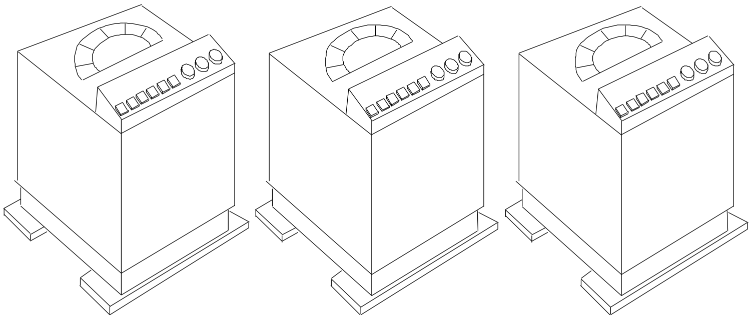
4.4.1 There are two motion sensors of the type Seatex on board, one MRU-5 and one MRU-H. Both MRUs are used as sensors to the SDP (MRU 1 and MRU 2). MRU 2 is also directly used for the HiPAP and both are used for MBES. The MRU system uses solid state device to measure the roll, pitch and heave rate. Integrating these signals gives the roll, pitch and heave measurements.

4.4.2 The MRUs are powered from the DP system. The MRU data is fed as ± 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.

4.4.3 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 ($1^0$) an alarm is given and it is up to the operator which VRS to select as input to the DP system.

The HPR only has 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 as a worst case. The checklists should make MRU 1 preferred so the DGPSs and Fan Beam are corrected by a different MRU to the HPR. If all are on MRU 2 they are no longer independent position references.

### 4.5 Gyro Compasses



**Courtesy: Kongsberg Simrad**

4.5.1 The vessel is equipped with three gyros; all three are of the same (SR180MK1 Mod 10). 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 3 gyro is used by the HPR. In this the case, another gyro must be selected as preferred because the fan beam and Dips may not be given a unique gyro input and will provide relative fixes to the DP control system.

4.5.2 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.

4.5.3 The difference alarm should be set at $1^0$. 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.

### 4.6 Wind Sensors

4.6.1 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 the 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.

### 4.7 Hydro Acoustic Position Reference (HPR)

4.7.1 The HPR system is named "HiPAP" ("**H**igh **P**recision **A**coustic **P**ositioning") 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).

4.7.2 The system calculates a sub sea 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.

4.7.3 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.

4.7.4 The transducer is directly hardwired to the HiPAP OS. The system is connected supplied 230V from UPS-2 and the transducer hoist is powered by 440V from main bus bar section. Loss of the 440V-power supply to the hoist control will not affect the HiPAP if in use.

4.7.5 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 back up 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.

4.7.6 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.

4.7.7 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.

4.7.8 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$^{TM}$. Windows $^{©}$conventional interface and is simple to operate.

## 4.8 DGPS

4.8.1 The vessel is fitted with four DGPS three of which are for DP. Two are identical DGPSs (Leica MX420B), the third is a Veripos dual frequency system (L1/L2 and LD2 integrated demodulator). The fourth is a Kongsberg Seatech SPH20, which supplies the hydrographic survey suite. The three DP units all have an NMEA-0183 serial line interface with the SDP21 system.

4.8.2 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.

4.8.3 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 a metre accuracy.

4.8.4 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 the 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.

## 4.9 DGPS Failure Modes

4.9.1 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.

## 4.10 Fan Beam

4.10.1 The vessel has an interface for an MDL fan beam, which was hired for the FMEA proving trials and will hired locally if and when needed on a project basis. No details of the unit have been supplied. However, the plan is for an NMEA-0183 serial line interface with the SDP21.

4.10.2 Possible failure modes of the fan beam are:

- failure of the vertical reference sensor
- Signal block due to dirty lens or
- line of sight obstruction,
- Loss of target / false target
- Low sun
- Bright lights, particularly at night
- Loss of serial link to DP
- Loss of 24V
- Loss of encoder feedback

As no fanbeam was on board during trials, commissioning tests will be required on a project basis.

## 4.11 Taut Wire

4.11.1 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 220V 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 sea bed 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. So the position of the sea bed 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.

4.11.2 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.

4.11.3 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
- 220V 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.

### 4.12 Position References & Weighting

4.12.1 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.

4.12.2 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 Fan beam, 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.

4.12.3 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.

# 5. COMMUNICATIONS

## 5.1 Bridge

5.1.1 The bridge is fitted with the following shipboard communication systems:

- Auto telephone
- Talkback
- Dive Alert System
- VHF
- PA

5.1.2 The telephone system communicates with the engineroom, all offices, cabins and internal work areas of the vessel.

5.1.3 The talkback system allows communication from the bridge to the engine control room and thruster rooms.

5.1.4 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.

5.1.5 The VHF system communicates with the handsets provided to all duty officers.

5.1.6 The PA system has two operational settings, either public areas or all areas throughout the ship.

# 6. CONCLUSIONS

## 6.1 General

6.1.1 The vessel meets DP Class 2 requirements with no exceptions. For recommendations please refer to the latest annual trials report.

# 7. 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:-<br>Fuel starvation<br>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 engineroom |
| | Mechanical failure of shaft between engine and generator | Low | | | | |
| 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 engineroom 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 engineroom 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<br>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<br>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 |
| 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<br>Split switchboard<br>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<br>Operator may shut down healthy machine in error | Minor | Other engine<br>Split switchboard<br>Engines running on low load |
| Instability | | | | | | |
| PMS Failure | Power loss | Low | Loss of voltage control on generator | Generator S/D | Minor | Other engine<br>Split switchboard<br>Engines running on low load |
| | Voltage loss | Low | | | | |
| Faulty bus tie status to PMS | Wire break | Low | Tripping of breaker | Loss of one engine | Minor | |
| | 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<br>Low load |
| | Electrical fault | | | | | |
| | Loss of cooling | | | | | |
| Converter fault | Electrical fault | Low | Generator S/D | Reduced DP capability | Minor | Other thrusters<br>Low load |
| | Loss of cooling | | | | | |
| Speed control fault | Wire break | Low | Overspeed | Unwanted thrust | Minor | Small position excursion if stopped |
| Lub 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<br>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<br>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<br>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<br>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 |
| 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:<br>DPC – 21 A(PU1)<br>SPP OS1<br>Fan Beam | Minor | Other DPC – 21 B takes control |
| Loss of UPS 2 | Failure of unit | Low | Loss of output | Loss of:<br>DPC – 21 B (PU 2)<br>SDP OS2<br>HIPAP<br>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<br>Correction signal failure<br>Masking<br>Configuration | Medium | No/failed input to DP, DGPS rejected | Other reference systems available | Minor | |
| DGPS 2 failure | Power failure<br>Correction signal failure<br>Masking<br>Configuration | Medium | No/failed input to DP, DGPS rejected | Other reference systems available | Minor | |
| Fan Beam Failure | Loss of vertical reference<br>Loss of target / false target<br>\loss of serial link to DP<br>Loss of 24V | Medium | Sensor out of range | Sensor deselected | Minor | At least two other sensor types should be in use |
| Taut Wire failure | Polentiometer 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 |

# APPENDIX 1

## Layout of DP Equipment