Podded Propulsion Drive for
Cruise Liner “Seven Seas Voyager”
The high luxury class cruise liner "Seven Seas Voyager" built at the Italian T. Mariotti shipyard in Genoa is managed by V. Ships Leisure in Monaco and operated by and Celtic Pacific (UK) Ltd. In behalf of Radisson Seven Seas Cruises (RSSC). She is equipped with the DOLPHIN podded propulsion system developed in co-operation by SAM Electronics in Hamburg (D), John Crane-Lips in Drunen (NL) and VEM Sachsenwerk in Dresden (D).

SAM Electronics was selected by shipyard and owner to supply the following systems:

- Propulsion system with DOLPHIN podded drives 2x7,000kW, 170rpm,
- Bow thruster system with propulsion drives 2x1,100kW, 1200rpm,
- Remote control system with joystick and machine telegraphs,
- Main diesel alternators 4x7,200kVA, 600rpm,
- High voltage propulsion switchboards 6,6kV, 60Hz,
- Mains transformers 2x3,750kVA and 6x1,250kVA.

Further SAM Electronics delivered the navigation and communication system.
Power Supply System

The necessary energy for the propulsion and the air conditioning drives as well as for the mains is generated by four diesel alternators which supply the two high voltage propulsion switch boards equipped with SF6 circuit breakers. Via eight transformers the different low voltage networks are supplied from the high voltage propulsion mains. Interconnections between the different low voltage boards allow a supply of all consumers also in case of a transformer failure.

The high voltage propulsion system is resistor grounded for continuous operation with a single grounding fault.

According to redundancy requirements of the classification rules RINA a failure mode and effect analysis (FMEA) was made showing the influence of all possible failures. After a single failure at minimum 50% of the propulsion power should remain. Such a “single” failure could be a flooding of a room or fire inside a fire section. This requires that, for example, the propeller drives, the converters, the diesel engines and the switchboards are located in different rooms and special pre-cautions are taken at the controls and the monitoring of the system. Also the auxiliary systems as e.g. cooling water system, ventilation have to be divided up accordingly and the cable trays have to run through different areas.

Single line diagram of the high voltage distribution system
Propulsion Drives

The two propellers are driven by synchronous motors mounted in the underwater compartment of the Pods. As usual for podded drives, the propeller is directly mounted onto the motor shaft. The propulsion motors are designed maintenance friendly with asynchronous exciter for brushless excitation. The stators are equipped with two galvanic separated 3-phase windings systems with 30° phase shifting for 12-pulses motor supply. This secures excellent torque characteristics of the propulsion motors with low torque harmonics in the air gap and low noise operation.

The motors with fully reversible speed are air cooled by cooling aggregates installed in the Pod room. Two fan motors per cooling unit provide a 100 per cent redundancy in the air flow. A de-humidifier unit reduces the humidity inside the Pod to prevent condensation at the walls. The de-humidifier unit is supported by space heaters at stand still periods.

For redundancy reasons both winding systems of each propulsion motor are supplied separately via synchro-converter and propulsion transformer from the high voltage switchboard. The control, monitoring and excitation supply system of each propulsion drive has been designed redundantly with one system in operation. Synchro-converters with DC intermediate reactors, propulsion, excitation and mains transformers and both propulsion switchboards are mounted in separate rooms.

Single line diagram of one propulsion drive
Harmonic distortion (THD)

The harmonics generated by the synchro-converters are reduced to admissible levels according to the classification rules and the design regulations for faultless operation of the sensitive consumers. The following measures are provided for a voltage total harmonic content (THD) of 5%:

- 24-pulses supply of the synchro-converters to the mains if both propulsion motor windings are operated (and 12-pulses operation if only one winding system is operated). For that each synchro-converter is supplied via two propulsion transformers each with two secondary windings with 30° phase shifting and ± 7.5° additionally phase deviation for 15° phase shifting between two propulsion transformers. Additionally the propulsion transformers are designed with enlarged impedance.

- Design of the mains transformers with grounded screen between primary and secondary windings.

- Design of the main diesel alternators with reduced reactance.

Additional measures as e.g. filter circuits for connection to the high voltage switchboard are not necessary. To reduce the magnetising current inrush each propulsion transformer is pre-magnetised before switching in.

The Fourier analysis based on measurements of the university of Genoa during the sea trials shows the excellent results also under half motor operation which is an emergency condition. The THD values are less than the required values, also in low speed and half motor operation (operation only with one converter per Pod).
DOLPHIN Pod

The DOLPHIN podded propulsion system with its electrical, mechanical and hydromechanical parts has been developed in co-operation by SAM Electronics and John Crane-Lips Netherlands with the input of the extensive experience with propulsion systems, propeller hydrodynamics and steerable thrusters. The special motor design is done by VEM Sachsenwerk in Dresden.

Pod Overview

Three main parts can be distinguished when looking at the mechanical and hydrodynamical part of the DOLPHIN. First is the underwater part of the DOLPHIN, the actual Pod, combining the synchronous motor, the propeller shaft, propeller seals and the propeller itself.

The second part, the steering mechanism, connects the Pod to the ship and allows the propulsion system to function as a rudder. Third and last part of the system is formed by the components that are necessary to support the propulsion line of electric motor, shaft and propeller. Examples of these components are the cooling system, the slip ring mechanism, the bearing lubrication system and the propeller shaft seal.

Ship owners, operators and component suppliers have provided feedback based on their operational experience with the current generation of podded propulsors. The feedback and experience have been included in the design of the DOLPHIN.

In the following, the key features of the DOLPHIN will be highlighted. This starts with the hydrodynamic aspects and is followed by the aspects of the steel construction, the shaft bearings, the steering mechanism, the shaft seals and the support systems.
Hydrodynamics
Several model test series have been carried out to define a shape with an optimal efficiency. CFD calculations have been made to investigate the flow and pressure pattern around the Pod. The actual cavitation tests show that the pulling propeller for this application is free of cavitation and that the pressure pulse levels on the hull are very low.

During the various sets of model tests, the loads by both the propeller and the complete Pod housing have been investigated to support the calculation method for the Pod and its drive components. To achieve this, a unique test set-up was designed and manufactured.

To reach a good propulsion efficiency, the underwater housing should be as small as possible. This limits the access to some internal components like bilge sensors or certain pipe connections. Also the bearings and the shaft seals have limited access and can be maintained only during dry-docking.

Shaft Bearing System
Two bearing positions can be distinguished in the DOLPHIN. The forward bearing position consists of a single SKF CARB bearing. This bearing has been selected for its capability to accommodate the variable radial loads generated by the propeller operating in an oblique flow, while compensating for axial displacements of the shaft caused by temperature differences.

Propeller thrust forces are transferred in the aft bearing position. The combination of the forward thrust, the radial and the reverse thrust bearing, acts as a ball joint, allowing each of the bearings to perform its own unique function. Several series of model tests were used to develop the calculation method for the loads on both the propeller and the rest of the Pod.

Slip rings
The slip ring unit is mounted at the top flange of the cooling air duct, the cooling unit at the side flange. The cooling air is not blown through the slip ring unit, so no oil or water dust from the underwater compartment can reduce the contact quality of the brushes. Also no carbon can influence the insulation resistance of the motor windings.

To avoid the passing of rotor induced electrical currents through the shaft bearings, the forward bearing is isolated from the Pod housing. A carbon / carbon slip ring system connects the shaft to the Pod housing to prevent potential differences which could damage the bearing insulation. The carbon / carbon system allows very long maintenance free operation periods.

All supplies to and from the underwater compartment have to run through a slip ring unit with integrated swivel unit to allow an unlimited turning of the propeller in azimuth direction. To limit the size of the slip ring, the number of rings has to be limited. So all signals from and to the underwater compartment are running via a serial data line, only power supplies have there own rings.

To increase the availability of the Pod controls, the serial data line is doubled. This requires also a double set of the most sensors. Additional spare sensors are build in and wired to Pod data transfer system PIO (Pod In / Out) for all units which are not maintainable without dry-docking, like the bilge sensors. In case of a sensor failure, the spare sensor can be quickly connected to the PIO.

All power rings are brass rings with carbon brushes, the data rings are gold plated with silver brushes. To ensure a good contact quality at all time, the main power rings are carved. This increases the wear of the brushes so that at all times a “fresh” contact is given to the ring. Also with the increased wear, the live time of the brushes is expected to be much more than 5 years.

Slip ring unit
**Steel Construction**

The Pod housing is designed as a welded steel construction. To validate the construction elements, a FEM model was made that describes the Pod construction in detail. The internal loads on the Pod housing by the internal components and the external (hydrodynamic) loads have also been modelled and serve as the input for the FEM model. Several iterations with small corrections of both the actual construction and the FEM model have lead to a solid construction, that under all circumstances forms a safe platform for the components it encloses and supports.
Azimuth Steering System
The steering function of the DOLPHIN is concentrated around the triple row slewing bearing. The bearing transfers all the loads, in particular the thrust, to the hull of the ship, while the integrated slewing gear is transferring the steering forces. Watertightness of the ship is safeguarded by the integrated multiple lip seal. The complete unit is connected to the ship by means of a bolt circle on top of the outer diameter of slewing bearing. This allows for an uncomplicated design of the seating in the ship and less time is necessary for the installation procedure.

For the steering actuators, the proven concept of the LIPS steerable thruster range was used, with the size of the components reflecting the higher demands of the DOLPHIN unit compared to a steerable thruster. The steering units are a combination of a medium speed radial piston hydraulic motor and a planetary gearbox. On the current 7 MW DOLPHIN, 4 of such units are placed within the slewing bearing circumference. The oil contained in the reservoir formed by the steering hub and the steering case lid lubricates both the slewing bearing and the slewing gear. The low viscosity oil is fully separated from the shaft bearing lubrication system.

The hydraulic power pack for steering of the DOLPHIN consists of two identical redundant sides. Either side can drive the complete DOLPHIN unit. A counter balance block installed close to the hydraulic steering motors prevents the POD from being rotated involuntarily by outside forces.

The controls of the azimuth system, the Lipstronic, is interlocked with the converter system of the propeller motor to prevent an overload of the mechanical system.
**Pod Control and Monitoring System**

The Pod’s can be monitored via touch screens located at the Engine Control Room (ECR) as man-machine interface. “Push buttons” at the main page lead to the detailed pages of the different systems, where the data of the system are displayed in a simplified system overview.

The page “Values” shows in detail the actual analogue data of the drive in a bar graph view, always both converter systems close together, so a comparation between the systems is possible very easily. Different pages can be selected to have enough space for all the values.

The page “Status” shows in detail the actual digital data of both systems. Color change from green to red show easily where a value is not at the expected status. Also different pages are available.

The page “Alarms” lists up all alarms. Help text is available on request for every alarm, further the alarms are stored in a alarm history. The history can be printed out on request.

The page “Pod” gives more details to the mechanical systems of the Pod. It has the four sub-pages Cooling, Bearing, Bilge and Seals. On these pages principle flow diagrams show the systems, the status of pumps or valves is indicated by animated symbols.

The pages “Conv. 1” and “Conv. 2” show the details of the associated converter with digital temperature, current and voltage information as well as status and alarm information.

The page “Setup” allows access to the internal clock and some parameter settings during commissioning. These parameter settings are blocked by a password.
Pod Subsystems

To support the operation of the Pod drives several subsystems are required. The most important subsystems are:

- The motor cooling system
- The bearing lubrication and monitoring system
- The seal support system
- The bilge system

Further the brake, turning device and shaft blocking system allows a maintenance and repair of rotating parts like the diodes of the exciter.

Motor cooling system

The motor is specially adapted to the requirements of the Pod underwater housing, it’s diameter is as small as possible with an extreme length of the rotor to get the output power. Therefore the motor requires cooling air from both ends with an air outlet through slots inside the stator. The air is re-cooled by a fresh water to air heat exchanger located at the Pod room inside the vessel. The heat exchanger is connected to the associated diesel cooling system and does not require chilled water. This increases the heat exchanger size but simplifies the system.

One air dryer per Pod is foreseen to control the humidity inside the Pod to prevent condensing water at the Pod structure. The air dryer is automatically controlled by a humidity sensor inside the underwater structure.

Bearing lubrication and monitoring system

The lubrication system for the shaft bearings is built up of two redundant pump sets situated in the Pod and an oil cooler and filters situated in the Pod room.

All shaft bearings of the Pod are completely filled with oil. Automatic started and stopped oil pumps for each bearing housing ensure a proper flow through the bearing. The oil temperature is thermostatic controlled by a oil to water heat exchanger and a heater at the storage / expansion tank. To monitor the bearings Pt 100 temperature sensors are mounted at each bearing housing. These sensors will give an alarm in case of too high or too low oil temperatures. In case of longer stand still periods, the oil pumps will be automatically started before the oil temperature get to too low values.

To monitor the bearings against wear a shock pulse measuring system is installed. This system has sensors at each bearing housing which are wired to a converter unit which is accessible during operation. The converter transfers the signal into a 4 to 20 mA signal which is transmitted via the PIO to the control, where it is processed into relative signal which gives an alarm at too high values. The system works continuously, it gives a good indication about the wear of the bearings. For a better analysis, the converter can be disconnected and a separate analyser system can be connected to the sensor. So more detailed information about the bearing is available.

Seal support system

The shaft seal package of the DOLPHIN consists of an outboard seal and two inboard seals sealing the bearing housings.

The seal support system inside the Pod ensures that a correct working environment for the seals is maintained at all times. Every seal at the motor shaft is build in together with a spare seal, which can take the job in case the first seal fails. To control the working and lubricate the spare seals, the seal support system is used. By loading the seals with different hydrostatic pressure from the oil tanks inside the Pod strut, the operation of the seals is controlled.

The main outboard seal to the propeller is a pollution free, water lubricated face type seal. A ventilated, void space between the main seal and the spare lip seal ensures that no oil from the Pod bearing can reach the open water. In case of an emergency, a inflatable seal can block the access water to the Pod underwater compartment.
Bilge system
Main function of the bilge system is the monitoring and draining of the void space of the outboard seal. In addition, the bilge system is designed to collect and drain oil or seawater leakage from every possible source in the Pod. The applied ‘closed circuit’ draining system provides the best possible safe and clean environment for the electric and electronic components inside the Pod.

All spaces which can be filled by oil or water are connected to two bilge tanks mounted close to the lowest cavity of the underwater compartment. One tank collects all the water, the second tank all the oil. Two interchangeable bilge pumps pump the liquids automatically into the inboard bilge tank, from where it can be drained into the ships bilge system. The ventilation of the water tank is run through the swivel unit and ends above the water line. Although the tank is flooded fully, no outside water can get into the underwater compartment. There are no open liquids inside the Pod housing, nothing can swap around and damage the insulation of the motor.

Additional bilge sensors at the aft fairing cap and at the lowest compartment of the Pod monitor a leakage.

Brake, Turning and Blocking System
Mounted close to the aft bearing housing are the shaft brake, shaft turning and shaft blocking system. Operation of these systems is automated and the control panel is situated in the Pod room. The mechanical blocking device allows ship operation with one driven Pod while the propeller shaft of the other Pod is blocked.

Bow Thruster
The two low noise bow thrusters of John Crane-Lips with variable pitch propellers are driven by asynchronous motors with constant speed for direct starting (DOL).
Navigation and Communication

The basic components of the navigation system NACOS (NAVIGATION and COMMAND SYSTEM) are RADARPILOT, CHARTPILOT, MULTIPILOT and for the steering of the ship - the TRACKPILOT.

The NACOS is based on a two network technology (CAN-Bus for e.g. navigation data transfer and LAN for e.g. exchange of electronic charts). So every system component has the same data information.

The installed navigation system is a NACOS 45-4 and consists of:

- Two ATLAS Radarpilots 1016/ARPA-3B14S-Band with 29” Monitor
- One ATLAS Multipilot 1029/ARPA-2BBX-Band with 23” TFT screen
- ATLAS Trackpilot 9401, Autopilot and Track Steering Processor with Engine Interface
- ATLAS Conningpilot 9330 CP-C with 21” Console Monitor
- ATLAS Chartpilot 9330 DP with 21” Office Monitor

Following navigational equipment has been installed as well:

- Speedlog ATLAS Dolog 23
- Echosounder ATLAS9205 with two 100kHz transducers
- Position Indicators DEBEG 4422 (GPS) and DEBEG 4422D (DGPS)
- Weatherfax
- UAIS DEBEG 3400
- Wind measuring equipment
- Voyage Data Recorder

Gyro system consisting of:

- Gyro compass STANDARD 20 PLUS (GGM)
- Magnet compass “CLASS A” FIBERLINE

The installed GMDSS (A3) consists of:

- SSB radio DEBEG 3105, 250W, D6T, DC
- (MF/HF Radio transceiver equipment mounted into Radio Console)
- VHF Radiotelephone DEBEG 6322, S/SD, INT/US
- (Semi-duplex Radio transceiver mounted into Radio/Bridge Console)
- INM-C SatCom equipment DEBEG 3220C

The Radio Communication also is equipped with Public Communication consisting of:

- VHF Radiotelephone DEBEG 6342, S/D, INT/US
- (Duplex Radio Transceiver for PANAMA)
- INM-B SatCom DEBEG 3232, Cl.2, HSD
- INM-B SatCom DEBEG 3232, Cl.1, HSD
- INM-M Satphone TT-3064A