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Control Systems II

Integrating Dynamic Positioning Systems with Remote Thruster Controls

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Introduction

A positioning system, such as dynamic positioning (DP) and joystick, is the 'end-user' of other equipment on a vessel and plays also the role as an integrating factor for the vessel operation.

Rolls-Royce is today one of the major players in the marine market with a large portfolio of products, such as thrusters, rudders, steering gear, stabilisers, engines, switchboards, automation products and ship design. The company has more than 30 years experience in operation of DP vessels.

As a consequence of the strategy of becoming a *total solution provider* Rolls-Royce will extend the product range to comprise positioning systems. A complete range of positioning products – from independent joystick control systems to IMO DP Class 1, 2 and 3 systems is now being rolled out.

The trend today is towards higher level of system complexity onboard vessels, requiring a higher level of integration. To cope with these challenges, many of the existing Rolls-Royce products are now in the process of migration to a *Common Control Platform.* This common hardware and software technology is the foundation for future integrated solutions. The first example of such solutions is the integration between Remote Thrust Controls (RTC) and dynamic positioning systems.

This paper addresses the general aspects of integration, with particular focus on the integrated RTC and DP solution. In addition, the design and configurations of new remote control systems and new positioning systems are described.

Integration Aspects

Bridge Challenge

Looking at a typical vessel today, the situation is often characterised by

- Systems and consoles demands large space and have often many push-buttons and indicators
- Systems appear as isolated units with one or several dedicated consoles or panels
- Little communication and interaction between systems
- Insufficient information of how systems depend on and affect each other
- Difficult to identify and segregate different systems physically on the bridge
- Difficult to get access to and get overview of all relevant systems for certain operations

As a result, it may some times be difficult to identify failure situations and to perform the adequate and safe corrective action.

Integration Challenges

With the recent advances in technology, especially in network solutions, new possibilities exist for developing advanced integrated solutions in marine vessel systems. Different approaches have been made the last decade, but still the level of integration between systems is low on most vessels, as in Case 1 below.

Definitions

In discussions on integration of marine systems, different terms are used to describe the integration principles and characteristics. In this paper we use following definitions:

Physical integration:	Description of the physical connection of systems. I.e. hardwired, serial, network or combined controller
Functional integration:	Description of the functionality offered by physically integrated systems.

Case 1 Direct IO Integration

In this solution, *physical* integration of the systems is through hardwired signals via IO modules or standardised telegrams on serial lines, see Case 1 in Figure 1. The integrated *functionality* of the two systems is limited to a minimum, strongly related to the number and nature of the connected wires. This approach has been attractive because the interface is simple and well defined. The independence and integrity of the systems are kept by simple means; The overall functionality and potential failure modes is be tested and verified by going through the interface list. Systems A and B can also be tested independent of each other. In most cases this is how systems from different suppliers are interconnected today.

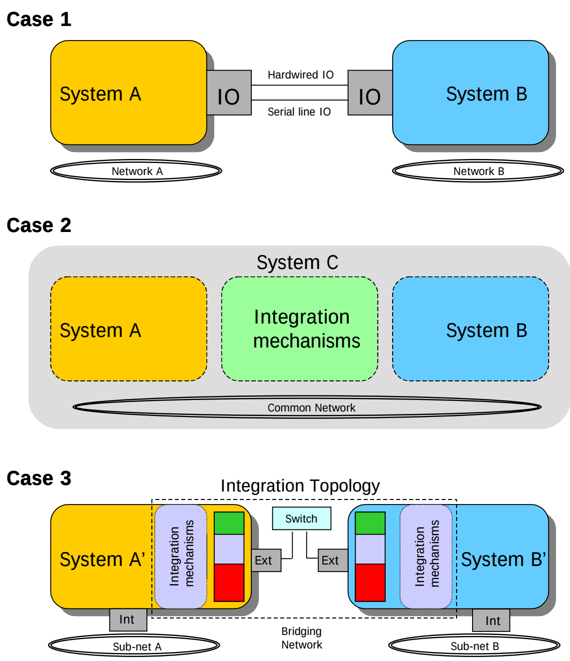

Figure 1 Different approaches to system integration.

The direct IO integration approach imposes strong limitations to the achievable level of functional integration. Even a modest integrated functionality may require large expansion of the interface list. Expanding the number of hardwired signals is often a practical limitation in any project.

Case 2 Combined Systems

To handle more complex interaction, additional *integration mechanisms* must be added to the existing systems. Case 2 in Figure 1 is an example of an integrated solution with high level of *physical integration*, where the original systems A and B are merged into a new system C which contains the desired integration mechanisms, sharing either the same physical controller or common network. Although facilitating the desired functionality, the centralised solution has several drawbacks due to the high level of physical integration, such as:

- The independence and integrity of the original systems A and B is lost
- Common failure modes and extensive failure effects are introduced
- Conflicts between system A and B regarding requirements and resources are introduced
- Both systems rely on the common network solution, which may be a bottleneck
- Deteriorated performance compared to the stand-alone original systems (e.g. limited sampling time on the centralised system may result in reduced dynamic performance)
- The new integrated system C is regarded as a separate system that must be handled by one supplier

Case 3 Network-Based Functional Integration

The Rolls-Royce approach to the integration challenge is to focus on the *functional* integration of the systems, through applying suitable network-based *physical* integration as in Case 3 in Figure 1. The design is characterised by:

Modularity and system integrity

Standardisation through modular design of hardware and software is required to achieve independence of the integration principle, which is the key to maintaining system functionality and integrity in an integrated solution. From a basic system composed by standard components, both Cases 1 and 3 in Figure 1 may easily be configured.

Integration mechanisms

Integration is facilitated by migrating the different systems to a common hardware and software platform. Functional integration, as in Case 3, is obtained by adding components for network-based communication and activating components with integrated functionality. The system's required segregation is maintained by applying proper network and application interface protection mechanisms. Further, a failure in components for interface handling or integrated functionality should not prevent operation of the basic functionality of the original systems.

Integration for functional benefits

Priority is on integration of systems that naturally depend on each other and where integration gives functional benefits. In order to integrate systems, the motivation and advantages of integration, and also the functionality and failure modes and effects of the integrated system must be well defined.

Integration towards systems from other suppliers requires close cooperation and clearly defined roles and responsibilities.

Note that the systems in Case 3 still support direct IO and basic functionality (Case 1) by applying components for direct IO handling.

Network integration alters the challenges of test and verification. In network-based solutions the hardware failure modes are reduced and more focus is aimed at system functionality and failure modes of software and network components, affecting also 3rd party verification of systems (failure mode and effect analysis, classification).

As a result, the system suppliers must put strong focus on:

- Proper and precise definition of the requirements to functionality and operation of the integrated solution, definition of software interfaces on functional and signal level
- Software design – clearly defined basic and optional components, and separate tailor made components
- Software maintenance and configuration control
- Test and verification of both the stand-alone systems and the integrated solutions

Integration Objectives

Despite the demands and responsibility put on suppliers of integrated systems, the motives and objectives for integration are:

- Extend the existing system's functionality when more complex solutions are relevant
- Simplify the physical interface between systems to reduce engineering & installation time, complexity and error sources
- Enhanced operational safety by making *required* detailed information regarding operation, status or performance available ***where*** it is needed to make the correct decision
- Facilitate mutual monitoring of interacting systems
- Consistent system operation, failure detection, failure handling
- Space saving
- Flexibility to reconfigure operator stations
- Maintaining system integrity

Figure 2 New consoles, operator stations and Operator's Chair from Rolls-Royce. New systems require less space and facilitate system integration.

Common Control Platform

In 2006 many of the well established marine products from Rolls-Royce will be released on a *Common Control Platform*, such as:

- UMAS alarm and automation system
- Remote propulsion control systems
- Deck machinery systems.

- New DP and joystick systems, which were from the beginning fully based on this platform.

The *Common Control Platform* comprises:

- Standard control cabinets (including hardware components such as controller CPUs, power supply, IO modules, network components, etc)
- Standard operator stations (graphical displays, input devices etc)
- Standard network solutions (Ethernet and CAN fieldbus)
- Standard system software (real-time operating system and middleware).
- Standard software libraries (IO drivers, alarm handling,
- Common graphical user interface
- Integrated bridge building-blocks

Standardised control cabinets (including all the components in the Common Control platform) have been *type approved* by major classification societies.

The new marine controller is one of the cornerstones of the Common Control Platform, see Figure 3, and plays the role as the integrator both on physical and functional level. Another key components for integration are the new series of graphical display computers, see Figure 4, which incorporates graphical display (with touch-screen functionality), computer, and power supply in *one single unit*.

Figure 3. The new Marine Controller from Rolls-Royce.

Figure 4. New range of graphical displays, here with a Poscon DP user interface.

Common Technology Across Systems

- Using common technology in the various control and monitoring systems has several advantages, such as
- Alignment and standardisation of products, spare parts and product appearance
- Common parts reduce the spares stock.
- Standardised interface library
- Standardised communication solutions
- Common tools and procedures
- Improved after market (service) handling

Middleware

Middleware is a standardised software package that provides an abstraction level between the real-time operating system and the different product applications (e.g. DP system software). The main purpose of the middleware layer is:

- Create independence of operating system and controller hardware
- Provide standardised mechanisms for signal routing and information exchange (messaging) between software components
- Scheduling of software components
- Standardised library for IO communications (Ethernet, fieldbus, serial lines, IO modules etc.)
- Facilitate component-based and distributed architecture of the control and monitoring systems

The middleware level is important for standardisation of the different applications and products running on the platform. The increasing library of software solutions that can be shared among different products enhance the quality and reliability.

The middleware is *essential* for obtaining effective integration between different systems, where the distributed architecture easily facilitates inter-controller messaging and signal routing.

Reducing Operational Complexity

The Human-Machine-Interface (HMI) has been a high focus area in the design process of the new products on the Common Control Platform, aiming at alignment of look-and-feel and operation across the different systems.

Industrial designers and experienced users have been consulted in the design process for new graphical interfaces, displays, consoles, panels and joystick and thruster levers. The new range of thruster levers has been awarded prices for good industrial design. Much effort has been placed on user-friendliness, effective and safe operation by providing the operator with easy access to the most important push-buttons and vital information on top level of the graphical interface.

Integrated Bridge Solutions

As a result of the Common Control Platform, new Integrated Bridge Solutions (IBS) are designed. When designing an integrated bridge, several constricting objectives are present. A new information layer will add additional components to the all ready complex bridge. The crux of integration is how to maintain system integrity, flexibility and space savings, while providing uniform, compact and well organized workstations for the user.

The key principles to accomplish bridge integration is:

- A clear definition of primary and secondary functions, and primary and secondary operator positions.
- Capability to let one screen show primary functions from many systems.
- Optionally use redundant screens to maintain safety at a given workstation.
- Independent access to subsystems at secondary operator positions.
- Modular workstations with defined geometry for hardware components.
- Modular, component based software to promote configuration management and distributed development.
- All design must be based on the same style-guide.

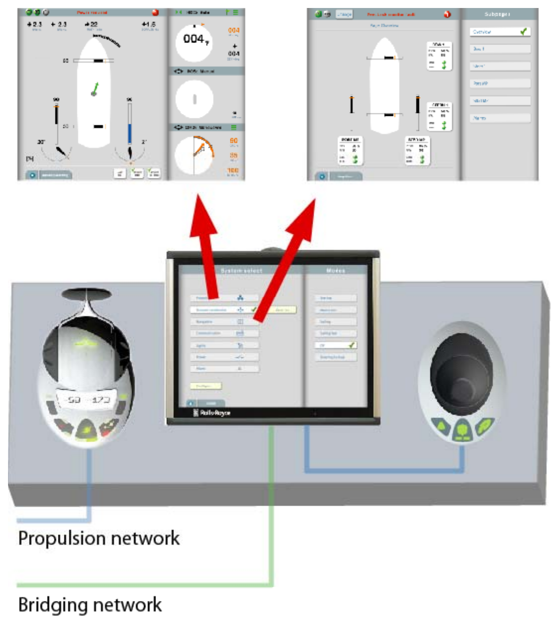

Figure 5 Wing workstation with integrated joystick and propulsion control.

Figure 5 shows a simplified sketch of a wing workstation with integrated joystick and propulsion control. The modular design of both hardware and software gives flexibility when making the arrangement. The top level display contains components for both joystick and propulsion control operations.

The wing-station is defined as a secondary operator station for the joystick application. The propulsion is a primary function, having a separate back-up communication channel for safe operation if a single fault in the screen should appear. The lever can then be operated totally independent of the screen, with indication on the levers. In case of a singe fault in the screen, the joystick can be operated at its primary operator position.

Since both applications are using the same underlying components, the graphical user interface appears with exactly the same "look and feel". The levers are also designed in the same style.

Integrating DP and RTC

In the early 90s several attempts were made to change the traditional way of controlling the thrusters. The individual remote control systems where removed and the handling of thrust control moved (and or centralised) to the DP control system. Obviously, the motives for this new approach where to simplify the interfaces and to integrate the control of thrusters with the DP systems.

For several reasons this integration approach failed and the lesson learnt are:

- Without proper system knowledge and proper control the drive systems can be overloaded, resulting in non-optimal or improper use of the thrusters or even cause permanent damage of the thruster
- Protective schemes in the remote thrust control systems for mechanical equipment are equally important as the control system itself
- It is difficult to detect failures and possibly even more difficult to place responsibility when failures occurs
- The supplier of thrusters must also deliver the remote thrust controls in order to take responsibility for operation of the thruster and related safety and warranty issues.

Traditional Solution – Direct IO

The traditional solution for communication between positioning and remote thrust controls has been as in Case 1 of Figure 1: Through two sets of IO modules and hardwired signals in-between, see Figure 6 for details.

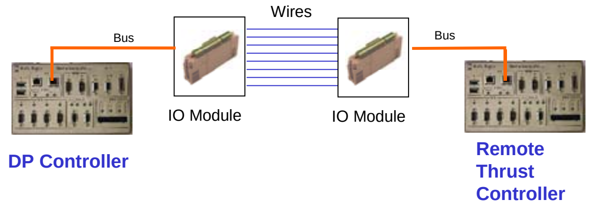

Figure 6 Hardwired interface example.

Typical signals in the standard hardwired interface are:

- Request / acknowledge status (digital)
- Pitch / rpm order and feedback (analogue)
- Power load active (digital)
- Available for DP
- Option: Azimuth thruster direction order and feedback (analogue)

Thrust command

The positioning system sends *request for command* signal to the remote thrust control system and receives acknowledge status signal if the thrust device can actively be controlled by the positioning system.

Failure detection

Failure detection with this interface is done through the mechanisms:

RTC failure:	DP looses acknowledge signal
Broken wire:	Current loop detection
Short-circuit:	IO module failure detection
Other errors:	Feedback-order monitoring in DP system – if available the DP system can detect steady-state deviations between order sent and received feedback value on pitch, rpm or direction

Failure Scenarios

The traditional interface to remote thruster control has obvious limitation in information sharing in error situations. Consider the two scenarios below:

Failure scenario 1. In some situations with error internally in the remote thrust control system (internal error, mode of operation, IO error) the only available error response is to release the acknowledge signal to DP. However, information on the causes for this action will not be available on the DP system.

Failure scenario 2. In situations requiring load reduction on the thrusters, due to e.g. high torque it is only the digital signal *pitch reduced* available. There is no information on the effects of this reduction, and the DP system cannot predict the behaviour of the RTC system. The lack of information may affect the dynamic DP performance, especially in critical situations where the power usage and thrust demand is high.

Disadvantages

Potential problems and drawbacks with the traditional interface are:

- Scaling of IO signals must be performed on both DP system and thrust control system (repeated for each thrust control unit) – a **time consuming** task, where both DP supplier and thruster supplier must be involved
- Installation cost
- Difficult and expensive to expand or change the interface during a delivery project run
- Hardwired interface provides limited information exchange between systems
- Difficult to establish root cause of errors, both DP supplier and thruster supplier are often involved in failure detection
- ‘Double protection’ schemes may limit the overall vessel performance when related functionality is present on DP and thrust control system (e.g. bus-power limitation and individual thruster load reduction).
- Misunderstandings, difficult to establish fail-safe handling when two suppliers are involved, especially if one of the parties changes the interface.

Network-Based Functional Integration of DP and RTC

Following the approach of Case 3 in Figure 1, network-based integration of positioning system and remote thrust control is achieved based on:

- DP Ethernet, for internal DP communication and interface between DP and RTC
- RTC Ethernet and CAN, for internal RTC communication

Functional integration of these two systems gives benefits through:

- Alarm and failure handling
- Operational information sharing; DP modes and operation, thruster operation and limitation
- Increased performance and safety by co-operating DP thruster utilization

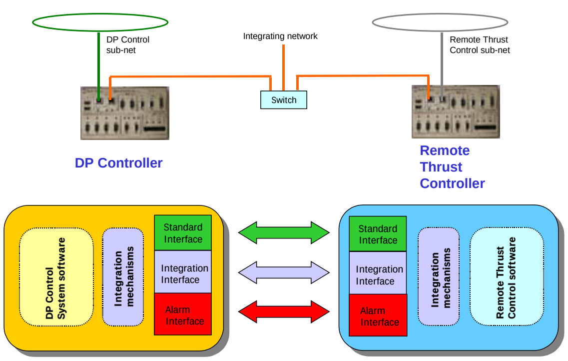

Figure 7 Integrated interface example.

The required system integrity and network load control is maintained by:

1. Dedicated channels for data transfer between the systems, segregated from the original (sub-) networks. And applying appropriate network protection mechanisms
2. Special routing mechanisms on both the RTC and DP system, where signal and information is specified on both ends.

The new interface comprises:

1. Original interface – stand-alone solution (green)
2. New integration interface
3. Alarm and monitoring exchange interface

This integration concept in Case 3 retains the independence and integrity mechanisms of the traditional solution (Case 1) through software solutions on network and controller level. At the same time, the flexibility of a software interface is introduced.

Based on the discussion above, the integrated solution can have several advantages, such as

- No need for IO scaling, hence more effective commissioning and interface tests, only one supplier involved.
- Less components, less cabling
- Flexible and expandable interface (also late in projects)
- New functionality possible (advanced load reduction etc)
- Improved alarm handling and information sharing

Inter-system Information Sharing

What is wrong – where? Information sharing between systems, gives access to failure, cause and effect (locally). Through alarm filtering and alarm expansion may e.g. a high-level thruster alarm in DP be expanded down to detailed alarm status in the remote control system.

Thrust device operations

Another operational requirement has been to provide flexibility for running thrust devices in combinations with manual lever control. Typically, one fore thruster can be used for auto heading control, while the operator manages the position of the vessel by levers.

Thrust devices can also be temporarily set to *Idle*, while the positioning system keeps the order to neutral value.

Design restraints

According to classification rules, a bus-oriented design must take into consideration that:

- Independent joystick and DP system may not share the bus connection (e.g. DNV)
- Levers must have independent wiring
- Each sub-system must maintain its own system integrity and potential errors in one system shall not affect or transmit to the other systems
- Independence of DP Backup system for DP 3.

Single Point of Contact

Integration of positioning products and remote thrust control exploits the potential in vendor single point of contact; one service engineer may handle thrust signals all the way, covering both remote thrust control and its interfaces to independent joystick and DP system.

Remote Thrust Control

A new series of remote thrust control systems from Rolls-Royce are also launched in 2005. The new products are based on hardware and software solutions from the Common Control Platform. The remote control system can control any kind of propulsion device.

The most evident changes compared to the existing products is the touch-screen based graphical user interface (see Figure 8) and the new thruster levers with integrated push-buttons and indicators, see Figure 9.

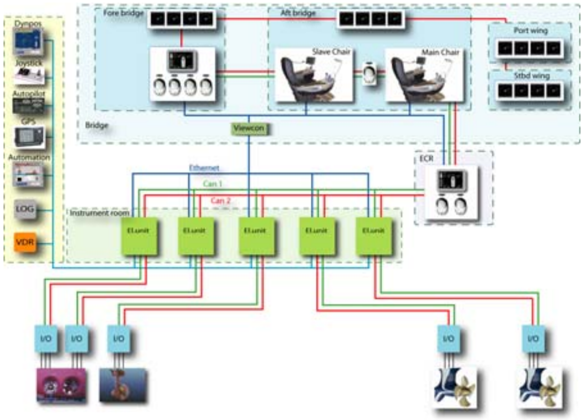

Figure 8 Remote thruster control configuration

Any operation of the system can be performed through the graphical interface. The most vital operations can in addition be performed by using dedicated pushbuttons on the control lever.

Control lever functions

Potentiometers and electronics for both normal and backup system are integrated in the lever. The display in the socket shows commands from the lever (pitch/rpm and direction).

The control lever has a dual CAN-bus interface for each propeller (*normal* and *backup*), and comprises all functionality required for backup operation. In an emergency situation, where *backup* operation is required, the user will proceed the operation using the same lever as in *normal* mode.

Figure 9 New thruster lever from Rolls-Royce with integrated push-buttons and indicators in the socket.

Graphical User Interface

The new remote control system also incorporates a touch-screen display; *ViewCon*, where detailed information on the thruster system is presented in normal operation, see Figure 10.

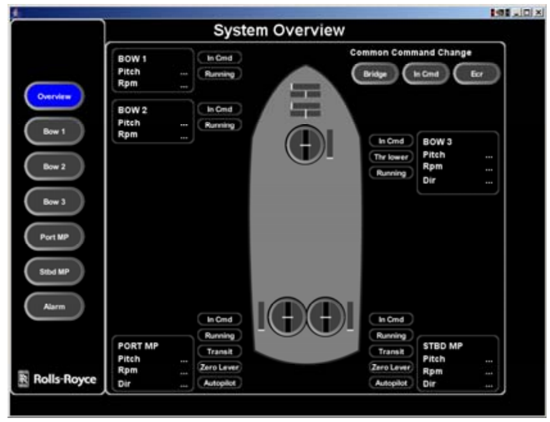

Figure 10 Graphical user interface on the New HCX remote control system

ViewCon comprises:

- *Main view page*, with overview of order and feedback for all thrusters, transfer between command positions on bridge (common in command) and access to detail-level pages.
- *Individual thruster pages*, including detailed information and operations for each thruster.
- *Alarm page*, with all thruster alarms in detail.

Adjustments of the remote thrust control system can be done via the display pages.

Positioning Product Range

Over the last 30 years, the Poscon joystick system from Rolls-Royce has been supplied to more than 500 vessels worldwide, mainly to the offshore market. A new version of the Poscon joystick was introduced in 2004. In 2005 an extended version of the new joystick system, *Poscon DP*, was released to the market, having functionality also for dynamic positioning, see Figure 11. This particular product is aimed towards vessels that traditionally would have joystick system installed, e.g. cruise vessels, mega yachts, ferries, tankers and workboats. The new Poscon Joystick can easily be extended to the easy-to-use Poscon DP system.

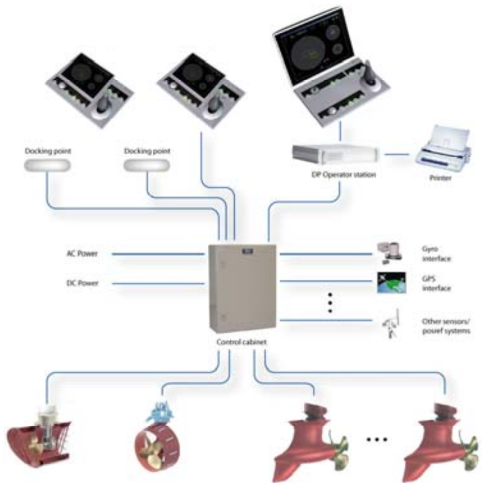

Figure 11 Poscon DP configuration, including DP and Joystick operator stations.

A range of DP systems targeting the ‘professional’ DP market are launched in 2006. The DP systems will comply with IMO DP Class 1, 2, 3 and all relevant class notations. In addition, the range of DP systems are designed in compliance with the new DNV class notation for Hardware-in-the-loop (HIL) testing.

DP Design Highlights

Development of new positioning products is performed in close co-operation with key customers in different market segments. The following key areas has been prioritised:

- Safe, intuitive and easy operation
- Positioning performance and thruster utilisation
- Reliable and flexible vessel operation
- Configuration flexibility

These design topics are addressed in the following sections.

System Operation

At the Human-Machine Interface (HMI) level emphasis is put on safe, easy and intuitive system operation. Any experienced DP operator shall easily get familiarised to the operation of a positioning system from Rolls-Royce.

The operation of a positioning system can be regarded as three level of interaction:

1. Continuous operation – monitoring the system by a quick glance and active control by using joystick levers or heading wheels.
2. Most common or critical operations – easy access to push-buttons or indicators on the operator station, only vital or critical information presented on the graphical display.
3. More rare operations or detailed information requests – use the screen for access to detailed views or make changes in system settings.

According to this three level of interaction approach, the number of push-buttons and lamps on the operator stations are reduced to a minimum – only those significant for operation of the system remains, see Figure 12.

Figure 12 Poscon DP operator station.

Performance

Performance of automatic positioning systems are mainly related to

- Accuracy of automatic control of vessel heading and position

- Utilisation of thrusters, main propellers and rudders to achieve the desired positioning and heading keeping, including interaction with the power plant
- System's ability to handle potential failure situations, especially related to position reference systems
- Reliability of the complete positioning system including operation of it

As the major vendor of propulsion equipment and thrusters, the Rolls-Royce positioning systems put extra attention on effective and optimal utilisation of this equipment. The company's know-how in e.g. thruster performance and hull interaction under various conditions is applied.

Thrust Device Utilisation

Several objectives exist related to propeller and steering utilisation

- Fast response of thrust generation
- Vessel speed
- Wear and tear, noise and vibration
- Fuel consumption
- Propeller and steering efficiency (including loss effects and speed effects)
- Positioning performance
- Positioning capability

Some of these objectives may contradict, and proper trade-offs and features are sought for different operations.

Vessel Operation

DP Class Monitoring

The general IMO rules of DP operations (Class 1, 2 and 3) have played a fundamental role in the design of the DP systems. As a consequence, the operation and navigating in the graphical user interface is strongly related to the selected DP Class operation. At a glance, the *DP Class monitoring* function will immediately provide an overview on failures or risks related to the present DP operation. The DP Class monitoring function continuously verifies

- Status and number of *active sensor and position reference systems*, related to the class requirement
- Status and number of active *thrust devices*, related to the class requirement
- Power split and status of *power system*, related to the class requirement
- Status and configuration of the operator stations, networks and hardware components of the complete *DP control system*, related to the class requirement
- Status and result of the on-line *consequence monitoring* function (Class requirement for DP 2 and DP 3 operations)

From the DP Class monitoring overview page the operator can easily access more details on the different systems and functions by using the shortcuts on the graphical display.

Configurations

Modularity and Flexibility

To facilitate configuration flexibility, the positioning products have a distributed architecture based on modular hardware and software components. This provides flexibility in configuration and number of operator stations, IO stations and controllers.

Design of operator stations and controllers are fully independent, supporting the configuration flexibility.

Software and Software Handling

As products become more and more software based, software standardisation is crucial. The Rolls-Royce positioning products are fully based on applying identical software revisions for different vessels and between the different products. No software compilation is done onboard vessels or to specific projects.

On the other hand, software revision upgrades are easily installed on any system component onboard vessels. The only required tool is a memory-stick.

Redundancy – triple voting

In DP 2 and DP 3 systems the main DP system is based on triple controllers as standard. The triple controller concept is chosen as standard because:

- Easy to handle failure situations by output voting principle (2 out of 3 principle)

- In the dual controller case the operator must decide which part if the control system that is faulty (in many cases difficult to decide)

Pilot Installations

The *Poscon DP* pilot was successfully installed on the Norwegian Cost Guard vessel K/V Harstad in January 2005. The system comprises integrated remote thrust control and DP.

Figure 13. Norwegian Cost Guard vessel, KV Harstad. Rolls-Royce UT 512 design with Poscon DP system.

Simulation and Testing

Extensive use of simulators and mathematical models is a keystone of the design process of the new products. The Rolls-Royce marine know-how within propulsion systems, ship design and control has been accumulated into a sophisticated simulation framework, comprising models of

- Vessel motion in 6 degrees of freedom
- Propellers and rudders
- Sensor and position reference systems
- Power system.
- Anchor and mooring systems

By extensive use of simulation and analysis during development and delivery project stages, we obtain

- Possibility to verify response to conditions and operations that cannot be fully tested in real-life, including failure modes and effects.
- Product quality assurance
- Possibility for factory tests of complete integrated solutions, not only single systems
- Reduced time for configuration, commissioning and sea trials

The simulation framework also enables testing of integrated solutions, such as combined DP and remote thrust control operations.

The flexibility and performance of the Rolls-Royce simulation framework was demonstrated by the installation of a complete anchor-handling simulator at the Offshore Simulator Center at the Aalesund University College in Norway in April 2005. Here, a copy of the aft bridge and its systems on an offshore vessel was replicated, including winch control systems, steering gear, propulsion control and DP / joystick systems from Rolls-Royce. The operation is realistically visualized on 3D screens with different view-points.

Figure 14. Visualisation in 3D of complete anchor handling operation at the Offshore Simulator Center (OSC) in Aalesund, Norway.