How to increase the safety and efficiency of anchor handling operations

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Introduction

Kongsberg Maritime has developed a new, innovative Anchor Handling Concept representing a shift of focus from stand-alone equipment, boxes and systems over to developing functionality especially for the Anchor Handling (AH) operation itself. The concept is characterized by a much higher degree of integration of the different components and equipment supporting an AH operation than existing solutions. Human-Centered-Design principles have been used extensively during the development phase of the new concept.

One of the new components is a system and method for real-time calculation and visualization of the stability of the vessel based on determining external loads/forces. In addition, new DP functionality has been developed especially tailored for the Anchor Handling operation.

The ‘king-pins’ and the centers for control, monitoring and presentation of information are two K-Master operator stations on aft bridge comprising a common and intuitive user interface and control for all AH equipment operated from aft bridge. In short, the concept comprises:

- Improved DP and maneuver control capabilities during the different phases of an AH operation.
- Real-time estimation of external forces and calculation and visualization of the vessel’s stability margin.
- A common and intuitive presentation of the current operational situation for increased local and shared Situation Awareness (SA) for both vessels and the rig.
- Interfaced with KM’s SIMOPS, the system offers use of datalinks in addition to voice communication for information exchange between all participating vessels.

Demanding Offshore Marine Operations

The background and the “driving force” behind the development of the new AH concept is the need for meeting the challenges posed by increasingly demanding Offshore Marine Operations:

- Anchor handling, rig moves, heavy lift operations, subsea construction, pipe-laying, FPSO offloading etc. all push people, vessels and systems to their limits.
- Deeper waters, heavier loads, larger forces, tougher environments, demanding weather conditions
- Control systems, organizations, operations and tasks have, as a consequence of this, become increasingly complex and challenging.
- The consequences of making wrong decisions during failure or stress situations can be disastrous.

To Kongsberg Maritime (KM), design is about maximizing performance through user-centered design and simplification.

This implies a change of focus from being “technology-centered” to being more “human-centered”, i.e. Human Factors play an increasingly important role in developing new control systems for offshore marine operations. Simplification indicates that systems should be less complex and more intuitive to use, but it also means to remove and strip down functionality instead of adding more functions and technology.
AH Concept and Components
The figure below shows the main components that constitute the new KM Anchor Handling concept. A detailed description of the System Architecture and the new functionality developed is found in the following.

System Architecture and K-Master Integration
The ‘king-pins’ and the centre for control, monitoring and presentation of information are two K-Master operator stations on aft bridge. K-Master is the main building block and the ‘enabling’ key to both the tight integration and to a common and intuitive user interface across system boundaries.

By the new concept, KM provides a complete aft bridge arrangement with K-Master workstations for AHTS in accordance with NAUT-OSV (DNV):

- Ship handling
  - Dynamic positioning
  - Independent joystick control
  - Manual thruster/ propulsion control
  - Conning
  - Chart radar
- Radio communications
- Alarm and monitoring/ control
  - Machinery and ship equipment
- Bridge auxiliary equipment (Deck light, window wiper, search light, etc.)
- Winch and deck equipment control

**Typical aft bridge arrangement of anchor handler**

The forward bridge is assumed to be a standard navigation bridge, arranged and equipped for use during vessel transit. As a minimum, it is equipped according to general SOLAS Chapter V requirements, and even if the vessel is classified according to a nautical safety standard (e.g. DNV NAUT-AW or NAUT-OSV) no AH specific controls are expected to be installed on the forward bridge.

The focus is thus on the aft bridge where there are two workstations, one for ship handling and one for controlling the AH equipment (“aft support”). Unless the vessel is designed according to DNV NAUT-OSV requirements, there are no or little requirements to the arrangement of these stations other than the general requirement for a practical workstation for safe operation.

The KM aft bridge workstations shall meet the NAUT-OSV(A) requirements. In particular this means that a chart radar display needs to be available in the ship handling workstation and a conning display needs to be visible from both stations. The aft support station shall be equipped for safe operation of the winch system and include CCTV monitors for observation of the winch and spooling system. It shall also include devices for instant takeover of the manoeuvring function from the ship handling workstation.

Realized with K-Master workstations, the basic arrangement could look like illustrated below (the “out of the window view” indicates that some monitors are suggested located above the aft windows):

![Figure 3 Typical aft bridge arrangement](image-url)
The ship handling station is shown to the right (port side) and the anchor handling (aft support) station to the left (starboard side). Each station has 4 displays—two overhead and two on the side. In principle, both stations can direct any available image to any display. However, the CCTV displays are suggested “fixed” although the camera feeding the display can be selected from the aft support station.

A supplementary console may be located in between the chairs to arrange auxiliary controls not included in the chairs. Additional indicators (thrusters, wind, etc) may be located together with the monitors above the windows.

The main functions in the ship handling workstation is DP and manoeuvring, supported with views from DP, DP position reference systems, vessel automation, conning and chart radar. The aft support station has controls for winches and deck equipment, together with views showing details about the winch system and with CCTV images. Both workstations are equipped with

- Two TCPs
- One DP joystick
- One thruster control command transfer panel
- One workstation alarm panel

Workstation for anchor handling

The next figure illustrates the controls considered necessary for safe operation of the AH winch system and deck equipment. The exact approach for implementation will be a case between KM and the equipment manufacturer.

![Figure 4 Workstation for anchor handling](image-url)
Workstation for ship handling

The next figure illustrates how the workstation for ship handling is equipped.

Anchor Handling Challenges

A DP system’s main function is to counteract and balance out all the external forces by the use of available thruster forces as illustrated on the figure. During Anchor Handling, very large external forces are acting upon the vessel. This influences both the stability and the manoeuvring capabilities, including the DP functionality, of the AH vessel. It is accordingly very important to measure and monitor the forces originating from the anchor line, wire or chain. Two of the main challenges to be addressed during Anchor Handling operations are therefore:
1. How to calculate and visualise the stability margin in real-time?
   On-line calculation and monitoring of stability margin is only possible if one has an estimate or measurement of the external forces acting upon the vessel.

2. How to improve DP and manoeuvre ctrl capabilities (heading & sway control)?
   The DP needs to know the very big external forces from anchor line or chain to minimize deviation from wanted heading and track-line.

The solution to both problems is to develop a system that gives a sufficiently accurate estimate or measurement of the horizontal and vertical forces acting on the vessel from the anchor line or chain in addition to the attack point for these forces. To-day, mainly the tension on the anchor winch is measured, but this will have no value when the line or chain is locked by the shark yaws. In addition, by only measuring the tension, the vertical and horizontal angles of the lines are unknown.

Anchor Line Forces Estimator

The figure shows a possible solution to the problems by a combination of sensors and instrumentation and a calculation of the forces based on a mathematical model of the anchor line. The readings from a number of sensors, e.g. one for measuring the vertical and horizontal angle of the line and one for measuring the tension are input to a Sensor Fusion & Filtering block, which main function is to combine the measurements, perform roll, pitch and heave compensation, filter the measurements and finally to translate the force readings to a common reference coordinate system.

Catenary calculation

The Estimator contains a Catenary calculation block that runs in parallel with the sensor elements. This functional block calculates the catenary profile of the wire or anchor chain based on line/chain parameters, initial conditions, length of wire given out from the rig, water depth and the AH vessel’s speed and heading.

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**Figure 8 Anchor Line Forces Estimator**

**Figure 9 Example of a catenary profile**
The difference between the force measurements from the sensor fusion block and the predicted forces from the Catenary block is weighted with a proper gain factor, fed back to the Catenary block and used as a correction term for this mathematical model, thus constituting a structure similar to a Kalman filter. The main reason for implementing the force estimator with this structure is to achieve a more robust solution, i.e. it should function also under periods of missing or corrupted “raw” sensor measurements and it should provide better filtering of the data.

The filtered “A posteriori” estimates of the force (attack point, total forces, horizontal force and vertical force components) are sent to the two main consumers, the DP-system and the on-line stability calculation and monitoring system.

Improved DP Functionality in Anchor Handling

The full 3-axis control by the DP system is normally not used in all phases of an AH operation. A mix of manual and automatic control is more common, e.g. manual control of the main propulsion in the surge direction combined with automatic sway and heading control or heading control alone. The main problems when using a DP system in an AH operations are connected to:

1. Very large ‘unknown’ external forces are acting upon the AHV from the anchor line. These forces are normally neither measured nor estimated to-day during all phases of the operation.
2. Due to these unknown external forces, the DP system will have problems keeping the heading deviation and also sway offset (cross track error) within acceptable limits. One often experiences large static offsets during periods of high anchor line tension.
3. For AHVs with traditional mechanical propulsion and shaft generators available Bollard Pull (BT) is reduced by power consumption of the thrusters. Similarly the available power to thrusters is limited because of priority given to BT.

The figure below shows a simplified block diagram of the main control loops and Kalman-filter of the KM DP-systems.

Figure 10 DP System Block Diagram
As shown on the figure, the total amount of external, unknown forces acting upon the vessel is, in its basic form estimated via integration over time of the Kalman filter’s innovation signal, i.e. the deviation between the measured positions and heading and the predicted, ‘a priori’ estimates of the same.

One possible explanation why the DP-system has problems keeping the heading and/or sway deviation below acceptable limits is that this method of estimating the unknown forces signal is too slow and that the Integral part of the control-loop consequentially does not function properly.

There are, in principle, the following ways to solve this problem:

1. To manually input (an estimate of) the total tension from the wire, the attack point of the force and the vertical- and horizontal angles of forces.
2. To develop a new system for estimation of these forces as described in the previous sections.
3. To develop new algorithms and mathematical models integrated in the Kalman filter for better estimation of and compensation for external forces.

All the above listed functionality have been implemented in the new concept resulting in a highly improved DP maneouvring capability in all three axis during an AH operation.

**Real-time stability analysis & monitoring system.**

The information about the estimated anchor line force, attack point and horizontal and vertical angles are also input to a load calculator that, including input from other sensors on board the vessel calculates the stability margin in real time.

The next figure gives an example of how the stability situation is visualised and monitor. The upper left display area/view is oriented aft of the vessel and indicates the limits of the force as a function of the horizontal angle of the line. The light blue dot indicates the current value of the forces and the shaded area shows the trend.

The data below the window shows three numbers, the tension used by the DP system, and the horizontal (azimuth) and vertical angle (elevation) angles of the anchor line. The icons to the right of the numbers indicate a measured value, a calculated value and a keyed-in value respectively.

The small window in the upper right corner shows a trend curve for the stability margin and the window below shows the trend for the list (static roll). Both curves show in this case a negative trend concerning stability.

*Figure 11 Stability Margin Visualization & Monitoring*
Shared Situational Awareness and SIMOPS

To-day, most of the exchange of information and data between all participants in an AH operation is done via voice over radio, mainly VHF. This is not an optimal solution as information easily can be misunderstood and or misinterpreted, but the more important consequence is the lack of direct and real-time exchange of digital computer-to-computer information. Examples of the latter may be the length of wire or chain given out from the rig, the accurate distance between the AH’s stern and the rig, the distance between each AH vessel etc. The consequences of not having real-time exchange of digital information and status between the different participants in an operation can be that actions to prevent accidents are taken too late or not at all. The need for a ‘Unified Communication Solution’ or local Datalink in the operation area is therefore obvious.

Kongsberg Maritime has developed the SIMOPS (Simultaneous Operations) system which includes a newly developed marine broadband radio that together with the standard AIS system constitute both datalinks between the participants and display systems showing the overall situation pictures for all participants. The SIMOPS system has been fully integrated into the new AH concept and offers:

- Shared Situational Awareness (SA) through consistent real time visualization on board all SIMOPS capable vessels
- Robust and reliable communication between SIMOPS capable vessels via Broadband Radio. AIS is used on-board none-SIMOPS capable vessels

![Image of Shared Situational Awareness and SIMOPS](image-url)
Anchor Handling Situation Awareness Plots

A series of new display pages, views and plots have been designed to increase the local Situational Awareness of the operators. The new display pages are called Anchor Handling Situation Awareness Plots and two of them are shown below.

**Figure 13 AH Situation Awareness Plot, Example 2**

In the upper left corner of this AH Plot we see the two trend curves for stability margin and list in addition to two bar graphs showing the consumed power on the two power buses. The large view on the left side shows a North-Up oriented overall surface situation with the rig in the middle, the anchor pattern and the number of each anchor line. Own ship has got a rectangle drawn around it. The right view shows a “blown-up”, Aft-Up view of the situation around own ship in this rectangle. The track line and the corridor is shown including the cross-track error (XTE) in addition to bearing and range to “target”, i.e. the drop point of the anchor. In the center column icons or pictograms are used to indicate in which control modes the surge and sway axis and the heading are in. On the figure, the surge axis is controlled by (manual) levers, the sway axis is controlled by the joystick and heading is controlled by the machine, i.e. the DP computer.

**Figure 14 AH Situation Awareness Plot, Example 2**
Conclusion

How will the presented concept increase the safety and efficiency of Anchor Handling operations level?

- By using principles and ‘best-practice’ from Human-Centered-Design during the development and implementation of the concept.
- By focusing on the task that the vessel is to perform and thus performing operational adaptation through integration of previously stand-alone equipment.
- By shifting focus from equipment, boxes and systems over to developing functionality especially for the AH operation.
- By offering a unified Human Machine Interface (HMI) for many subsystems via the K-Master workstation.
- By supporting increased local and shared Situation Awareness though AH and SIMOPS Situation Plots.
- By supplying Decision Support tools, e.g. on-line calculation and visualisation of the stability margin.
- By having a DP and manoeuvre control system with functionality especially tailored to the operation.
- By the use of datalinks instead of voice communication for information exchange between all participating vessels and between vessel and rig.
- By offering a comprehensive training package including DPO courses and operational AH training as the solution is integrated with Kongsberg Simulation’s new Offshore Vessel Simulator for operational training.

Even if the picture shown below is not from an AHTS vessel, it illustrates in a good way what we want to achieve with KM’s new design approach, namely a system operating in fully automatic mode, all ‘lights are green’ and with a relaxed and happy operator sitting in his K-Master chair.