**DYNAMIC POSITIONING CONFERENCE**
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**Thrusters Session**

# From Factory to Field: Ensuring Thruster Performance - Verification and Validation

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## Abstract

**Thruster verification and Validation**

This paper presents KM's approach to addressing the Verification and Validation (V&V) challenges associated with implementation of thrusters and propulsors, focusing on how discrepancies between expected and actual performance can impact vessel operations. It examines scenarios where thrusters appear to operate at full capacity but deliver less thrust than anticipated, highlighting the importance of identifying and understanding such mismatches.

These discrepancies often stem from errors introduced within the integrated systems such as Programmable Logic Controllers (PLCs) or automation frameworks and human errors in design and/or implementation. A key concern is ensuring that localized performance losses are accurately captured and communicated, as they can have significant implications for the vessel's overall operational capability.

These challenges extends beyond detection—it involves recognizing how these issues affect assumptions about vessel performance, which typically rely on idealized capacity figures. When integration errors or intentional limitations in control systems go unreported, operators may unknowingly rely on reduced capabilities, increasing the risk of hidden failures and operational incidents.

KM's methodology emphasizes need for thorough analysis and documentation during the design, implementation and delivery of equipment to the vessel. This paper also raises the need for communication of findings and documentation to be incorporated within the vessel Failure Modes and Effects Analysis (FMEA). The paper advocates for improved communication of local performance issues to ensure they are properly reflected in global vessel assessments, thereby enhancing operational reliability.

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## 1. Failure Modes and Effects Analysis (FMEA)

Failure Modes and Effects Analysis (FMEA) is a core element of validation and risk mitigation strategy throughout the thruster lifecycle. Each thruster is delivered with a system-specific FMEA worksheet which identifies critical components, potential failure modes, detection mechanisms, and corrective actions - especially for scenarios affecting dynamic positioning (DP) capability.

FMEA inputs are derived from multiple validation stages:

- From Factory Acceptance Testing (FAT), where mechanical integrity and functional responses are confirmed
- From commissioning, where alerts, control logic, and feedback signals are tested under simulated fault conditions
- From DP readiness supervision, which identifies faults in control interfaces or hydraulic systems that could compromise positioning
- From Condition Monitoring (CMS) and Remaining Useful Life (RUL) systems, which can reveal developing or progressive issues not captured during early tests

Observed discrepancies—such as alerts not triggering during partial thrust loss or unexpected actuator behavior—are used to update and refine the FMEA prior to final acceptance. This ensures that the thruster's known limitations and failure responses are fully documented, traceable, and communicated to operators, classification societies, and vessel DP assurance teams.

Table 1: Simplified FMEA worksheet for DP-Critical Thruster Functions. shows a simplified FMEA example highlighting failure modes in key subsystems. These include power loss in azimuth control units (ACUs), signal errors in thrust direction transmitters, pressure loss in the hydraulic system, and lubrication issues. For each case, the FMEA outlines failure effects, alert detection logic, and potential corrective actions—such as fallback to local hydraulic control or operational limitations.

| No | Equipment name and indentify code (overview dwg) | Failure effect | | Failure detection | Failure cause | Corrective action | Remarks |
|---|---|---|---|---|---|---|---|
| | | Failure Mode | End effect | | | | |
| 1,1 | Azimuth thruster control unit (ACU) | Power failure<br><br>Computer failure | Manoeuvrebility lost. | "ACU failure" in alarm unit | Fuse is switched off or power supply failure.<br><br>Malfunction in CCN unit (EEPROM, internal power or program execution). | Control locally by hydraulic valves is usable. | |
| 1,2 | Azimuth thruster control unit (ACU) | I/O unit failure | Manoeuvrebility lost. | "ACU failure" in alarm unit | Disconnection or malfunction in control devices or SLIO unit | Control locally by hydraulic valves is usable. | |
| 2,1 | Thrust direction transmitter | Mechanical or electrical failure | Manoeuvrebility lost. | "ACU failure" in alarm unit | Malfunction in thrust direction transmitter (internal power, cable). | Control locally by hydraulic valves is usable. | |
| 3,1 | Hydraulic system | Booster pressure low | Manoeuvrebility lost. | "Booster pressure low" in alarm unit | Malfunction in hydraulic system, hydraulic pump motor starter. | | |
| 4,1 | Lubrication system | Lubrication oil pressure low | Manoeuvrebility stays. | "Lubrication oil pressure low" in alarm unit | Malfunction in lubrication system, lubrication pump motor starter. | | Only short term use of PM is allowed |

*Figure 1. Table 1: Simplified FMEA worksheet for DP-Critical Thruster Functions.*

## 2. Factory Acceptance Tests (FAT)

Before delivery, each UUC thruster undergoes a structured Factory Acceptance Test (FAT) at the Kongsberg Maritime facility. FAT is a key part of the company's quality assurance process and is conducted according to internal engineering guidelines and documented procedures. The primary objective is to verify the mechanical integrity and functional performance of the main thruster components before shipment.

Factory Acceptance Tests are performed under the supervision of the classification society when applicable, and customers or their representatives are welcome to witness the tests.

The FAT process includes the following stages:

- Preparation, including mounting the thruster on a dedicated test bench with the propeller facing downward, connecting piping and cabling, filling the system with oil, and cleaning the surrounding area to allow for visual leak detection.
- Spinning test, where the input shaft is rotated by an external hydraulic motor for a specific duration. This test confirms that there are no oil leaks, that the bearing and seal temperatures remain within acceptable limits and that no abnormal noise or vibration is present.
- Steering hydraulics test, which includes pressure testing of piping and components, setting of pressure relief valves, validation of brake function, and full steering motion verification.
- Control equipment test, where thrust direction transmitter function and signal integrity are confirmed.

Measured values such as RPM, pressure, temperature, and oil levels are logged throughout the process. Any deviations are documented, addressed, and revalidated prior to final acceptance.
The FAT procedure is carried out in accordance with Kongsberg Maritime's certified management systems, which include:

- ISO 9001: Quality Management
- ISO 14001: Environmental Management
- OHSAS 45001: Health and Safety Management
- EN 3834-2: Welding Quality Assurance

The FAT layout and test bench configuration are illustrated in Figure 2

*Figure 2. UUC thruster prepared for factory acceptance test.*

## 3. Commissioning

Verification and Validation (V&V) of thruster control system begins with thorough commissioning to ensure that performance aligns with design expectations. For Kongsberg Maritime's thruster systems, this process combines structured calibration, signal verification, alert validation, and physical system checks, supported by tools such as the Handheld Terminal (HHT) and formal startup checklists.

During commissioning, the HHT is used to configure and verify analog and digital I/O channels, simulate command signals, and monitor real-time feedback from steering and thrust sensors. This enables detection of scaling mismatches, signal polarity errors, or encoder misalignments - common causes of hidden performance degradation.

Key control-related steps include:

- Calibration of azimuth and speed (RPM/pitch) feedback encoders using defined analog input ranges
- Simulation of control signals to verify correct actuator response from controller
- Alert testing to confirm that deviations in thrust, speed, or steering trigger appropriate alerts
- Validation of command/feedback tracking under both manual and automated control modes

In parallel with control validation, mechanical startup procedures are carried out in accordance with the commissioning guide which includes:

- Verification and filling of lubrication and hydraulic systems, including air bleeding
- Function checks of shaft brake and flushing of shaft seals
- Startup of gravity drain, main hydraulic pumps, and maintenance hydraulics with proper direction and suction checks
- Initial steering movement trials in both clockwise and counterclockwise directions

Sea trials are conducted in sufficiently deep water, following a structured run-in schedule. Power is increased incrementally over a specified period, with continuous monitoring of parameters such as:

- Lubrication and steering hydraulic oil pressures and temperatures
- Inlet/outlet temperatures of lubrication and steering cooling systems
- Speed and thrust response
- System behavior under full load at maximum speed for one hour

A specific focus is placed on validating that steering angle demand, encoder feedback, and actual thruster position remain aligned. Deviations are corrected via encoder calibration or scaling adjustments. Similarly, thrust validation ensures that actual motor output matches command input, with HHT signal tracing used to verify that alerts respond appropriately to test conditions.

Post-sea trial, final flushing of seals is performed, and all configuration and measurement data is archived for traceability. Any deviations found during testing are resolved before the thruster is accepted into DP or mission-ready use.

By incorporating simulation-based testing, system diagnostics, and full-scale mechanical testing, KM ensures that each thruster installation is tuned, validated, and verified for safe and reliable operation in demanding offshore conditions.

**Control System Alerts**

Effective control system alerts are essential for identifying discrepancies between commanded and actual thruster performance - especially when subsystems report nominal operation. In Kongsberg Maritime's

thruster systems, the automation platform generates alerts for both hardware and logic-related issues. These are logged, displayed via the HHT terminal, and forwarded to bridge alert systems.

To ensure Verification and Validation (V&V) accuracy, particular attention is paid to alerts that can indicate performance degradation. These include both direct thrust losses and steering malfunctions that may not trigger full alarms but still affect vessel performance.
Key alerts related to steering and thrust include:

- Thrust Loss
- Thrust Command/Feedback Deviation
- Thrust Failure
- Speed Command/Feedback Deviation
- Speed Feedback Error
- Steering Command/Feedback Deviation
- Steering Failure
- Steering Feedback Error

These alerts support proactive diagnosis and are logged with timestamps for traceability. KM's methodology emphasizes integrating these alerts into FMEA processes and acceptance testing. This ensures that control system behavior reflects actual capabilities, improving reliability assessments and reducing the risk of hidden failures.

## 4. Automatic Safeguards for DP Thruster Control

A thruster is considered "ready for DP" when it is fully operational, under remote control, and able to respond reliably to steering and thrust setpoints from the Dynamic Positioning (DP) control system. In Kongsberg Maritime systems, readiness for DP depends on both hardware status and the integrity of communication with the DP interface.

When in DP mode, the thruster accepts continuous speed and azimuth commands from the DP system. The control system supervises these inputs and monitors several internal readiness criteria. If the steering angle setpoint signal from DP is lost, the propulsion unit will respond to a defined fail-safe condition which may include *frozen to last set* or *fail to zero* depending on control mode and state.

In addition to DP command supervision, the following conditions must be fulfilled for the thruster to be considered DP-ready:

- Hydraulic steering pressure must be OK — if steering pressure is too low or lost, the system will block azimuth movement and signal a fault
- Feedback signals must be valid — loss or error in speed or steering feedback will take the thruster offline
- Internal control communication must be intact — any CANALARM or SLIO I/O fault can disable functionality
- No local/remote control conflict — the thruster must be in remote (DP) command without interference from local stations
- Emergency stop and interlock conditions must be cleared
- Power supply and actuator status must be within operational thresholds

The control system includes logic to supervise these conditions continuously. If any of the conditions are violated, the thruster is taken offline from the DP system and locked in a safe state, with alerts routed to

both vessel automation and the bridge. These safeguards ensure that the thruster only participates in DP when full control authority and functional reliability are confirmed.

The overall system architecture showing the interaction between DP control, actuator control units (ACUs) - in some cases referred to as thruster field stations, and individual thruster drives and AZT units is illustrated in Figure 3.

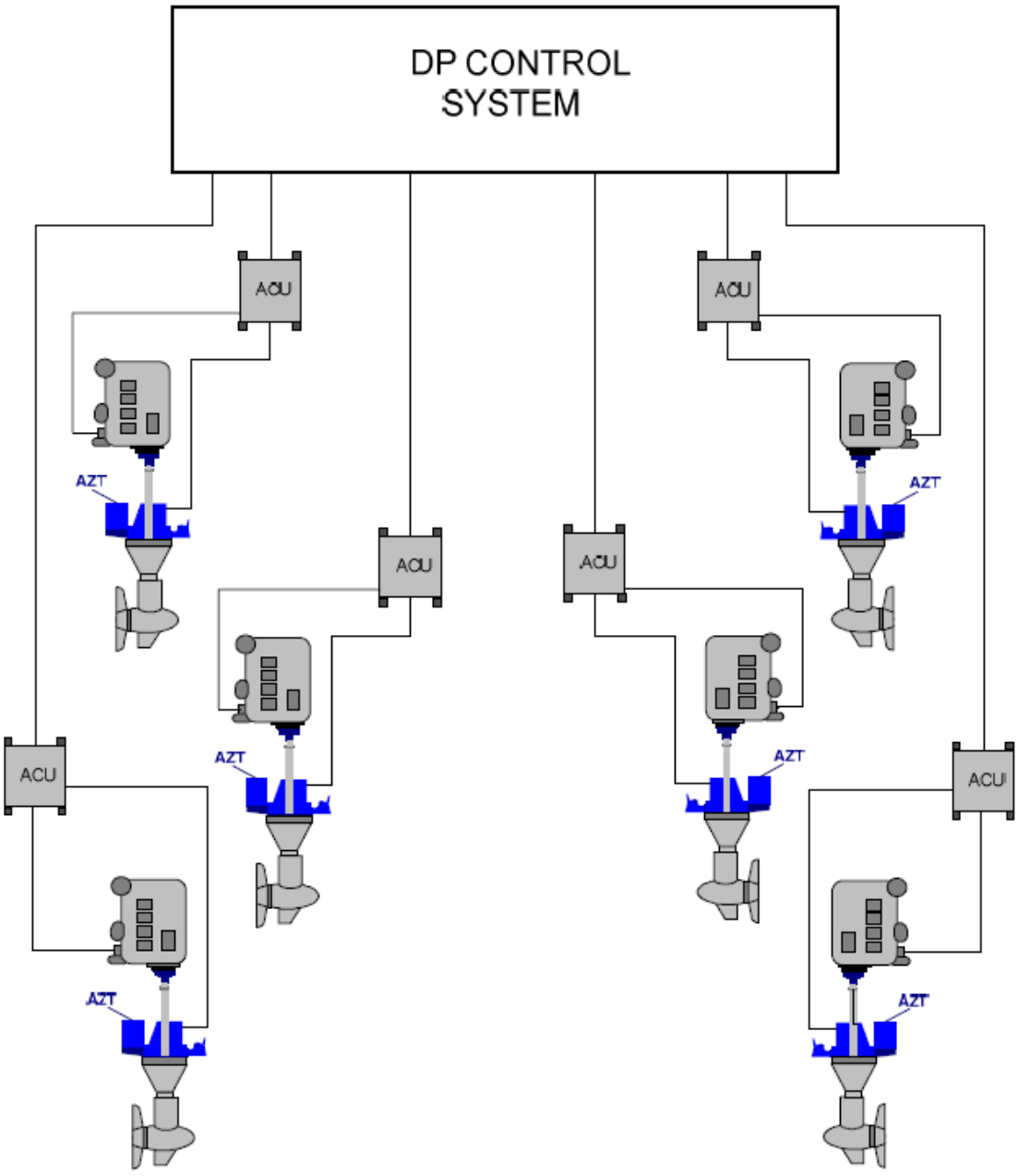



*Figure 3. DP Thruster Control System Architecture with Integrated ACUs on a drillship.*

## 5. Dynamic Positioning Control System (DPCS)

Key steps in the Verification and Validation (V&V) process for a Dynamic Positioning and Control System (DPCS) include:

- **System Documentation Review**
  Review of design documents, control logic, and safety functions against class and customer requirements.
- **Factory Acceptance Tests (FAT)**
  Conducted at OEM facilities before delivery. Includes DPCS hardware and software verification and is performed under the supervision of the classification society (when applicable) and the customer or their representatives.
- **Commissioning and Harbor Acceptance Tests (HAT)**
  Onboard tests after installation, covering communication, redundancy, alerts, and fail-safe settings.
- **Sea Trials**
  Full-scale operational tests, including thrust response, DP capability, blackout recovery, and failure scenarios.
- **Customer Acceptance Test (CAT)**
  Full-scale operational tests verifying DPCS functionality and performance. Includes testing DPCS response to component and interface failures to confirm redundancy.
  CAT is performed by the customer and OEM under the supervision of the classification society when applicable.
- **DP FMEA Trials**
  The Failure Mode and Effects Analysis (FMEA) is verified by simulating or provoking thruster, power, interface, and component failures, and then verifying the system's expected response to each failure case.

The Commissioning and Harbor Acceptance Tests (HAT), along with Sea Trials, are elaborated below, as these steps may reveal discrepancies between the thrusters' rated performance and their actual behaviour during full-scale operational testing. These steps commence after the commissioning of the thruster units, and the Thruster Control System has been completed.

## 6. Commissioning and Harbor Acceptance Tests (HAT)

During commissioning, all I/O signals between the DPCS and the thrusters and/or the Thruster Control System are verified. This includes signal polarity, response to signal failures, fail-safe settings, and alert reporting.
Typical I/O signals include:

- Thruster running (thruster is running but not controlled by the DPCS)
- Thruster ready (thruster is ready to be controlled by the DPCS)
- Speed command and feedback (RPM, pitch, force, load)
- Steering command and feedback (azimuth)

In addition, the DPCS receives I/O signals from the Power Management System (PMS), which indicate the power consumed and available.

When the DPCS is integrated with the Thruster Control System, alerts from this system can also be displayed on the DPCS.

## 7. Sea trials

Sea trials are carried out in sufficiently deep water under bollard pull (zero-speed) conditions. During this phase, command signals from the DPCS and feedback from the thrusters are scaled to ensure the rated thrust (RPM) is achieved. The actual thrust, steering angle, and power consumption are then verified against independent instrumentation (sensor readings).

Response times to thrust and steering commands, as well as deadband and hysteresis, are checked to confirm that the thrusters perform as expected. These measurements are used to update the thruster response models within the DPCS. If the actual thruster response deviates from the model, the DPCS will trigger a “thruster prediction error” alert.

Next, the effective thrust produced by each thruster is verified through acceleration tests. Several factors can reduce effective thrust compared to theoretical or rated values, including:

- Mechanical losses
- Thruster misalignment
- Thruster tilting
- Hull–Thruster interactions
- Thruster–Thruster interactions
- Cavitation
- Ventilation
- Fouling

These losses can vary significantly depending on thruster direction. In such cases, thruster loss versus direction tables are implemented in the DPCS.

In some cases, unstable thruster response may occur when a certain speed command level is reached. This typically happens when the thruster reaches its maximum torque limit before achieving the rated thrust. Such unstable response will compromise DP performance and must be addressed.

In such cases, the DPCS may limit the maximum speed command to the level at which the torque limit is reached. This adjustment is agreed upon with both the customer and the thruster manufacturer, as it reduces the vessel’s overall DP capability. The impact of these limitations should be documented in the vessel’s records and reflected in the FMEA.

Since this typically represents the final stage of implementation and testing during vessel delivery, subsequent activities for assuring in-service thruster and control system performance of the vessel focuses on annual trials, maintenance and inspections, FMEA renewal, and logging of any performance reductions to identify and address thruster degradation over time.

Section 8 and 9 document capabilities to monitor and manage such degradation proactively and section 0 comprehensively documents real life examples of typical causes for thruster losses and degradation. As is typical, such degradation noted from the list above present challenges which must be managed as part of the design, implementation, delivery, and management, to effectively ensure the vessel performance is not negatively impacted in unforeseen circumstances. Overall, it remains important that the thruster losses are captured and documented in order to ensure the total impact is considered on the vessel`s capability. Further, such cases where performance has been observed as “degraded” should be further accounted for as part of risk control measures such as post failure assessment, TAGOS, ASOG, and CAM/TAM configurations.

## 8. Condition Monitoring System (CMS)

All UUC thrusters are equipped with integrated 3-axis acceleration sensors as standard. The client may choose to activate a Condition Monitoring Service (CMS) package, which enables continuous measurement of vibration and rotational speed (RPM).

When CMS is active, the system monitors the dynamic behavior of the driveline in real time. This allows early detection of anomalies or developing faults in critical components such as bearings and gears. By identifying signs of wear, imbalance, or misalignment at an early stage, the system helps prevent unplanned downtime and ensures that the thruster continues to deliver reliable performance throughout its service life.

The overall architecture of the CMS system - including onboard sensors, data acquisition, analysis platform - is illustrated in Figure 4.

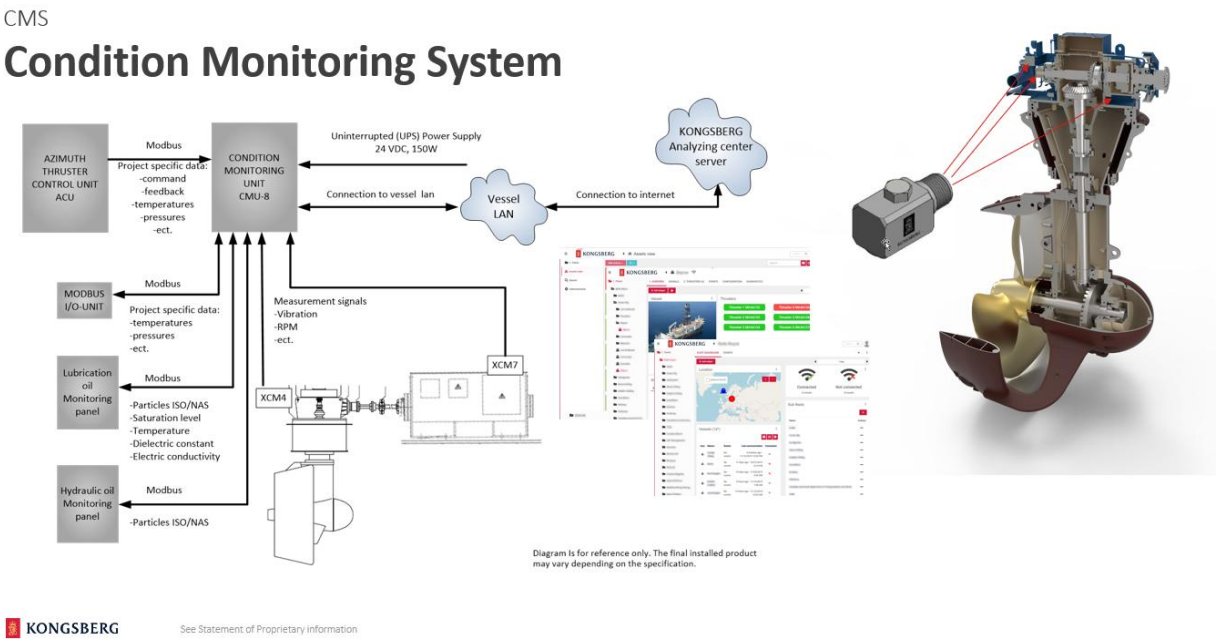



*Figure 4. Thruster Condition Monitoring System Architecture*

## 9. Remaining Useful Life (RUL)

Remaining Useful Life (RUL) is Kongsberg Maritime's flagship predictive maintenance package, offered as an optional upgrade. Unlike the standard condition monitoring setup, RUL requires a dedicated suite of sensors, which are installed based on client selection.

The system includes high-frequency torque and RPM sensors mounted on the input shaft, as well as temperature and oil cleanliness sensors at key locations. These are connected to an onboard edge-processing unit that continuously analyzes measurement data in real time. Based on actual operational loads, the system provides a quantitative prediction of expected service life for critical driveline components such as bearings, gears, and shafts.

The overall architecture of the RUL system—including data acquisition, onboard analytics, and digital twin–based life prediction—is illustrated Figure 5.

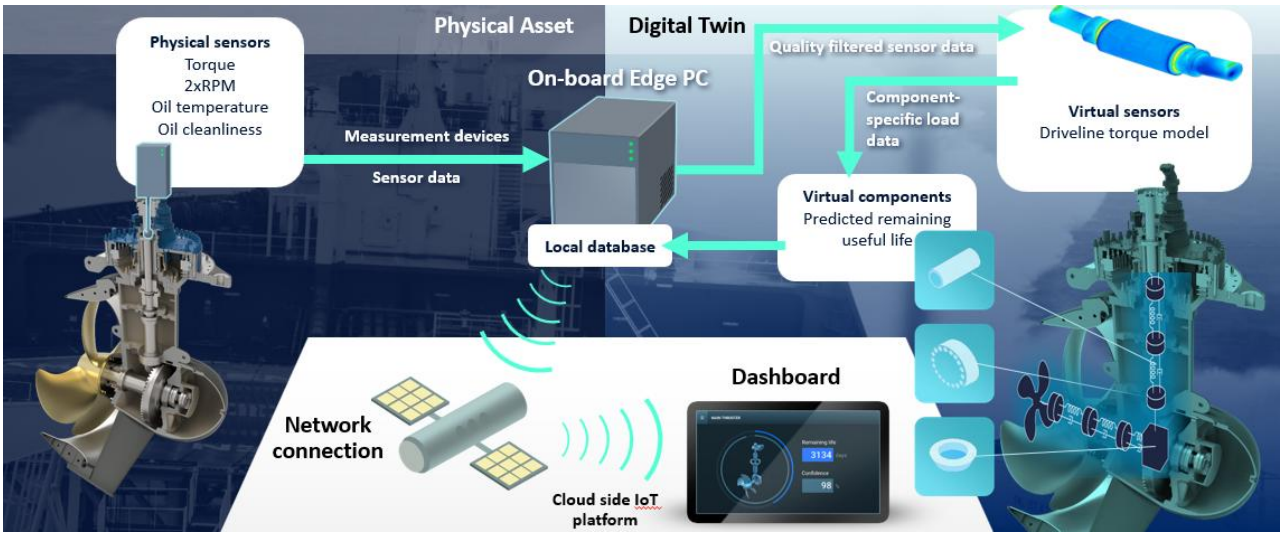



*Figure 5. Thruster RUL Predictive Maintenance System Architecture*

In addition to life prediction, the real-time torque and RPM measurements enable validation of actual thruster performance against design expectations. Deviations from the expected propeller curve—i.e. measured torque-RPM combinations that fall outside predicted ranges—can indicate emerging mechanical or hydraulic issues that may require further investigation.

Furthermore, Figure 5 illustrates how digital twin–based predictions enable flexible maintenance planning across the thruster's lifecycle. By continuously estimating the expected service life of critical components, operators can pursue three distinct strategies:

1. Defer or reduce the scope of scheduled overhauls when component health remains within safe limits
2. Proactively advance maintenance to a commercially optimal time to avoid unplanned downtime
3. Apply scenario-based analysis to extend the life of selected components—such as gears or bearings—through temporary power limitations or operational adjustments

These options support smarter lifecycle management and help reduce total cost of ownership.

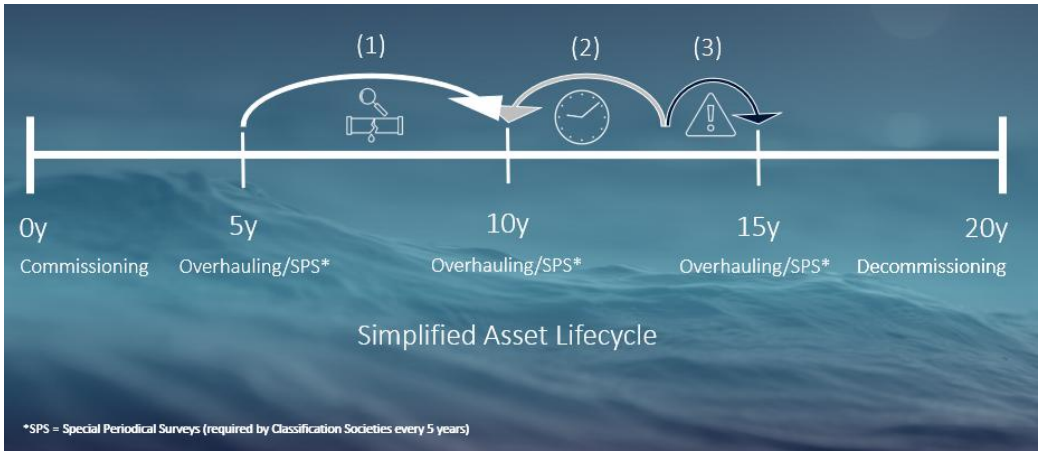


*Figure 6. Thruster RUL Predictive Maintenance System Architecture*

# 10. Real-World Scenarios: Adressing Performance And Lifespan

## 10.1. Excess Torque Absorption Limiting Achievable Thrust

In certain operational cases, torque and RPM measurements have indicated that the thruster does not achieve its specified bollard pull thrust. One contributing factor can be higher-than-expected propeller torque absorption, which may result from external influences such as marine growth on the propeller, unfavorable inflow conditions, or hull-propeller interaction effects. These conditions can cause the drive motor to reach its torque limit before attaining full RPM. Since thrust is proportional to the product of torque and RPM (Thrust = Torque × RPM × hydrodynamic factor), this limits the achievable thrust below the design specification.

To resolve such cases, the KM thruster design and engineering team reassessed the torque limit settings based on the vessel's actual operational data. Where supported by measured load profiles and within safe design parameters, a slight increase in torque limits was applied. This change has, in multiple instances, allowed the thruster to achieve its intended bollard pull performance while still meeting system safety and integrity standards.

## 10.2. Performance Limitation as a Strategy for Extending Component Service Life

In some cases, Kongsberg Maritime (KM) experts have identified driveline components with lower-than-expected service life compared to the operator's scheduled overhaul interval. These findings have been based on endoscopic inspections, offline measurements, or online monitoring systems such as the Condition Monitoring System (CMS) or the Remaining Useful Life (RUL) predictive maintenance tool.

KM's flagship product, RUL, quantifies the expected service life of critical driveline components by combining real-time operational data with engineering models specific to the thruster design. This enables operators to make data-driven maintenance decisions based on actual usage, rather than relying solely on fixed schedules.

For vessels not equipped with the onboard RUL system, KM's engineering team has provided equivalent analyses as a service, utilizing case-specific measurement data collected from the vessel. In addition, scenario-based analysis offers valuable business insight—for example, estimating how the expected service life would extend if the thruster's maximum output were temporarily reduced. This supports more flexible maintenance planning and helps operators align technical decisions with operational and commercial priorities.

In practice, reducing maximum power has proven highly effective, since component fatigue and wear are primarily driven by peak load conditions. This approach often has minimal impact on vessel operations, particularly on rigs with multiple thrusters. In many such cases, temporarily capping thruster output to 80% of its nominal rating has allowed continued operation while postponing overhaul to a more commercially favorable time. As such adjustments are expected to be considered based on short term vs long term actions and would normally be conducted as part of the MOC processes. It is important that while there are benefits of extending the life of equipment by reducing utilization the must remain considerations of such adjustment and their impact on total vessel performance and post failure capability.

## 10.3. Troubleshooting and Restoring Steering Performance

In one service case, steering-related issues were reported across several thruster units on the same vessel. Observed symptoms included unstable steering speed, difficulty adjusting the hydraulic pump's neutral position, and occasional mismatch between control commands and feedback signals. While the precise symptoms varied between thrusters, many of the underlying problems were ultimately traced to previously conducted third-party repairs that had not restored the components to OEM specifications.

Corrective actions focused on re-establishing consistent steering performance. In several units, key hydraulic valves—such as proportional and sequence valves—were replaced, which eliminated speed fluctuations and stabilized azimuth motion. Pressure switches responsible for monitoring hydraulic and lubrication systems were tested and found faulty in multiple locations. These were replaced or recalibrated to restore correct alert behavior and internal supervision.

System pressures were measured throughout the work and found to be within expected ranges—typically 28–30 bar in the booster circuit, around 4 bar for lubrication, and 50–55 bar in the steering hydraulics. These confirmed that the hydraulic network performed correctly once faulty components were addressed.

Particularly in units where steering instability persisted, the root cause was found to be hydraulic pumps that had been repaired by local workshops. In these cases, neutral position adjustment was no longer possible due to internal wear or improper assembly. Full pump replacement was therefore recommended and carried out to restore OEM-level performance.

One thruster also exhibited persistent deviation in steering angle indication at the bridge. This was resolved by replacing a faulty signal converter and recalibrating the feedback potentiometer to match known angular positions such as 0°, 90°, and 180°.

Following these interventions, all thrusters demonstrated stable and responsive steering with verified pressure and feedback behavior. The case highlights how third-party repairs can introduce latent faults in hydraulic systems, and how structured OEM-level troubleshooting is often necessary to restore control precision and DP-class reliability.

## 10.4. Intentional thruster reduction limits

Cases where maximum speed command from the DPCS have been limited due to reaching torque limits on the thruster are documented in sea trial or service reports from the OEM.
The DPCS online analysis tools reflect the applied settings. However, it is very important to address and apply these limitations when performing offline vessel capability analyses, as they will impact the vessel's capability compared to using rated thruster data.

## 10.5. Thruster maintenance

Degraded positioning performance has been reported after service or scheduled maintenance on thruster units. This has been linked to changes in interface scaling and/or thruster response settings.
These cases highlight how thruster repairs and maintenance can introduce latent reductions in DPCS performance. It is recommended to perform DPCS trials to verify system performance before starting DP operations.

## 10.6. Fouling

Degraded positioning performance has been reported after vessels have been in operation for a period of time. Verification of interface scaling and thruster response settings showed no issues. One symptom observed on the DPCS was that the 'DP current' value was much higher than the actual sea current and tended to follow the direction of thrust.
Inspections revealed that fouling had caused a gradual loss of thruster efficiency and was the root cause of this issue.

Figure 7 illustrates how DPCS HMI will look like with loss of thruster efficiency. Thruster command and feedback follows while 'DP current' is high.

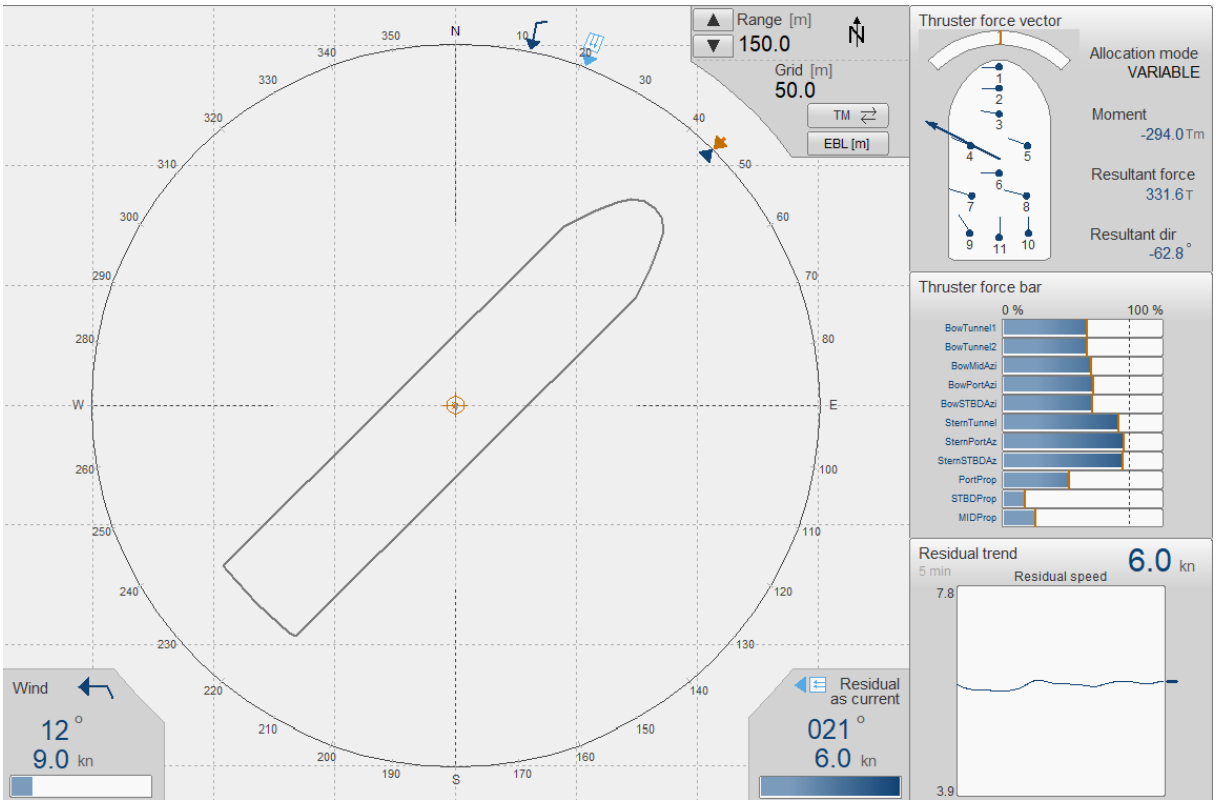



*Figure 7. DPCS HMI where thruster command and feedback follows while 'DP current' is high.*

## 11. Comprehensive Verification and Validation

MTS Techop emphasizes that verification and validation (V&V) processes must address a comprehensive range of failure modes to be effective, as outlined in D-01: *"The verification and validation process will only be effective if it considers a comprehensive range of failure modes"* [TECHOP (D-01 - Rev1 - Jan21) Section 8.1.1]. This principle is crucial for assessing and capture impacts of events which effects vessel performance, which integrates **evidence-based methods** throughout the lifecycle of thruster and control system management.

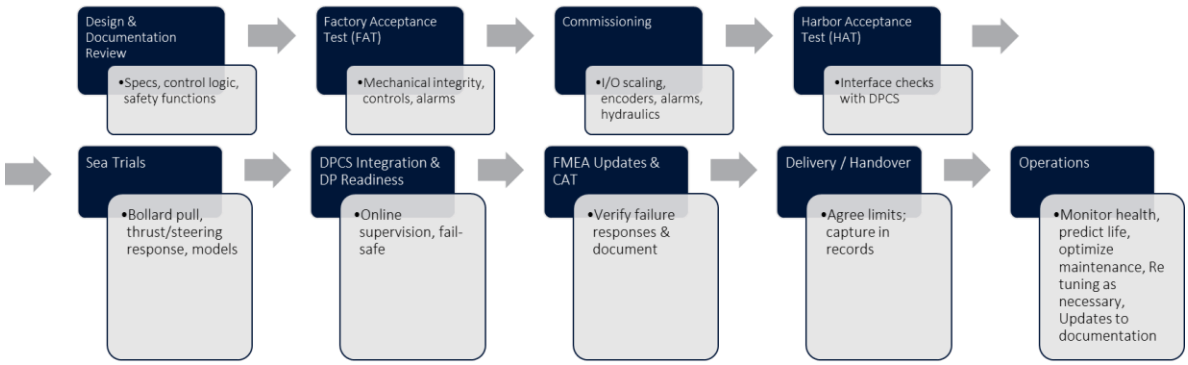
The guidance documentation supports a structured execution process for investigating and documenting both functionality and failure modes. In this context, the mechanical implementation of the thruster, its

operational response post-installation, and its integration with the control system are all subject to rigorous validation. Each phase of delivery and post-delivery support incorporates activities led by the OEM and Ship Integrator, with oversight from Marine Assurance teams.

The **evidence base** for these assessments originates from multiple stages of testing and monitoring, including:

- **Factory Acceptance Testing (FAT)**: Mechanical integrity and functional performance are verified under controlled conditions, with deviations logged and addressed.
- **Commissioning and Sea Trials**: Real-world operational data is collected to validate control system behavior, thrust response, and alignment between command and feedback signals.
- **Condition Monitoring (CMS) and Remaining Useful Life (RUL)** systems: These provide continuous data on vibration, torque, RPM, and component wear, enabling predictive insights and lifecycle management.
- **Failure Modes and Effects Analysis (FMEA)**: Updated iteratively using observed discrepancies, alert logs, and performance data from all validation stages to ensure traceability and risk mitigation.

Below: is a general example of the phases from Factory To Field:




## 12. Conclusion

Comprehensive verification and validation (V&V) of thruster performance are essential to ensure vessel operability and dynamic positioning (DP) reliability. This paper has demonstrated how discrepancies between rated and actual thruster performance can result from mechanical losses, control system constraints, mistakes at installation, and operational factors such as fouling or misalignment. If left undocumented, these deviations can lead to overestimated vessel capability and increased operational risk. Therefore, the combined delivery of mechanical, electrical, and control system functionality must be evaluated and documented to capture their cumulative effect on performance.

Kongsberg Maritime's structured methodology—encompassing Factory Acceptance Tests (FAT), commissioning, Harbor and Sea Trials, and the integration of Condition Monitoring (CMS) and Remaining Useful Life (RUL) systems—offers a robust framework for identifying and mitigating these issues. Incorporating these findings into the vessel's FMEA and capability assessments ensure transparency and supports informed decision-making throughout the lifecycle. By coupling rigorous testing with predictive maintenance and digital tools, the vessel is enabled for more reliable, data-driven operability strategies that minimize risk, optimize lifecycle costs, and enhance safety in offshore operations.

## Abbreviation / Definition

ACU – Actuator Control Unit
AZT – Azimuth Thruster
CAD – Computer Aided Design
CAT – Customer Acceptance Test
CMS – Condition Monitoring System
DPCS – Dynamic Positioning Control System
DP – Dynamic Positioning
DPO – Dynamic Positioning Operator
DynCap – Dynamic Capability Analysis
FAT – Factory Acceptance Test
FMEA – Failure Modes and Effects Analysis
FLNG – Floating Liquified Natural Gas Production Facility
HAT – Harbor Acceptance Test
HHT – Handheld Terminal
ISO – International Organization for Standardization
KM – Kongsberg Maritime
OEM – Original Equipment Manufacturer
OHSAS – Occupational Health and Safety Assessment Series
PLC – Programmable Logic Controller
RUL – Remaining Useful Life
SLIO – Serial Local Input/Output
StatCap – Static Capability Plot
TAGOS – Thruster and Generator Operational Strategy
TAM – Thruster Allocation Mode
UUC – Underwater Mountable Azimuth Thruster
V&V – Verification and Validation
WCF – Worst Case Failure

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