DYNAMIC POSITIONING CONFERENCE
October 14-15, 2025

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Safe Handling of Thruster Failures in Dynamic Positioning (DP) Operations

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Introduction

In a DP (Dynamic Positioning) operation one of the most severe failures is a thruster running of to 100% thrust. If not handled promptly this will often lead to loss of heading and position. This paper will go through different failures modes for thrusters producing either uncommanded thrust or steering and handling of these failures. Reported cases such as the MTS DP Committee LFI 2017-3 [2] which describes an incident where a main propeller failed to full ahead and was not clutched out before more than 70 seconds had elapsed, shows the possible severity of thrusters failing.

The paper have simulated the effect of thrusters failing to full, showing the effect of vessel size, number of thrusters and reaction time on the vessels position and heading. Typical barriers preventing thruster run off and their effectiveness are discussed.

This paper will only consider equipment classes 2 and 3 with redundancy in thruster capacity. Most of the discussion will still be relevant for lower equipment classes where loss of a thruster often will cause loss of station keeping ability.

Thruster types and failure modes

Thrust is typically controlled by altering the propeller RPM or pitch, and in the case of azimuthing thrusters by controlling the steering angle. For some thrusters all three parameters can be controlled. Each controlled parameters will have different associated failure modes.

In this paper the term ***Thruster*** is used in the same broad sense as typical DP class rules and covers both shaftline propellers, azimuthing thrusters and tunnel thrusters.

Requirements

IMO MSC.1-Circ.1580 [5] states ***Failure of a thruster system including pitch, azimuth and/or speed control, should not cause an increase in thrust magnitude or change in thrust direction.***

DNV have in their rules Pt.6 Ch.3 Sec 7.3.4 [3] ***A single failure in the thruster control system should neither cause significant increase in thrust output nor make the thruster rotate. . . .***

ABS states Sec.4 Ch.9.5 [1] ***A single fault in the manual thruster control system is neither to cause significant increase in thrust output nor make the thruster rotate. . . .***

These requirements can be met by several means and does not dictate how failures should be handled, only that the thrust vector should not change uncontrolled. The class rules only consider failures in the thruster control system while IMO states the broader ***thruster system***.

IMO MSC Circ. 1580 and class rules also have rulings on thruster feedback indication in the DP control center intended to give the operator a possibility to verify the operation of the individual thrusters.

RPM control

Contemporary DP thrusters usually have RPM control. The most common means to control RPM is by using so called variable frequency drives (VFD). They can typically control the RPM from 0 to 100% rpm with high accuracy. In principle an VFD is a device which change the frequency of the AC power on the ship's switchboards to another frequency to drive the AC motor driving the thruster at the required RPM. To

achieve this objective both control systems and several components are necessary. Each component with a set of failure modes.

The obvious failure modes such as loosing power to the VFD, or loosing interface between the VFD and thruster control system, is typically well handled and clearly defined by vendors and in the vessel DP FMEA. Normally the thruster control system will send a RPM command signal to the VFD and will have a RPM feedback signal in return. The actual control of the thruster RPM is inside the VFD. If there are a deviation between the commanded RPM and the actual RPM an alert can be issued by either the thruster control system or the DP control system.

In the case a failure leads to the thruster RPM changes uncommanded some thruster control systems will automatically stop the thruster, some systems will only give an alert and leave it to the operator to take action and stop the thruster and some systems will leave it to the operator (possibly helped by alerts from the DP control system) to detect that the thruster is misbehaving by looking at the indicators.

Pitch control

For DP thrusters which have a operating profile which involves both transit and station keeping, controllable pitch often will give reduced energy consumption in transit or more efficient thrusters for DP operation. Some retractable type azimuthing thrusters also function as tunnel thruster in the retracted position. In ordnance to produce thrust in both directions pitch control is usually used. Shaftline propellers used in DP operations also typically are of controllable pitch type.

Most of current DP thrusters with controllable pitch also have RPM control using VFDs. The controllable pitch system can adjust the pitch such that full thruster power can be utilized in all operating conditions without exceeding torque limitations of the thruster motor. Hence maximum efficiency is available in all operating conditions.

A controllable pitch thruster is normally controlled by a hydraulic piston connected to the propeller blades, pushing and pulling to adjust the angle of the blades. The thruster control system will typically control a hydraulic value sending oil to one or the other side of the hydraulic piston. To monitor the position of the blades a mechanical arrangement connecting the position of the hydraulic piston with an sensor (typically a potentiometer) needs to be arranged. This mechanical arrangement can be quite complex as it for an azimuth thruster need to transfer the mechanical motion of the hydraulic piston from the underwater unit, which can rotate 360 degrees into the vessel where the electronic sensor can pick up the motion and transfer it to the thruster control system.

Failure modes of pitch control systems includes both hydraulic leaks, electrical failures and mechanical failures in the feedback arrangement. Even if some (azimuthing thrusters used for propulsion) have dual independent electrical feedbacks, only one mechanical feedback arrangement is typically provided. So a failure in the mechanical feedback arrangement can possibly provide both the closed loop control of the pitch and the operator with the same erroneous feedback.

Some failures like hydraulic leakage over the control valve and leakage in the hydraulic piston might be small and only leads to minor reduction of performance of the thruster. However, gradually, they might increase in severity and lead to lost control over the pitch. Some failures will directly lead to loss of pitch control, e.g. failures in the mechanical feedback arrangement.

As for RPM control the handling of the failure by the thruster control system differs. Some systems will automatically stop the thruster if the actual pitch deviates from the order. Other systems will only warn the operator and leave the decision to stop the thruster with the operator.

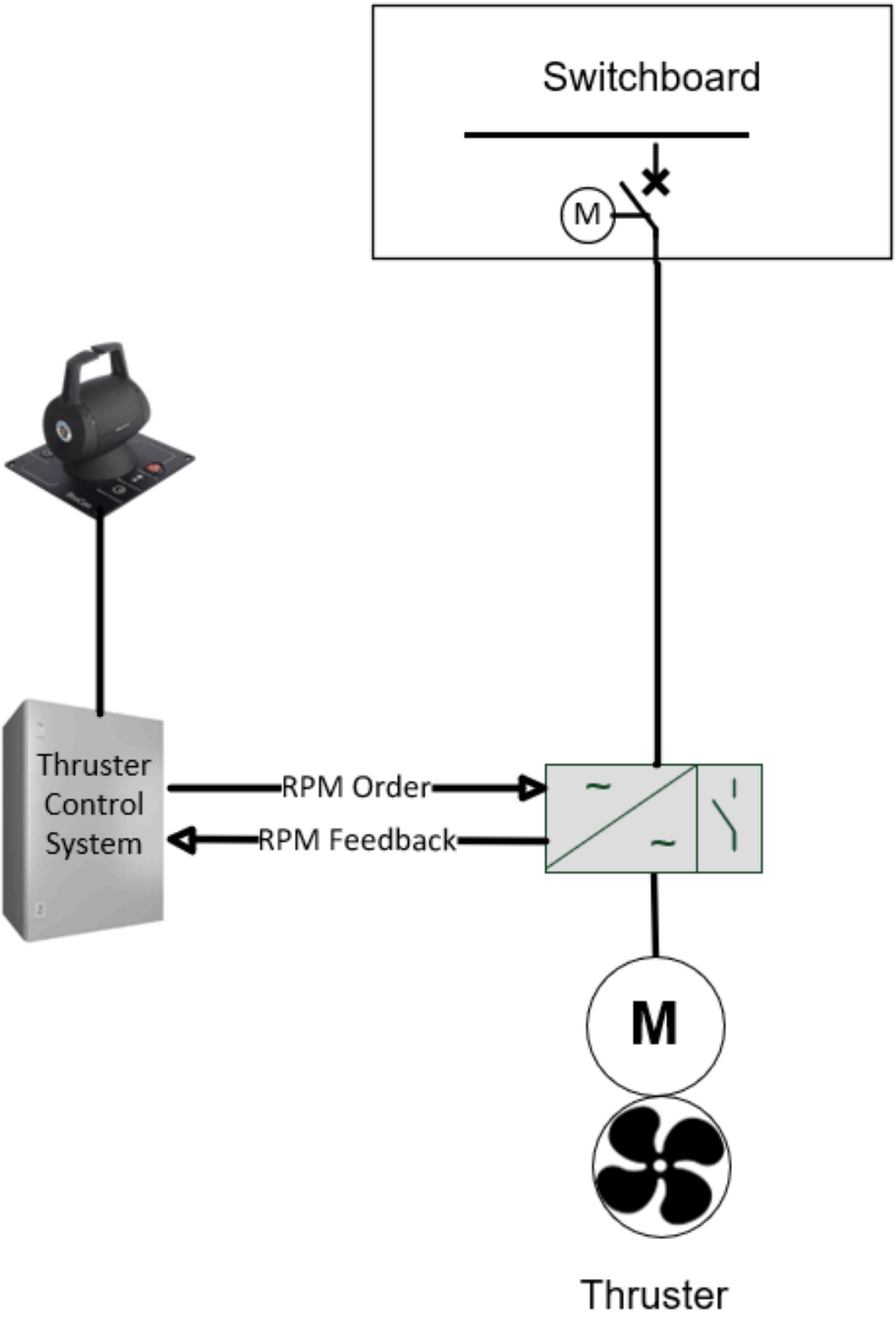

Figure 1: Thruster rpm control loop

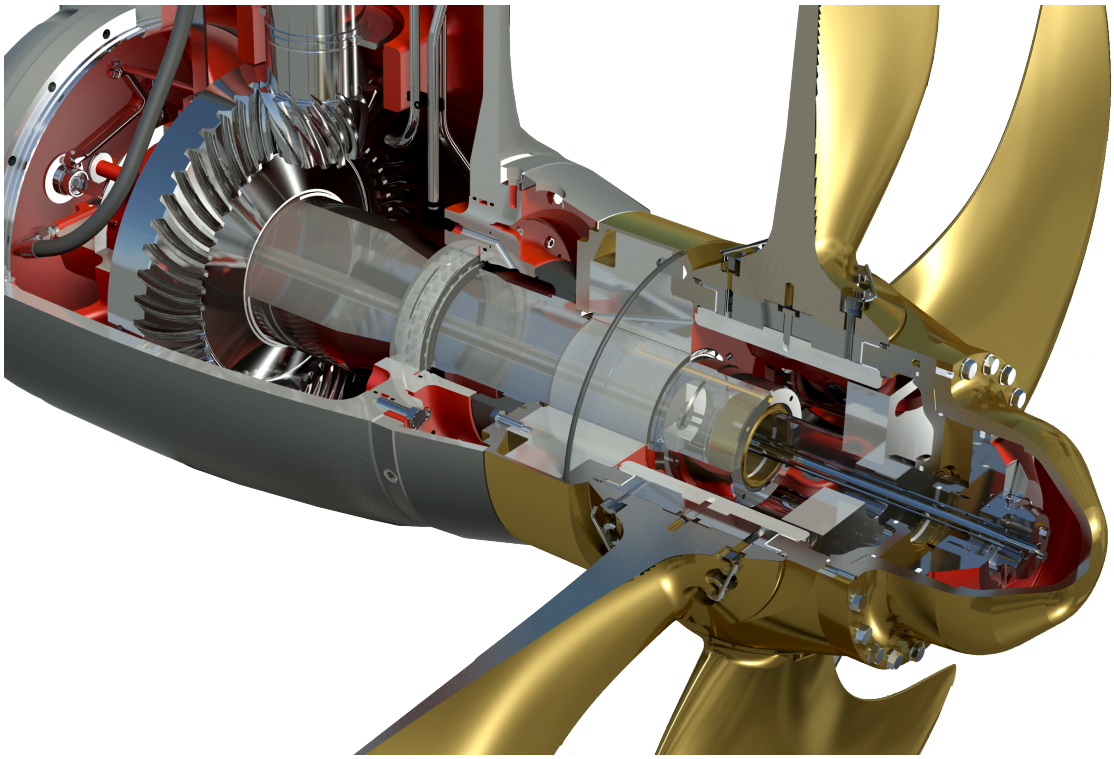

Figure 2: Controllable pitch thruster

Shuttle tanker typically have two directly driven shaftline propellers where stopping one of the engines will also stop the shaft generator providing power to half the thrusters. To reduce the consequence of stopping one propeller it is often required to have a so called ***zero pitch*** system which forces the propeller pitch to zero in cases where the normal control over the pitch is lost.

Steering / azimuth control

Steering control over azimuth thrusters are either provided by hydraulic motors or electrical motors, Usually more than motor is used in combination to provide necessary torque to control the steering angle. Most of the failure modes as described in the ***Rpm control*** and ***Pitch control*** section also applies also for steering control.

In some cases e.g. in high current scenarios, or when one steering gear motor is lost or malfunctioning, the torque from external forces can exceed the available torque from the steering gear motors, and lead to loss of steering control of the azimuth thruster.

Failure handling in cases where control over steering is lost, is similar to rpm and pitch failure handing.

Verification of failure handling

Verification of the failure handling mechanisms described in the sections above is part of the FMEA proving trials for DP equipment classes 2 and 3. In IMCA M190 section 4.10 [4] it is stated that variable speed thrusters should be tested every 5 years and controllable pitch thrusters annually. In these tests the failure modes tested are typically at the interface level consisting of pulling leads on interfaces between different parts of the thruster control system such as the VFDs, pitch actuator valves and steering gear signals. And

also the order and feedback signals between the DP control system and the individual thruster control systems are tested by removing individual leads.

Fine granular testing of failure handling in both thruster control systems and DP control systems can be achieved by connecting software controlled interfaces replicating the behavior of the thrusters and enable the test engineers to impose any kind of failure verifying failure handling in almost any scenario.

Failure handling

In a DP system there will be many layers of failure handling protecting against loss of position caused by thrusters producing erroneous thrust. The thruster control system will often have protection mechanism, ranging from simply providing alerts to automatically stopping the thruster failing. In severe cases where the thruster exceeds the maximum power limits the power system might even trip the thruster motor. DP control systems will also give alerts or stop using thrusters which do not follow the orders from the DP control system. The vigilant operator, detecting the failing thruster and activating the emergency stop (see section Intervention), provides the final barrier against loss of position.

For each level away from the thruster, detection of failures will be less effective. The system providing the closed loop control over a parameter always have the best possibility to detect when control is lost. The drive can more or less instantly detect when RPM is not following the internal reference. If pitch or steering control is lost the thruster control system have all possibilities to detect and act promptly. The operator will normally only be aware of the failure after warned by an alert or possibly by the increase of noise and vibrations produced by the failing thruster.

As will be shown in the simulation section Simulation of failures, effective action need to be taken quickly to avoid loss of position. Either by an automatic response by the thruster control system or by the operator.

Intervention

Most thruster control systems used on classed DP vessels will have mechanisms providing alerts when RPM, pitch or steering misbehaves. Many systems also provides mechanisms to automatically stop the thruster upon failure. All thrusters used for DP shall have emergency stop located at all control stations.

As required by IMO MSC.1-Circ.1580 [5] ***Individual thruster emergency stop systems should be arranged in the DP control station. For equipment classes 2 and 3, the thruster emergency stop system should have loop monitoring. For equipment class 3, the effects of fire and flooding should be considered.***

As described in ABS 191-dps-guide [1] ***The emergency stop activation buttons are to be placed in a dedicated layout representing the thruster location and which is consistent with the vessel's axis and layout, or they may be arranged together with the corresponding thruster levers. . .***

And in DNV rules Pt.6 Ch.3 7.3.8 [3] ***The emergency stop activation buttons shall be placed in a dedicated mimic representing the thruster location and which is consistent with the vessel axis and layout, or they may be arranged together with the corresponding thruster levers. . .***

Figure 3 shows some common emergency stop layouts in use on classed DP vessels. ***1*** shows emergency stops on each manual thruster lever, ***2*** shows a emergency stop panel with buttons placed according to thruster placement on the vessel. ***3*** shows a traditional layout where the emergency stops are arranged according to the numbering of the thrusters. ***1*** and ***2*** are in compliance with the current rules cited above, ***3*** does not comply with current rules, but many vessels built before the new rules came into effect are still in operation.

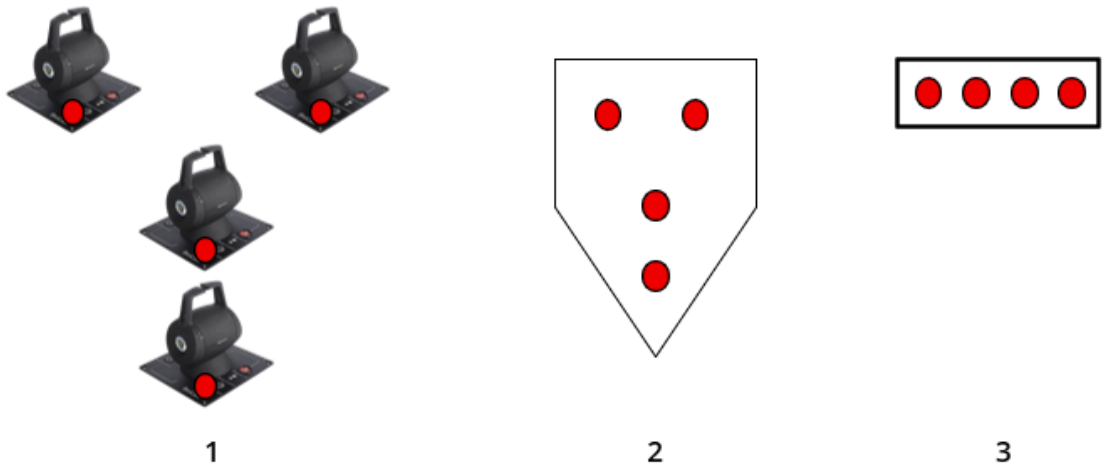

Figure 3: Common emergency stop layouts

In the case where using the emergency stop is required the stress level of the operator will probably be high and the extra burden of trying to decipher the placement of the emergency stop button will increase the likelihood of pushing the wrong button.

In cases where a thruster is failing to 100%, many alerts will often come in succession on several system. The DP control systems will issue alerts, thruster control systems for other thrusters might also give alerts shortly after, as other thrusters need to thrust to arrest the motion caused by the failing thruster. Power related alerts might be issued as the loading of the switchboard will rise quickly from the failing thruster and the rising thrust on other thrusters.

DP control systems will usually have alerts informing the operator e.g. the well known ***Prediction Error*** alert or an alert similar to ***Thruster Not Following Order***. When the DP control system detects deviation different measures will be taken to reduce the position loss due to the failing thruster. The normal control loop of the DP control system will automatically generate thrust commands to counter the deviations caused by the failing thruster. The DP control system might use the calculated feedback thrust from all thrusters including the failed thruster to provide the optimal estimation of the vessel motion. In a case where the feedback from the failing thruster is erroneous, this might lead to wrong estimates of the vessel motion, possibly leading to a drive-off scenario. If the thrust from the failing thruster are not taken into account it might lead to a slowed down response of the position and heading excursions caused by the failing thruster.

Simulation of failures

Simulation can be an effective tool to asses consequences of different thruster failures. Any failure scenario and any combination of weather conditions can be tested. We have used Brunvoll's in-house 6 degrees of freedom, high fidelity vessel simulator for the simulations shown in this paper. Environmental condition used in all simulations are described in table 1. Wind, waves and current are assumed to come from the same direction.

Table 1: Environmental condition used in simulations

Parameter	Value
Direction	330 degrees (30° on the port bow)
Beaufort	3
Wind speed	5.4 m/s
Significant Wave Height	0.8 m
Peak Wave period	5.5 s
Current Speed	0.5 m/s

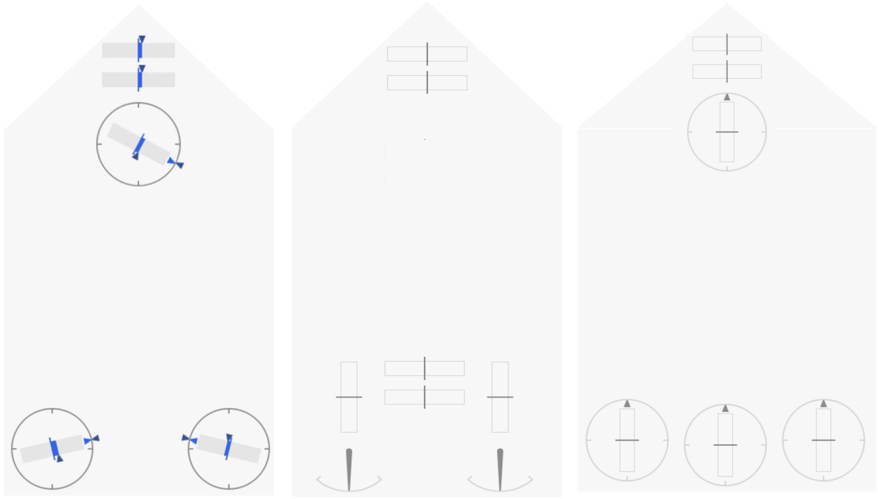

Figure 4: Thruster configuration of simulation cases.

Table 2: Main dimensions of example vessels

Vessel	Length [m]	Breadth [m]	Displacement [t]
Supply Vessel	82.6	20.0	7524
Anchor Handler	60.0	17.6	3521
Cable Layer	142.8	31.0	24809

Figure 4 shows the thruster layout of the example vessels. Thruster data are described in table 3, 4 and 5.

Bow 1 tunnel failing to 100% for different vessels

The consequences of a bow tunnel thruster failing to 100% will depend on the vessel and the redundancy in installed thrusters. In figure 5 the excursion of three different vessel where the foremost tunnel thruster is failing to 100% (port). In this simulation, the failure is not rectified. As can be seen from the figure, the anchor handler have the most severe loss of position and heading compared to the other two vessels. This is both due to the lower mass of the anchor handler relative to the maximum force of the tunnel thruster and that the two other vessels have three thrusters in the bow, leaving two to oppose the failing tunnel.

Table 3: Thruster configuration for Supply Vessel (leftmost)

Thruster	Max Thrust [t]	Type
Bow 1	13.5	Fixed pitch tunnel
Bow 2	13.5	Fixed pitch tunnel
Bow Azimuth	15.8	Controllable pitch and rpm retractable azimuth
Port Main	31.4	Fixed pitch azimuth
Stbd Main	31.4	Fixed pitch azimuth

Table 4: Thruster configuration for Anchor Handler (center)

Thruster	Max Thrust [t]	Type
Bow 1	12.5	Fixed pitch tunnel
Bow 2	12.5	Fixed pitch tunnel
Stern 1	8.7	Fixed pitch tunnel
Stern 2	8.7	Fixed pitch tunnel
Port Main	53 Ahead, 27 Astern	Controllable pitch shaftline propeller
Stbd Main	53 Ahead, 27 Astern	Controllable pitch shaftline propeller
Port Rudder		Flapped highlift rudder
Stbd Rudder		Flapped highlift rudder

Table 5: Thruster configuration for Cable Layer (rightmost)

Thruster	Max Thrust [t]	Type
Bow 1	40	Fixed pitch tunnel
Bow 2	40	Fixed pitch tunnel
Bow Azimuth	48	Controllable pitch and rpm retractable azimuth
Port Main	50	Controllable pitch and rpm azimuth
Center Main	50	Controllable pitch and rpm azimuth
Stbd Main	50	Controllable pitch and rpm azimuth

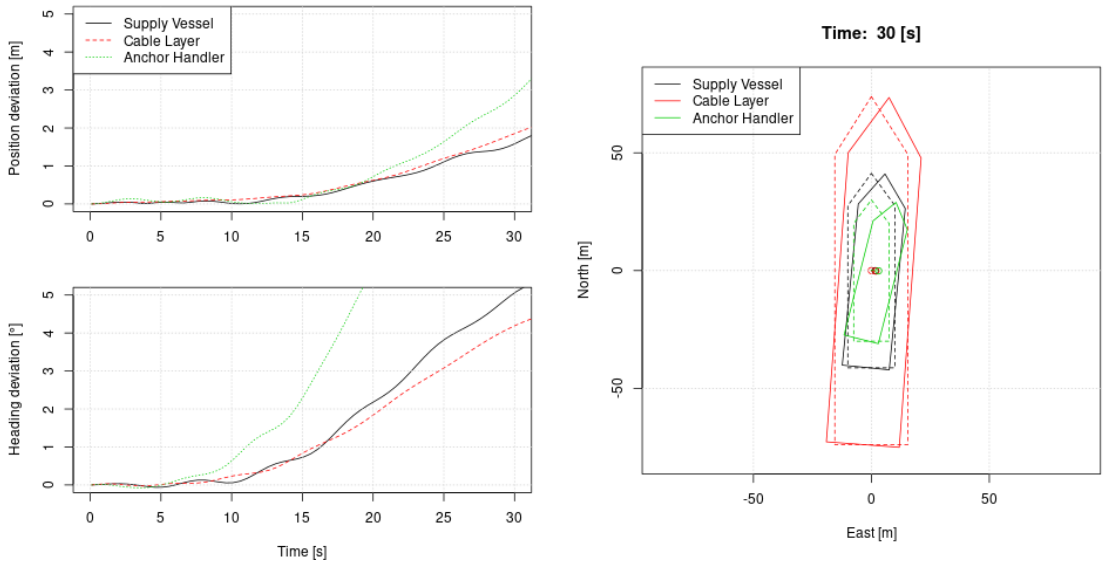

Figure 5: Bow tunnel 1 failing to 100% - Deviations

Bow 1 tunnel failing to 100% for mid size Supply Vessel

Even if a failing tunnel thruster often is the least significant failure the time before the thruster is stopped will determine the loss of heading and position caused by the failure. Figure 6 compares the deviations for different times elapsed before the thruster is stopped. As can be seen from the figure heading deviation will exceed 3 degrees if the time before the thruster is stopped exceeds a little more than 15 seconds.

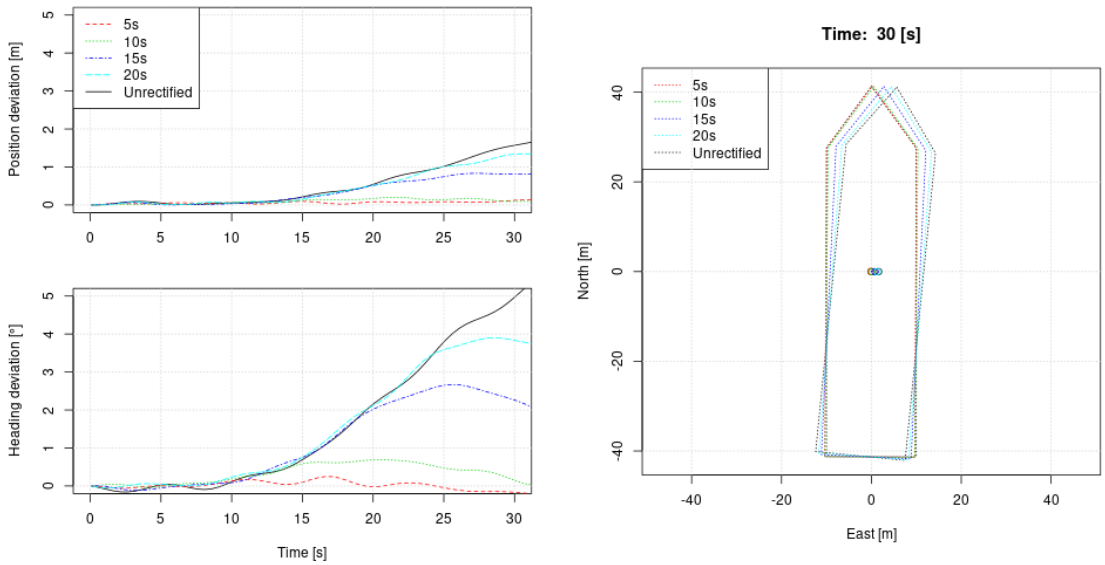

Figure 6: Port main propeller failing to 100%

Port main propeller failing to 100% Ahead on Anchor Handler

A shaftline main propeller failing to 100% is probably the worst case scenario for thruster failures. In this case effectively stopping the propeller as quickly as possible is important. In figure 7 the deviations for different reaction times are compared. As can be seen from the figure, even if the propeller is stopped 10 seconds after running off to 100%, the position deviation exceeds 5 meters.

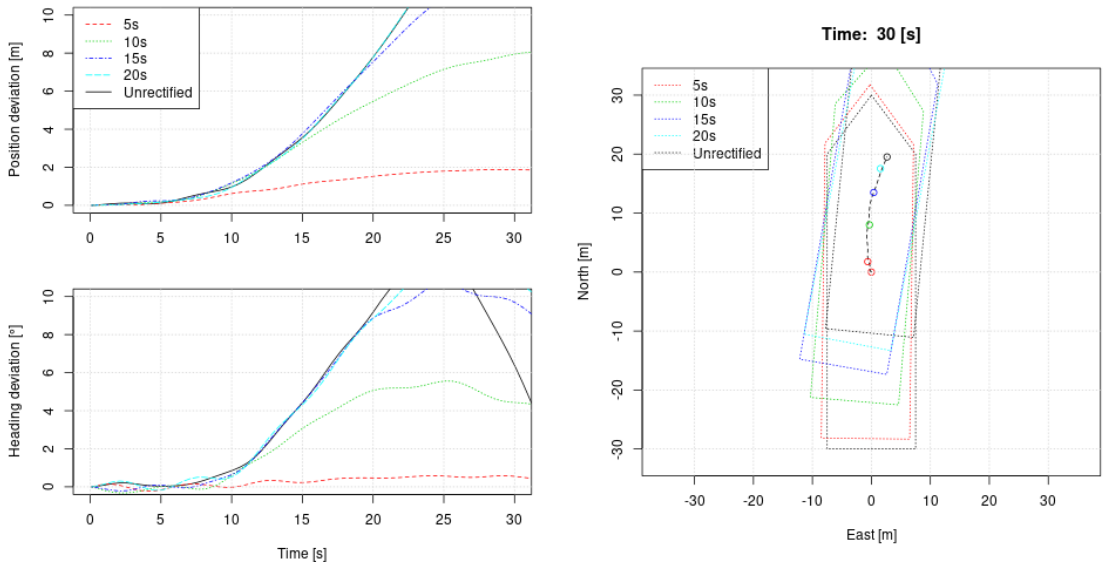

Figure 7: Port main propeller failing to 100%

Discussion

Achieving safe handling of thruster failures in DP operations is one important step to reduce the risk of DP operations. As have been discussed in this paper and demonstrated in the simulations a thruster failing to 100% will possibly cause the vessel to loose heading and position, jeopardizing the industrial mission of the vessel. If the failing thruster is stopped quickly and the vessel is operating within the post failure environmental limits, position and heading excursion will be negligible and the DP operation can be terminated safely.

As the simulations show, time is critical to avoid loss of position and heading. A main propeller failing to 100% will cause loss of position and heading if not stopped within 5-10 seconds. In a complex system such as a DP system, expecting an operator, independently of his or hers qualifications and level of vigilance, to be able to identify the failure and take correct action in such a short time frame is unrealistic. Hence the only realistic mean to be able to arrest the failure before position and heading loss is inevitable is by automatically stopping the thruster. As discussed in the Failure handling section, to be as effective as possible this automatic stop function should be at the thruster control system level.

References

[1] ABS. Guide for Dynamic Positioning Systems, 2025.

[2] MTS DP Committee. LFI 2017-3 - Diving Vessel Drive-off - Propeller Failure to Full Pitch, 2017.

[3] DNV. RU-SHIP Pt.6 Ch.3 Navigation, manoeuvring and position keeping, 2024.

[4] IMCA. M190 Code of Practice for Developing and Conducting DP Annual Trials Programmes, 2024.

[5] IMO. MSC.1/Circ-1580 Guidelines for Vessels and Units with Dynamic Positioning (DP) Systems, 2017.