Thrusters and Thruster control systems
Thrusters - Overview
Thruster types - Overview, advantage, disadvantage
Thruster allocation / Modes of operation - e.g. bias and considerations therein
Thruster control system - the basics including EM stops and emergency/Backup controls
Thrusters - Failure modes and their effects on operations
Lessons learnt from DP Events
New developments in the last 5 years

THRUSTERS – OVERVIEW

Thrusters play a critical role in the operation of an DP vessel.

DP vessels typically have multiple thrusters installed around the hull, including azimuth thrusters that can rotate 360 degrees and tunnel thrusters that are mounted in the bow or stern of the vessel. These thrusters work together with a computer control system to make small adjustments to the vessel's heading and position in real-time.

For DP the primary function of the thrusters is to provide the necessary thrust to counteract the environmental forces acting on the vessel and keep it in its desired heading and / or position.

In many vessels the aft propellers are also required for transit, towing, etc. and may have a rating disproportionate to that required for DP purposes.

The positioning of the thrusters should be such that effective thrust can be generated in surge, sway and yaw in both intact and post worst case failure conditions. Effective thrust capability is dependent on the lever arms. This should be taken into consideration during the design phase. Location of thrusters should be optimized and is dependent on the hull geometry.

For a monohull, the most onerous criteria for the assessment of the DP capability of a vessel are its performance when exposed to environmental forces from the beam direction. A vessel which excels in this condition typically performs well in any other situation. Care should be exercised when assessing DP capability of a vessel where a portion of the thrust is required to carry out the industrial mission (for example thrust to overcome bottom tension on a S-Lay pipe lay vessel.

For effective counter forces against wind, the size (capability) of the thrusters should be approximately proportional to the windage area at the area of installation. In other words, a vessel with a high superstructure forward requires the installation of adequately sized thrusters forward. Failure to follow this basic design philosophy introduces the potential to lose station in conditions where the wind velocity and direction is shifting rapidly.

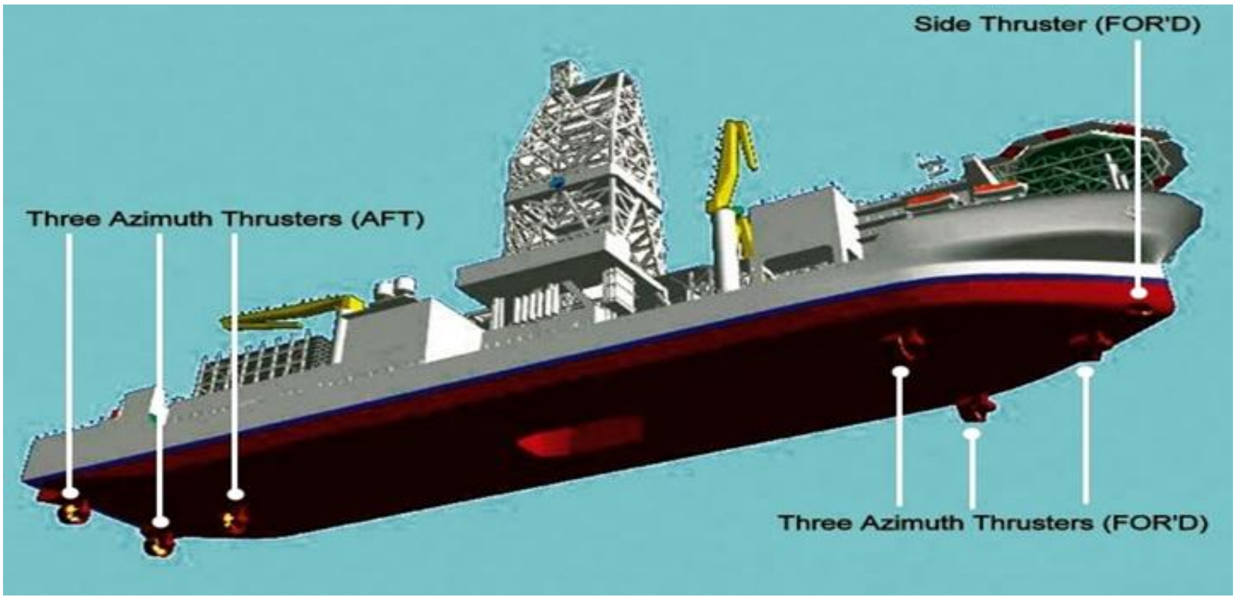


FIGURE 45 - TYPICAL DRILLSHIP THRUSTER LOCATIONS

The number of thrusters should be determined by:

1. The ability to develop forces in surge, sway and yaw post worst case failure.
2. Classification society requirements for redundancy post worst case failure.
3. The desired post failure DP capability for the industrial mission.
4. Maintenance considerations - maintaining redundancy for both intact and post worst case failure conditions when a thruster is taken out of service for IRM. For example, a scenario where a vessel with a four-thruster configuration where power distribution is such that two of them come off each switchboard. When one thruster is required to be taken out of service - post worst case failure capability is reduced to one thruster and vessel may not be able to maintain station.

THRUSTER TYPES OVERVIEW

There are three types of thruster:

- Azimuthing propulsors.
- Fixed direction propulsors.
- Hybrid concepts utilizing a combination of azimuth thrusters and fixed-direction thrusters.

ADVANTAGE, DISADVANTAGE

Propulsors with fixed direction of thrust			
TYPE	**APPLICATION**	ADVANTAGES	**DISADVANTAGES**
In-Line Conventional propulsion systems	Used widely for transit as well as station keeping (providing thrust in longitudinal direction) on ship shaped DP vessels (OSV's, diving support vessels, pipe-laying vessels, older generation of drill vessels)	Simple, reliable, robust and proven system. Very low maintenance, highly efficient for DP when equipped with ducted propellers	Requires reverse gear or CP propeller to change direction from AHEAD to ASTERN. Additional thrusters needed for transverse thrust forward and aft. Efficiency reduced in reverse operations
Transverse Tunnel Thrusters	nstalled in the bow and/or stern of vessels to provide transverse thrust and forces for yaw manoeuvres	Simple installation inside a transverse tunnel in the hull. Well protected; hydrodynamically smooth uniform operation; long life	Mediocre performance (depending on length of the tunnel, tunnel exit/entrance configuration). For fixed pitch propellers, reversing of the sense of rotation is required to change the direction thrust. No access for maintenance. Removal/instal lation requires drydocking in most cases; may lose thrust during heavy motions of the
Ducted transverse thrusters	nstalled below the hull, forward and aft to provide transverse thrust; mostly installed in retractable containers. Bi directional ducts and propellers generate equal amounts of thrust in both transverse directions. Many successful installations on first generation DP drill vessels	High performance in both directions. Simple and robust design. Access for maintenance after retracting the assembly	For fixed pitch propellers, reversing of the sense of rotation is required to change the direction of the thrust.

Propulsors with fixed direction of thrust			
TYPE			
Azimuth thrusters including Azipods	Most popular thrusters applied for transit as well as station keeping for DP MODUs (Mono hull and column stabilized) Typically installed under the bottom of the hull thus increasing the draft of the vessel, Smaller ship shaped DP vessel (OSV's etc.) uses azimuth thrusters installed in the skeg of the vessel (above the base line). Installation forward requires retractable azimuth thrusters to minimize draft during transit	Reliable proven designs, High performance. Bottom mounted thrusters are accessible for maintenance after underwater removal, No drydocking required for maintenance. Containerized azimuth thrusters:- This thruster is installed in a watertight container which encloses the drive motor and the auxiliary systems. The entire container is retractable to a position above the waterline at which servicing the thruster is feasible. This is the optimum installation for DP application if achievable.	Underwater installation and removal complicated and time consuming. Requires support vessels in many cases. Retractable azimuth thrusters (without containers) are mechanically complex, expensive, require a high degree of maintenance. Access typically only during dry-docking. Custom dock preparations necessary
Voith Schneider propellers (VSP)	A very special type of propulsor applicable for DP operations. It is a cycloidal propeller operating on a vertical axis.	The VSP is an ideal propulsor for DP combining the propeller characteristic of a controllable pitch propeller combined with control of the direction of thrust through 360 degrees. Allows step less control of thrust in magnitude and direction. Can be supplied with active anti-roll system. (This might introduce commonality and use on	The mechanical complexity, high costs, and maintenance of a large diameter seal limit the application to low draft vessels and usually for specialized applications.

THRUSTER ALLOCATION - EG BIAS AND CONSIDERATIONS THEREIN

THRUSTER ALLOCATION

Thruster allocation refers to the process of determining which thrusters to use and how much power to apply to each thruster to achieve a desired position or heading for a dynamic positioning (DP) vessel.

On a DP vessel, the thruster allocation system is a fundamental part of the DP and is responsible for distributing the required force on the vessel to the thrust generated by each thruster in a manner that maximizes the vessel's manoeuvrability while minimizing the fuel consumption. The thruster allocation system takes into account various factors such as vessel speed, heading, wind, current, and wave conditions to determine the most efficient thruster configuration.

The thruster allocation system is typically integrated with the vessel's DP control system, which constantly monitors the vessel's position and heading and makes adjustments as necessary. The thruster allocation system also takes into account the limits of the thrusters, such as maximum thrust, minimum thrust, and maximum speed, to ensure that the thrusters are used within their design parameters.

Thruster allocation is an important aspect of DP vessel operation as it allows the vessel to maintain its position accurately, even in challenging weather conditions, while minimizing the use of fuel and reducing the risk of damage to the thrusters or other components of the vessel.

THRUSTER BIAS

MTS DP Vessel Design Philosophy Guidelines (Rev2 - Apr21) states that *DP Control system thruster allocation logic on vessels with azimuthing thrusters often have a 'thruster bias' feature. This feature allows thrusters to be run against each other.*

The "thruster bias" feature or 'bias mode' of a DP control system refers to a function that allows the operator to group thrusters so that they generally act against each other to provide the thrust required. The thruster bias feature is generally used when the environmental forces are low. Typically, azimuth thrusters are directed towards one another and run at an equal but minimal thrust producing a net zero force. If thrust is required in one direction one thruster increases, and hence the vessel is pushed that way, to stop the motion the other thruster increases and the first goes back to minimal. This avoids having to turn the thrusters through 180 degrees each time thrust is required in the opposite direction.

Note when the environment increases then all the thrusters will 'push' into the environment and if the push too hard and hence the vessel position is 'up wind' then by reducing the thrust the environment bring the vessel back rather than rotating thrusters 180 degrees.

With the thruster bias feature, the operator can adjust the amount of thrust generated by each thruster, either individually or as a group, to achieve the desired control for the vessel.

The thruster bias feature can help to improve the control of the DP system in light environments by allowing the DP system to minimize the azimuth rotation of the thrusters. It can also help to reduce the risk of damage to the thrusters and other components of the vessel by preventing overuse by the DP constantly rotating all the thrusters.

To use the thruster bias feature effectively, it is important for the operator to have a good understanding of the vessel's operating conditions and the performance characteristics of the thrusters. The operator should also be aware of the limitations of the thrusters and the DP control system and should use the thruster bias feature within these constraints to ensure the safe and efficient operation of the vessel.

The bias system will have limits that can be adjusted by the DPO, so for instance if the thrusters in bias have a minimum power setting of 5% but a maximum of 25%. As the force required grows to get the required thrust one may be at 20% while the other is still at 5% so the net result is 15% (but using 25% total power for that group) if the force required was to be the equivalent of 40% , then if they were still in bias one would be 45% and the other 5% , but the limit is set at 25% so in fact 'bias' is overridden and both thrusters provide 20% in the same direction.

In some DP systems once bias is overridden the DPO must initiate it again if conditions allow, in other systems it is overridden while the condition exists but then will revert to bias automatically if the thrust demand falls within the limits once again.

In reality, the thrusters may not directly oppose one another and there is another factor which overrides ‘bias’ and that is the ‘turn factor’.

Finally, if two thrusters are part of a bias group and one trips, then the other reverts to free mode.

MTS DP Vessel Design Philosophy Guidelines (Rev2 - Apr21) offers the following comments on thruster bias and it’s use.

1. In light conditions, Thruster bias is used to prevent excessive azimuthing causing undue wear and tear.

2. Thruster bias is sometimes used to provide a base load intended to protect the power plant from blackout. The failure scenario involves a diesel generator governor taking the engine to full load and the remaining diesels tripping on reverse power.

3. This however is not without potential problems as in an incident where a governor failed, and the base load of the bias was sufficient to avoid a black out. The operator however saw the faulty generator at full load and manually reduced the bias to try and lessen its load, this then tripped the healthy remaining generators on reverse power and the unhealthy one on overload which blacked the vessel out.

4. This method of protection also requires that the healthy generators are able to accept the step load which occurs when the faulty generator trips.

5. Thruster bias can be shed manually or automatically. Shedding bias automatically can cause a position excursion to the surprise of the operator. Position loss can also occur in the case of systems that only have manual selection / de-selection of bias. Forgetting to remove the bias as the weather increases has resulted in loss of position incidents.

6. Some DP control systems shed thruster bias automatically on:

a. Thruster alarm conditions.

b. Detection of insufficient thrust.

c. Insufficient power or insufficient thrust.

7. Designs that shed bias on insufficient power should be considered for vessels with critical power consumers required by the industrial mission. For example, DP drilling vessels with active heave compensation.

THRUSTER BARRED ZONES

A "barred zone" or “Forbidden zone” with regards to thrusters on a dynamic positioning (DP) vessel is a restricted area (or angle) within which a thruster should not be used. The barred zone is typically defined by the manufacturer or the DP system provider and is based on the design of the vessel to avoid wash being directed into another thruster, or towards a moonpool, acoustic pole, taut wire, ROV LARS etc.

The purpose of the barred zone is to prevent the thrusters from being used in a way that could cause damage or compromise the performance of other equipment.

The barred zone is an important consideration when operating a DP vessel, as it can affect the manoeuvrability and efficiency of the vessel.

To ensure that the thrusters are not used within their barred zones, the DP control system is typically programmed with the restricted areas for each thruster. The DP control system will then prevent the thrusters from being used in these areas, and will automatically adjust the distribution of thrust among the thrusters to ensure that the vessel remains in its desired position and heading while avoiding the barred zones.

Often it is also possible for the DPOs to add further barred zones on a temporary basis depending on the industrial mission being undertaken.

MTS DP Vessel Design Philosophy Guidelines (Rev2 - Apr21) notes the following thruster bared zones.

> *17.17.1 Barred Zones are used to prevent thruster wash in certain directions. They are used to avoid thruster to thruster interaction, interference with hull mounted acoustic transducers, ROV launch area, etc. Care must be taken to test these thoroughly as incidents have occurred when a barred zone has been active even not required. For example, when barring is active for an adjacent thruster even when it is stopped and barring is no longer required. In such cases the barred thruster is unable to produce thrust in the direction of the stopped thruster and position is lost.*

THRUSTER MODES

As well as bias there are other modes that can be allocated in the DP system depending on the type of vessel and type of thrusters.

Many DP systems will enable a fixed mode for a thruster and this is when the DPO can fix an angle and thrust for one or more thrusters, though care needs to be taken as this limits the ability of the DP to utilise all the thrust that would otherwise be available.

On anchor handlers with very large and powerful main propellers often the DP will offer a ‘push/pull’ mode. This is similar to having a bias mode on the main props, so one will be ahead and one will be astern. Two things to note here. The first is that the rudder associated with the ahead propeller will be the only one to provide athwartship thrust and second that the two props are creating a turning moment. This can be a useful feature to ‘assist’ slightly the bow thrusters, so it may be advantageous to define Port Ahead or Starboard Ahead depending on the environment.

If the DPO considers it appropriate they can select ‘free’ mode and this is where the DP is free to allocate any thrust and direction to all selected thrusters.

THRUSTER AND GENERATOR OPERATING STRATEGY (TAGOS)

MTS DP Operations Guidance - part 1 paragraph 1.2.10 recommends the use of a Thruster and Generator Operating Strategy (TAGOS)

> *This is a document that provides informed guidance, usually derived from a review of the FMEA and if necessary, validation from personnel knowledgeable about vessel specific information, on appropriate configurations of thrusters, generators and power distribution, and associated constraints, so as to enable correct choices to be made to provide optimum level of redundancy.*

DNV-GL's document Dynamic positioning systems - operation guidance state that the DP operations manual should represent the way the vessel is operated, and that,

> *For complicated power systems and/ or thruster configurations, it may be useful provide the operator with a thruster and generator operating strategy (TAGOS) to assist in the decision on what generators and thrusters to use for different circumstances and different equipment availabilities.*

They also suggest that additional DP capability plots correlated to the TAGOS be provided on the vessel.

THRUSTER CONTROL SYSTEM - THE BASICS INCLUDING EM STOPS AND EMERGENCY/BACKUP CONTROLS

DP control systems operate on the same basic control system principles as any other control system. Where significant differences exist, it is in the type and range of protection functions provided, the means of detecting faulty position and sensor data and the means of dealing with internal faults. DP control systems can be distinguished by their thruster interfaces.

MSC.1/Circ 1580 - GUIDELINES FOR VESSELS AND UNITS WITH DYNAMIC POSITIONING (DP) SYSTEMS

States:

3.3 Thruster system

3.3.1 Each thruster on a DP system should be capable of being remote-controlled individually, independently of the DP control system.

3.3.2 The thruster system should provide adequate thrust in longitudinal and lateral directions, and provide yawing moment for heading control.

3.3.3 For equipment classes 2 and 3, the thruster system should be connected to the power system in such a way that paragraph 3.3.2 can be complied with ***even after failure of one of the constituent power systems and the thrusters connected to that system.***

3.3.4 The values of thruster force used in the consequence analysis (see paragraph 3.4.2.4) should be corrected for interference between thrusters and other effects which would reduce the effective force.

3.3.5 ***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****.*

3.3.6 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.

IMCA M103expands in these requirements and give guidance on how thrusters should fail (if they do fail) so as to minimise the impact on the vessels station keeping ability.

2.18 Thrusters, Main Propellers and Rudders

Unlike some other parts of the DP system, thrusters and their control systems can fail in such a way as to cause a drive-off. Such failures can be compounded by load shedding measures. If a large thruster fails to full thrust when there is insufficient spinning reserve, the power management system may command a phasing back of thruster rpm or reduce pitch for all thrusters. As the faulty thruster cannot respond to the command to reduce load the effect is to exaggerate the drive-off as the healthy thrusters are no longer able to oppose the faulty unit.

Unlike thrusters provided with hydro-mechanical CPP mechanisms, fixed pitch propeller (FPP) thrusters driven by variable frequency drives very rarely fail to full thrust. DP rules and guidelines generally require thrusters not to fail in such a way which results in an uncontrolled increase in thrust or change in thrust direction. Fail safe conditions are taken to be

- *fail as set*
- *fail to zero thrust;*
- *drive motor trips.*

Although almost all thrusters now exhibit a failsafe response to the type of faults simulated during DP FMEA proving trials, the extent to which thrusters and their local control systems are truly fail safe is not well established. Very few thruster control systems have a completely independent protection system monitoring the performance of the thruster. An unambiguous alarm should be given for a command/feedback deviation and not for a wire-break.

The very low incidence of failures to full thrust in FPP thrusters tends to place this issue well down on the list of DP failure modes to be addressed.

Although it would be relatively simple to develop independent monitoring and protection systems for thrusters it is important not to reduce reliability by introducing a system which can spuriously trip one or more thrusters. IMCA M 216 – Thruster integrity management guidance – provides further guidance by presenting and describing a thruster integrity management system for thruster units installed on a new build and existing vessels.

MTS DP Vessel Design Philosophy Guidelines (Rev2 - Apr21) offers guidance on assessing the effective force on the vessel being produced by the thruster. This is in the context of the capability plots but offers useful insights into real world conditions:

6.4.1 The thrusters generate the counter forces necessary to establish the force equilibrium. A realistic assessment of the actual thruster net forces acting on the vessel is a prerequisite for accurate polar plots.

6.4.2 The following should be considered when assessing actual thruster net forces:

The basic thruster performance data should be based on sound hydrodynamic principles, not on marketing considerations.

The thruster data used for generating capability plots at different current inflow velocities should be based on performance curves for that inflow velocity. Using bollard pull data which is usually based at zero inflow velocity leads to inaccuracies.

The potential impact of current inflow on thrusters that are not aligned with inflow should be considered.

The thruster performance data provided is usually for open water conditions. Thruster data used for station keeping calculations should account for thruster to hull interaction losses. The magnitude of the losses is a function of the hull shape, thruster location, degree of tilt of the propeller or nozzle axis, etc.

'Barred zones' prevent thrust in defined sectors. These zones can be created in the DP control system software to address issues associated with thruster wash for azimuthing thrusters. Such barred zones may result in reduced capability. Typically, the arc of this sector is small and the associated losses are a few percent of the nominal thrust.

100% thruster power in DP is not always the actual 100% power due to scaling the thruster in DP within a linear range. Some drives are tuned 0-80% or similar leaving less power available in DP.

The thruster power used for generating capability plots should be based on the actual maximum power achievable in DP control.

Propeller performance if provided at all will tend to be 'bollard' condition (i.e. assuming no inflow into the propeller) and will be a curve of thrust/power versus Speed. For propulsion propellers we often see a set of 'Robinson Curves' and these show the relationship between speed and thrust at increasing inflow rates (i.e. as if the vessel were sailing). We observe some of this effect if the vessel is in DP in a real current. So with an inflow the thrust as a particular propeller speed will be less than we calculate from the bollard condition.

THRUSTER DRIVE SYSTEMS

Thruster drive systems can be:

- Electric motors - AC induction, synchronous (salient pole machines), DC (less frequently used).
- Hydraulic motors.
- Direct drive by diesel engine.

Electric motor driven thrusters are most common in DP service. Thrusters that are driven directly by diesel engines are common in logistics vessels. Some vessels are outfitted with thrusters powered by hydraulic motors.

Most modern-day electric motors for thrusters are powered by AC variable speed drives. The characteristics of these drives are a good match to the characteristic of a propeller. The drive system can deliver a constant torque to the nominal speed and power and then over that rpm range of the motor the torque reduces to keep the power constant (approximately 110 to 115% of the nominal rpm). This feature is similar to the field weakening feature of older DC/SCR controlled systems; however, it utilizes simpler motors, and operates at higher efficiencies.

A thruster drive system for a DP semisubmersible, for instance, can be designed to deliver power to match the propeller characteristic the thruster over the entire operating range of the vessel. In this case, the thruster propeller pitch is selected for bollard pull. By increasing the rpm (by field weakening), full power is available even at a transit speed of 5 to 7 knots.

For a typical DP monohull vessel, the operating range is too large to utilize the field weakening effectively. The propeller pitch must be optimized between bollard pull and transit to deliver an effective thruster. However, the thrust required for transit is normally way beyond anything required for DP.

Thrusters (or in-line main propellers) with fixed pitch propellers driven directly or through a reduction or reverse/reduction gear by Diesel engines are not able to control the lower part of the engine rpm below the engine's minimum idling rpm, which is may be 40% of the rated rpm. Operating the diesel engine in this range with a clutch leads to high wear of the clutch and is not desirable. Where thrusters are driven by diesel engines, control of thrust in magnitude and direction (ahead/astern) is best achieved by a controllable pitch propeller.

EMERGENCY STOPS

ABS GUIDE FOR DYNAMIC POSITIONING SYSTEMS 2021

Emergency Stop (1 March 2021)

An emergency stop facility for each thruster is to be provided at the main DP control station. The emergency stop facility is to be independent of the DP control systems, manual position control system and manual thruster control system. The emergency stop facility is to be arranged to shut down each thruster individually.

This emergency stop is to be arranged with separate cables for each thruster.

Electrical cables potentially exposed to hydrocarbon fires in engine rooms and spaces where fuel oil is contained these cables are to be fire-resistant coated.

An alarm is to be initiated upon loop failure (i.e., broken connections or short-circuit) in the emergency stop system.

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 if these are arranged in accordance with the physical thruster layout. Where an accidental operation of the emergency stop buttons can occur, a protective cover is to be mounted.

Emergency stops for thrusters are to be located within easy reach of the DP operator (DPO) e.g., within the bridge, at the main DP control station.

Emergency stops for thrusters are to be laid out in a logical manner which reflects the position of the thruster in the vessel's hull.

For equipment classes 2 and 3, the thruster emergency stop system is to have loop monitoring.

ABS GUIDE FOR DYNAMIC POSITIONING SYSTEMS 2021 states:

9 Control Mode Selection

9.1 Manual/DP Control Modes *(1 November 2013)*

A simple device is to be provided in the DP control station for the selection of the thruster control modes (i.e., manual thruster control, Manual Position Control and DP control). The device is to be designed so that it is always possible to select manual thruster controls after any single fault in the DP control mode.

Thrusters within the DP control system may also be individually de-selected from DP control to manual thruster control for service and vessel specific operations.

9.3 Main/Backup Control Station

For **DPS-3** notation, the mode selector between main DP control station and backup DP control station is to comply with redundancy requirements. The transfer to the backup DP control station is to be fail-safe, so that if the main DP control station is damaged in any way, transfer of control can still be initiated and assumed at the backup DP control station. Transfer of control to the backup DP control station is to be performed manually, such that inadvertent control transfer to an unattended station is avoided.

Let's remind ourselves of some basics.

IMO MSC/Circular 1580 defines failure as,

> *an occurrence in a component or system that causes one or both of the following effects:*
>
> *.1 loss of component or system function; and/or*
> *.2 deterioration of functional capability to such an extent that the safety of the vessel, personnel or environment protection is significantly reduced.*

And a hidden failure as

> *means a failure that is not immediately evident to operations or maintenance personnel and has the potential for failure of equipment to perform an on-demand function, such as protective functions in power plants and switchboards, standby equipment, backup power supplies or lack of capacity or performance.*

Worst-case failure design intent (WCFDI) means

> *the specified minimum DP system capabilities to be maintained following the worst-case failure. The worst-case failure design intent is used as the basis of the design. This usually relates to the number of thrusters and generators that can simultaneously fail.*

And Worst-case failure (WCF) means

> *the identified single fault in the DP system resulting in maximum detrimental effect on DP capability as determined through the FMEA.*

The vessel's failure mode effect analysis (FMEA) will systematically analyse all systems and sub-systems to a level of detail that identifies all potential failure modes down to the appropriate sub-system level and their consequences.

The FMEA may identify several faults that all result in the WCF condition, and although many single line diagrams look symmetric in terms of power and thrust in fact the location of the thrusters on the hull will normally result in one RG failure being worse than another.

Therefore, the failure modes of any particular thrusters, on any particular ship, with any particular redundancy WCFDI are idiosyncratic.

For example consider the azimuth thruster system diagram below.

The FMEA might identify such as the following:

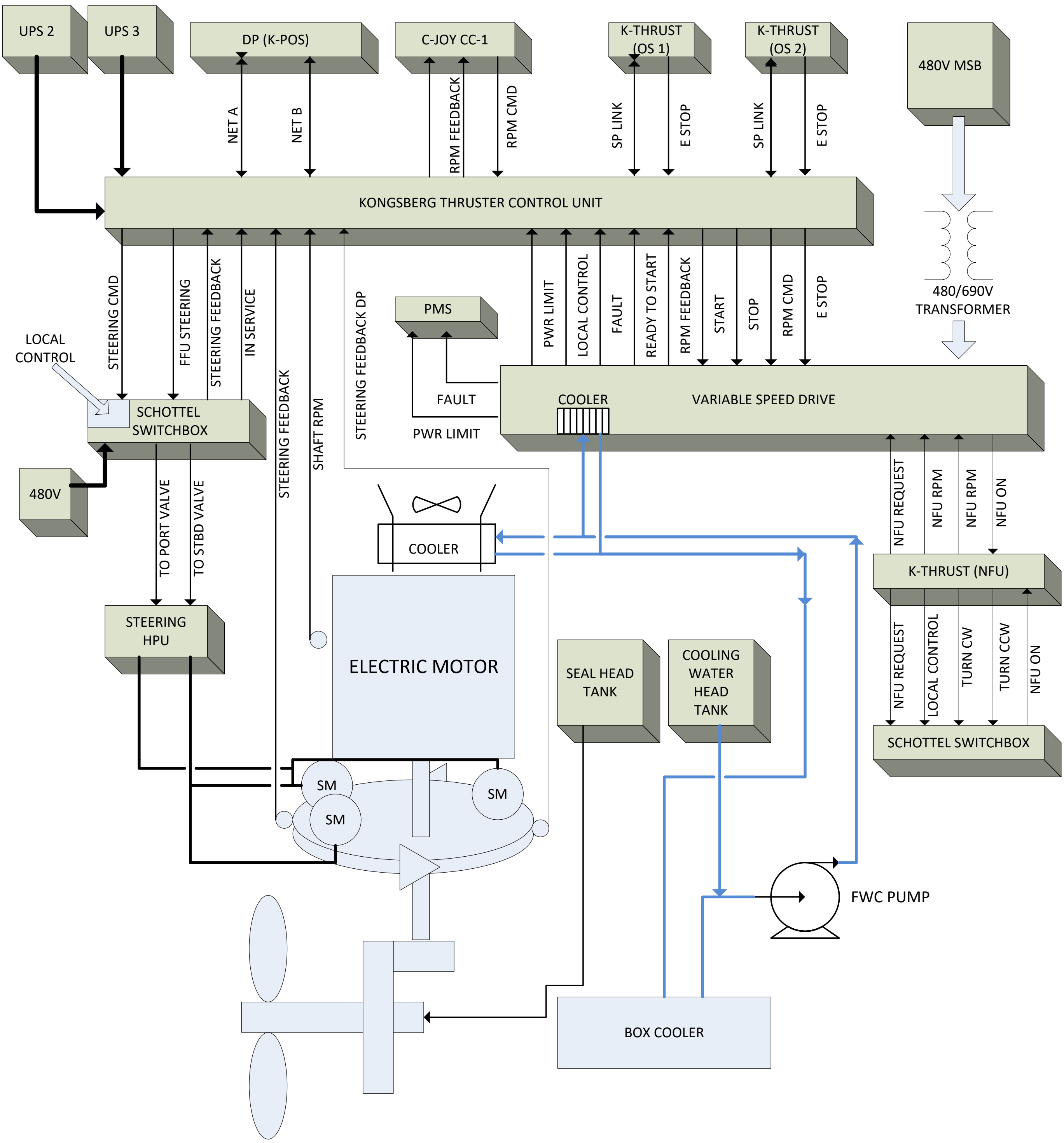


FIGURE 46 - EXAMPLE AZIMUTH THRUSTER SYSTEM DIAGRAM

Problems with the hydraulic oil, such as contamination, could result in erratic or delayed thruster azimuth and eventual wear and damage to the steering pump internals. It is important that the correct filtration is used for the oil and a program of regular oil sampling and analysis is implemented for all thrusters. However, in mitigation any single azimuth thruster's deteriorated steering capability will be compensated for by other thrusters and position loss should not occur. The Operator will be alerted to the correct thruster for shutdown by a command and feedback error.

Any failure of a hydraulic or LO circuit will only affect one thruster. Alarms are provided for hydraulic, lube oil pressure and temperature, tank levels, pump status, filters, etc.

Thruster shutdowns will be initiated by low servo pressure.

The effects of incorrect thruster speed control signals could range from a minor change in RPM to a thruster full RPM setting. A minor change may have little or no effect on position keeping ability and the DP system will *attempt to compensate with the other thrusters. A thruster failing to full RPM would require DPO intervention to deselect the thruster or emergency stop the thruster if the force could not be overcome.*

A failure of the thruster speed command signal will result in the thruster RPM going to the idle setting. This will have little effect on the vessel's position keeping ability as the remaining thrusters will be able to compensate.

The effects of incorrect thruster direction control signals could range from a minor change in direction to an incorrect direction setting. A minor change may have little or no effect on position keeping ability and the DP system will attempt to compensate with the other thrusters. A thruster failing to a direction opposite of what is required would require DPO intervention to deselect the thruster or emergency stop the thruster if the force could not be overcome.

The effects of incorrect steering box indication on the Azimuth thrusters cause incorrect steering data being sent to the TCU and DP system. The DP system uses the incorrect data in its force calculations and the DP model becomes unreliable. The DP system will attempt to compensate with the other thrusters, however the DPO may have to deselect or stop the thruster if the force could not be overcome.

A failure of the 'DP in command' signal to the Azimuth thrusters will cause the thruster ready contact to open and the thruster to take commands from the manual control stations. If the control levers on the manual control stations are not at the zero position, thrust will be applied. Operators are to keep manual controls in the zero position when in DP mode to prevent position keeping instability upon thrusters coming out of DP.

These failure modes could also be presented in tabulated format as below

Thrusters and Propulsion Failure Modes

Azimuth Thruster Control

Failure Mode	*Causes(s)*	*Probability*	*Local Effect*	*Final Effect*	*Criticality*	*Remarks*
Loss of VSD running signal to Kongsberg	Open circuit	Low	Thruster continues to follow DP commands however DP deselects thruster	Thruster not ready on DP. Thruster deselected.	Minor	Remaining thrusters compensate
Loss of VSD local control signal	Short circuit	Low	Thruster to idle. DP deselects thruster	Thruster not ready alarm on DP. Thruster deselected	Minor	Remaining thrusters compensate
Loss of Kongsberg speed command	Open circuit.	Low	Thruster VSD to idle. RPM feedback alarm	Thruster RPM to idle. Thruster continues to run	Minor.	
Incorrect speed command	Corrupted data	Low.	Thruster effect from unstable RPM to full RPM	Thruster RPM feedback alarm.	Medium	Thruster at full RPM would require DPO intervention to stop the thruster
Loss of Kongsberg speed feedback	Open circuit.	Low.	Thruster continues to operate on estimated feedback.	Thruster RPM feedback alarm. Thruster continues to operate on estimated feedback	Minor.	
Incorrect speed feedback	Speed pick up failure	Low	Thruster continues to follow DP speed commands	Thruster RPM feedback alarm. DP model calculations can be effected	Minor	Position keeping will weaken if other thrusters cannot compensate
Loss of thruster stop signal	Short circuit	Low	Thruster motor stops. Deselected from DP	Thruster 'Not Ready' alarm on DP. Thruster not available	Minor	Remaining thrusters compensate
Loss of converter fault signal	Short circuit	Low	Thruster stops. Deselected from DP	Thruster 'Not Ready' alarm on DP. Thruster not available	Minor	Remaining thrusters compensate

Thrusters and Propulsion Failure Modes Azimuth Thruster Control (continued)						
Failure Mode	*Causes(s)*	*Probability*	*Local Effect*	*Final Effect*	*Criticality*	*Remarks*
Loss of converter 24V control power	Open circuit	Low	Thruster converter fails. Loss of thruster	DP and VMS alarm. Thruster not available	Minor	Remaining thrusters compensate
Loss of electric Lube Oil pump	Mechanical / Electrical failure	Low	Thruster shuts down	Thruster not ready alarm on DP	Minor	Remaining thrusters compensate
Loss of hydraulic pump.	Mechanical / Electrical failure	Low	Thruster shuts down.	Thruster not ready alarm on DP. Azimuth frozen. Motor stopped	Minor.	
Low hydraulic pressure	Mechanical failure	Low	Thruster shuts down.	Thruster not ready alarm on DP. Azimuth frozen. Motor stopped	Minor.	
Loss of Schottel steering command signal	Open circuit	Low	Steering box opens healthy signal and freezes direction. RPM to idle	Thruster not ready alarm on DP. Thruster deselected	Minor	
Loss of steering box control feedback	Open circuit	Low	Steering box opens healthy signal and freezes direction. RPM to idle	Thruster not ready alarm on DP. Thruster deselected	Minor	
Loss of steering box indication feedback	Open circuit	Low	Loss of MTC and DP steering data.	DP system detects fault and uses estimated thruster performance to command	Minor	
Mechanical feedback link	Mechanical failure	Low	Incorrect control and indication feedback. Thruster fails to rotate	Thruster steering appears frozen. Heading and position control may weaken	Major	DPO intervention required. Deselect thruster if position keeping is threatened

DP Event Bulletin	ITEMS
IMCA DP Station Keeping Bulletin 04/19 November 2019	Steering motor failure leads to loss of both aft thrusters – DP incident
IMCA DP Station Keeping Bulletin 04/19 November 2019	Pipe leak leads to loss of all thrusters – DP incident
IMCA DP Station Keeping Event Bulletin 03/16 September 2016	Separate problem with two thrusters caused loss of DP

NEW DEVELOPMENTS IN LAST 5 YEARS

The need for improved efficiency, cost-effectiveness, and environmental sustainability in the maritime industry have driven developments to thruster systems. The use of advanced propulsion systems and control technologies will continue to play a crucial role in the design of dynamically positioned vessels.

SRP-D RUDDER PROPELLERS FOR SOVS

Propulsion system specialist Schottel, Spay, Germany, has introduced a new rudder propeller optimized for DP use.

Meeting the growing requirements for W2W (walk-to-work) vessels to operate efficiently and reliably, the new SRP-D is a further improved rudder propeller variant for highly demanding DP operations by service operation vessels.

"With the SRP-D, we have significantly increased the DP performance of our rudder propellers, resulting in a product that meets the requirements of today's offshore wind industry even better," says Manfred Heer, vice president-technology at Schottel. "Based on the proven principle of the Schottel Rudder Propeller, a cost-efficient yet powerful solution has been developed that greatly improves the positional accuracy of the vessel for the special DP requirements of these applications. For customers, this means a significant increase in safety and possible operating times on offshore structures, especially in difficult weather conditions."

In developing the SRP-D, extensive CFD simulations and calculations were taken into account. The new SRP-D variants are characterized, above all, by reduced propeller acceleration/deceleration times. In combination with a high-speed azimuth steering system with reinforced gear components, the SRP-D enables faster thrust allocation than conventional rudder propellers. With shorter response times, it is possible to react faster and in a more targeted manner to external forces from wind, weather and currents, thus achieving a higher positional accuracy of the vessel. At the same time, fuel consumption is reduced.

FIGURE 47 - TYPICAL RETRACTABLE AZIMUTH THRUSTER (1)

In addition, the SRP-D has an extremely low profile, vertically integrated LE-Drive and an additional 8-degree tilt of the lower gearbox.

Despite its integrated design, the LE-Drive allows a free choice of motor for vessels with an electric, ideally battery-supported, energy supply. Due to its compact design, the LE-Drive opens up more freedom in vessel design.

The SRP-D is optionally also available with the drive train in Z-configuration.

Thanks to an additional lower gearbox downward tilt of eight degrees, the interaction between propulsion unit and hull as well as the propeller flow interaction are reduced. This results in increased thrust efficiency in DP operation and minimizes "forbidden zones."

UNDERWATER DEMOUNTABLE AZIMUTH THRUSTERS

Underwater demountable azimuth thrusters are designed for easy underwater mounting and dismantling without dry-docking the vessel. This is of utmost importance to large vessels and semi-submersible oil drilling rigs to continue operation without any delays. Dynamic positioning thrusters are in service 24/7 during drilling operations. Interrupting drilling and leaving the site in order to repair a unit would be a costly decision.

There are three main components of the underwater installation system. The receptacle with the outer cap (top), the inner cap (middle), and the thruster (bottom). The inner and outer caps are installed at the factory and shipped to the site. Once installed into the vessel the outer cap is removed to access the inner cap. The inner cap is then removed to reveal the hydraulic steering motors and attachment for the cardan drive shaft.

WATERJETS

Waterjets are available in four model sizes ranging from 1000kW to 4000kW to accommodate vessels from 15m up to 45m with stainless steel jets supported by a complete range of electronic controls with joystick docking. These high performance units are specially designed and built for continuous commercial use and to meet the exacting standards of marine classification societies. They can be installed as single or as multiple jets in fiberglass, aluminium or steel hulls. They can also be supplied as booster jets.

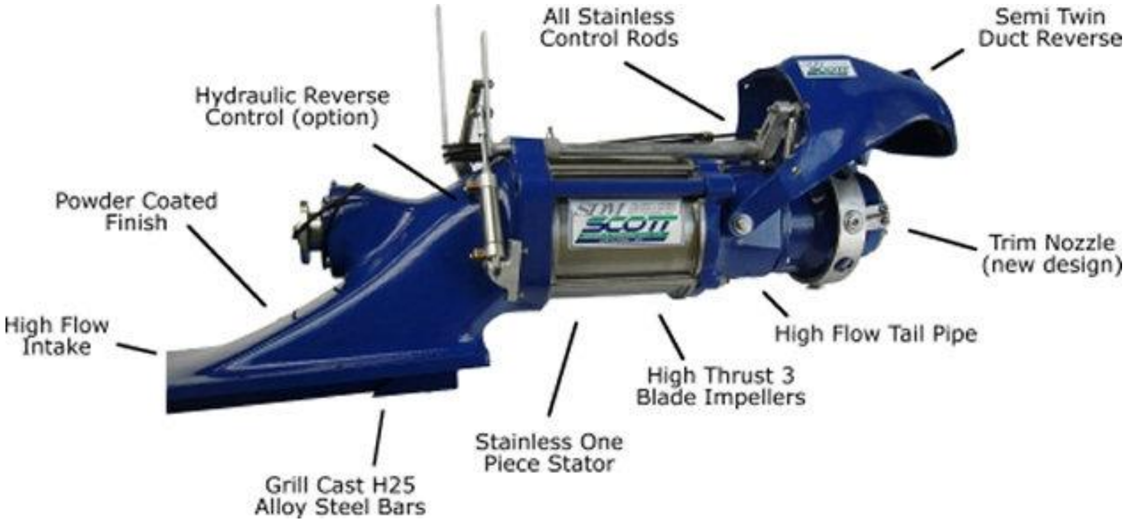


FIGURE 48 - TYPICAL WATERJET

The prefabricated duct is manufactured from Aluminium or Steel plate material resulting in an extremely strong and lightweight structure.

FIGURE 49 - TYPICAL RETRACTABLE AZIMUTH THRUSTER (2)

Electric retractable thrusters are fixed pitch propeller thru-hull azimuth thrusters capable of retracting completely into the hull. They are configured for vertical variable speed electric motor input.

Sizes range from 250 to 10,750 HP (185kW to 8.0MW) with a wide selection of reduction ratios and propeller/nozzle diameters to suit the application requirements. They are normally supplied complete with electric motors and variable frequency drives, but they can also be made to fit flange and shaft end of a customer supplied or shipyard supplied electric motor. The motor travels up and down with the thruster, so the drive line is never disconnected.

Electric retractable thrusters can supplied with an open propeller or with a nozzle. They are also available as combination thrusters, functioning as tunnel thruster in the retracted position and freely azimuthing in the lowered position. Compact units are available for vessels with limited hull depth. A hull fairing piece is normally attached to the bottom of the thruster to reduce drag when the thruster is stowed.

Whilst not new, the Voith Schnieder propellers have been used more extensively in recent years for offshore vessels.

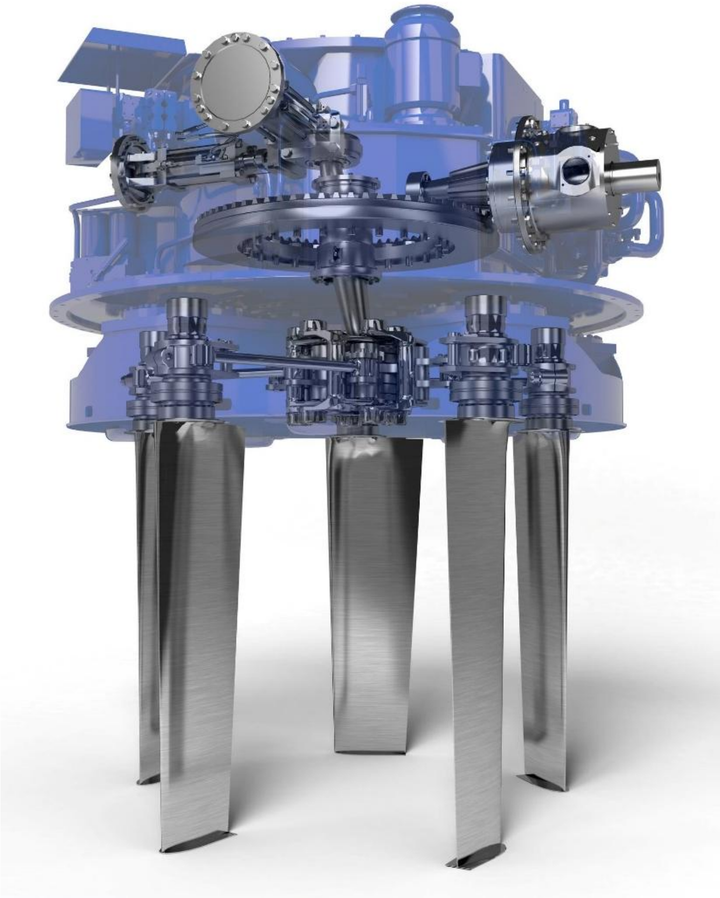
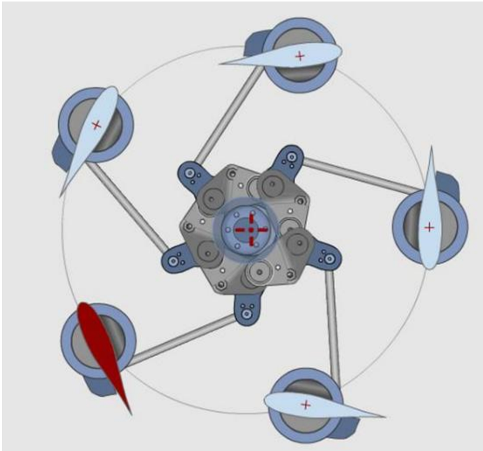


FIGURE 50 - VOITH SCHNIEDR PROPELLER



Clicking on the picture above will take you to the Voith Website where an animation of the propeller principle is available.

As the assembly rotates, the linkages adjust the angle of attack of the vertical blades causing then to all direct the water on one direction.

The advantage is that magnitude and direction of thrust can be changed very rapidly.