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DYNAMIC POSITIONING CONFERENCE

October 13-14, 2009

Design

Design Issues and Failure Modes in OSV Propulsion Systems

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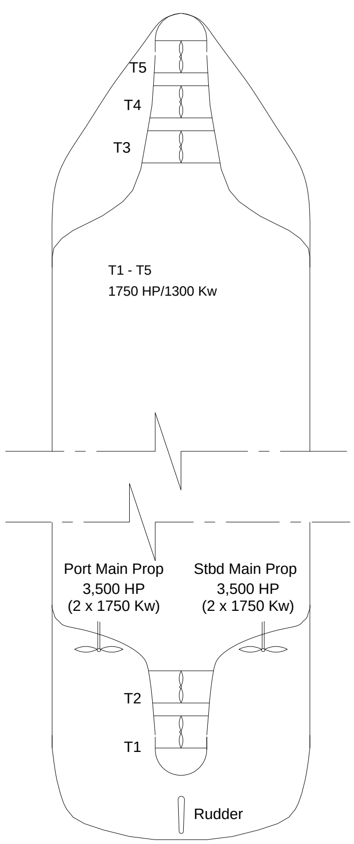
Abstract

The choice of propulsion and thruster equipment for offshore service vessels is dependent on a number of factors which the designer and operator must take into account when considering the construction or modification of a vessel. When Dynamic Positioning is included into the design these choices become considerably more complex.

New technology has introduced new machinery control concepts which are having radical effects on traditional designs.

This paper considers three different thruster, propulsion and power arrangements which have been introduced for OSVs, their integration into the DP System and areas of particular importance to the FMEA practitioner.

Traditional Designs and their Development



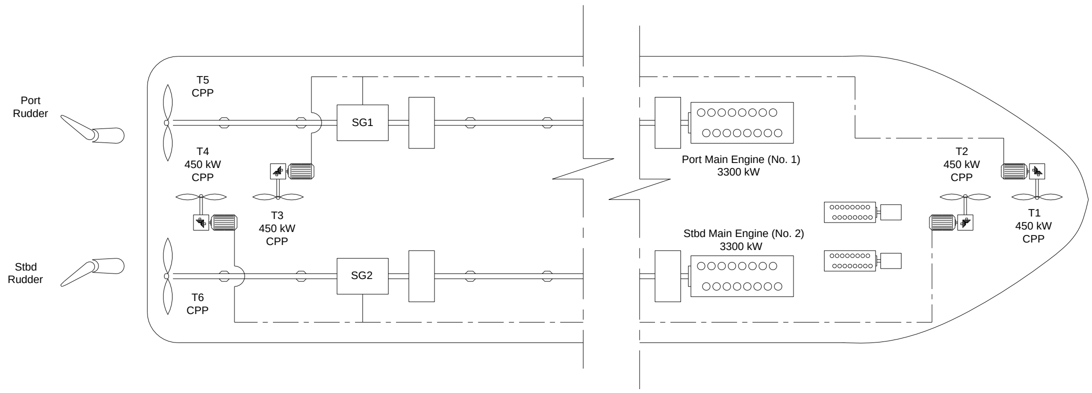
Thruster and Propulsion Arrangment. Pelican Class Drillship

The IHC Gusto 'Pelican' series of drillship was constructed through the mid nineteen seventies, to a design was culmination of the research of the previous two decades of experimentation. The simplistic elegance and featured redundancy in propulsion and power distribution exercised a significant influence on DP vessel design until the late nineteen nineties.

The Pelican design had certain variants however the Pacnorse 1, delivered in 1978, is typical of the type; a 504ft vessel with three bow and two stern tunnel thrusters, all of 1750 Kw and two main propulsion propellers of 3500 Kw each. In order to obtain the infinite control through the power range required by dynamic positioning both propulsion and manoeuvring equipments utilised constant speed electric drives with controllable pitch propellers.

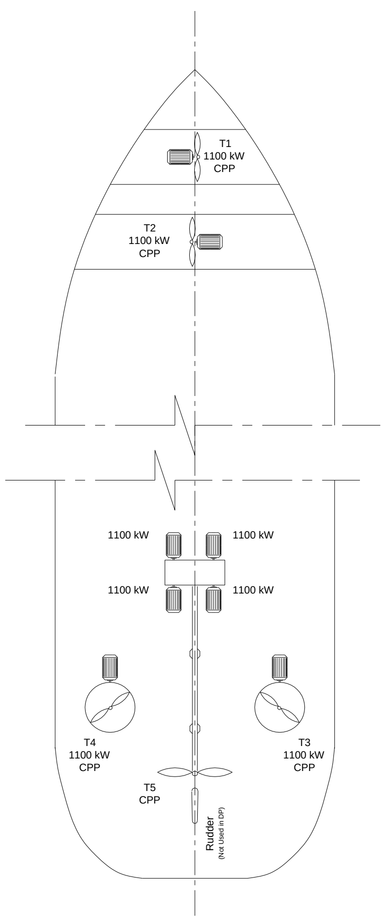
CUSS 1 and Shell Eureka demonstrated both the control and cost advantages in using azimuthing thrusters. Unfortunately the units available in the early sixties were both too small and unreliable for practical use, tunnel thrusters and propulsion propeller combinations therefore became standard. Adequately reliable azimuthing units began to appear in the mid to late nineteen seventies. However these remained relatively small and hybrid designs such as those seen on the Stena Seaspread Class were utilised to obtain reasonable transit speed.

For smaller vessels the large and complex power plants of the drillships and multi-service vessels was not feasible. The main-propulsion/shaft generator combination offered in the basic Ulstein UT 7xx lent itself to a simple supply configuration which was used to great success, vessels constructed in the early 1980's. The Moray Harstad, in service in 1982 is typical of this arrangement.



Thruster and Propulsion Layout, DSV Moray Harstad - 1982

Common factors shared by all these designs were dual power distribution systems, a minimum of two bow and two stern thrusters. Although fixed pitch variable speed units were built the majority of vessels employed controllable pitch propellers. All the vessels specifically mentioned employed this means of thrust control.



DSV Seaspread, Hybrid Thruster Arrangement

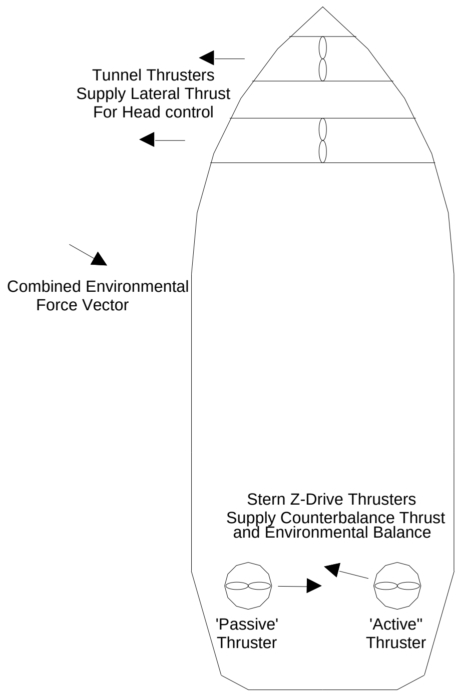
Although available, rudders were not typically used in the DP configuration. The rules of one Classification Society make specific note that lateral thrust from rudders may only be considered as a back-up in the event of failure of the dedicated stern thrust unit.

The reliability of standby-start systems was identified early in DP development as a potential source of DP control failure. A second design feature which common to all the examples described is that of ‘on-line’ line redundancy. Total positioning power available is two hundred percent of power required in any vector, the loss of thrust from any unit is made up by increasing the power, or thrust, delivered by the remaining units.

With the exception of the DP Computer controllers little evolution in the equipment installed in DP vessels would be seen through the middle eighties towards the close of the nineteen nineties.

In latter years the application of technology to control functions has permitted a number of implementations to be considered in DP applications which could not have been considered twenty years ago. Many of these applications have the benefit of considerable economic saving when considered against traditional designs and products. The designer of any vessel using these methods should, however carefully consider their operation and function when integrating them in a DP system. A full understanding of behaviour is essential in providing adequate specifications for construction which can avoid ultimate compromise and failure to meet the design goal of the end product.

Diesel Driven Azimuthing Thrusters



Fixed Pitch Thrusters: 'Forced Bias'

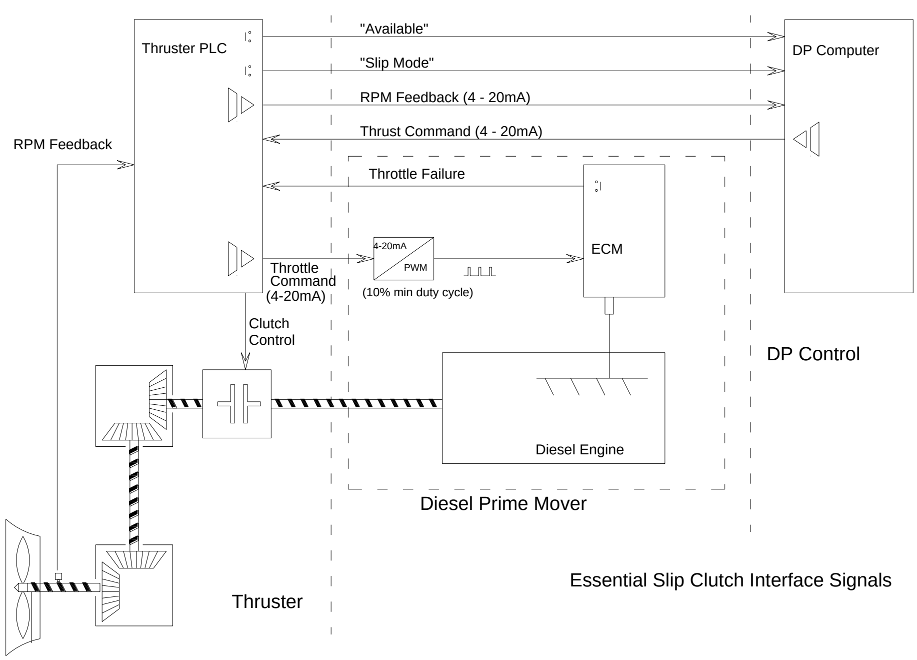
Fixed pitch azimuth thrusters may be employed as propulsion/manoeuvring units in a DP system. As noted above fixed pitch units enjoy a considerable economic advantages and the Owner would enjoy a considerably reduced build cost in using these devices.

The typical 60M PSV would employ two main propulsion units of about 2500 HP. When clutched in such a unit could be expected to generate as much as four tons of thrust when running at idle speed. A force of this magnitude will easily cause significant position displacement if no means of negating it's effect can be found.

Typically such units are placed in counter opposition, or 'forced bias' mode so that the idle force of one thruster is negated by its opposite. One thruster will be used by the DP system to counter the standing environmental forces, the other will operate at idle speed.

The disadvantage of this arrangement is that, should either stern thruster fail, the thrust developed by the remaining unit will force a loss of position control unless the sea forces are sufficient to counter the idle thrust force.

By modulating the hydraulic pressure against the clutch plates and varying the degree of engagement a 'slipping clutch' provides a means of obtaining graduated control of the thrust developed from the force developed with the engine fully clutch in at idle speed to virtually zero.



Slipping Clutch: Equipment Interfacing

In order to reduce wear on the clutch plates by continuous slip in light weather conditions some manufacturers choose to operate the units in the standard ‘forced bias’ configuration, reverting to slip action only when one of the units becomes unavailable. This requires dedicated signal lines to indicate equipment status and fast reaction times. If the thrust on the remaining engine is not brought down within four seconds of engine failure significant position disturbance is likely to be experienced.

Interface signals must be carefully considered. The thruster command/force curves in slip and normal drive modes have different relationships. The DP computer must be advised of the operating status of the thruster.

Shaft RPM feedback to the thruster controller is a critical part of the thruster control loop. When the commanded RPM is not achieved within an acceptable range the controller must release the ‘Available’ signal to the DP computer and disengage the clutch.

RPM monitoring of the shaft alone is not sufficient, the throttle signal to the prime mover must also be monitored. Where the thruster is operating in the slip range the RPM is constant at idle speed, should the throttle signal fail the engine will not be capable of delivering the desired thrust when the thruster exits slip mode.

Trolling Mode

Conventional propulsion units may be used to provide the lateral thrust vector required to maintain position control. In this arrangement two propellers can be arranged in inverse mode, one ahead, one astern, to balance the idle force developed when the main reduction gear is engaged and clutched in.

In the event of failure of either main propulsion unit the operational unit must now repeatedly pass from forward to astern mode in order to provide a zero-sum force. In achieving this the propeller may not spend more than a few seconds in each direction or the vessel will adopt a shunting motion.

In a typical vessel damage to the reduction gearbox is avoided by applying the shaft brake to reduce or halt shaft rotation before declutching and shifting gear. The gears may then be fully engaged before the shaft is released and the engine takes the full load of the torque in reversing direction of the propeller against the inertial force of vessel movement. Typically, the shaft brake will be engaged from six to ten seconds before it is release. This time-span is too great in a DP environment and the vessel is again likely to adopt a shunting movement. Due to the time lag and the force developed by the propeller the oscillation of position is likely to increase in amplitude until all positioning control is lost.

Trolling mode, originally developed for use in trawlers, uses a proportional engagement valve and spring return mechanism in the reduction gearbox to provide a slip action to permit rapid transition between astern and ahead drive.

In trolling mode, as the vessel is effectively stationary, the inertial loads generated by vessel motion are relatively small and the brake may be disabled.

The shaft may then clutch and engage directly through the gearbox at will with no delay.

The slip action provided through the trolling valve reduces impact force on the gearbox preventing premature mechanical failure. When used in the DP environment the lack of precise force control in employing a trolling valve may prohibit its use and the transition between drive direction made virtually instantaneously.

Timing is again critical to the success of the transfer from forced bias to trolling mode. Any delay in fault recognition and signalisation to the DP computer to change the operating mode will cause the idle force developed by the propeller to displace the vessel in the lateral plane.

Large marine gearboxes are designed to withstand considerable forces and the manufacturers of the units where these operations are practiced have stated that they do not expect the action to result in mechanical breakdown. The operation of the hydraulic controls to change gear direction may however present a potential hidden failure and should be carefully considered by the designer.

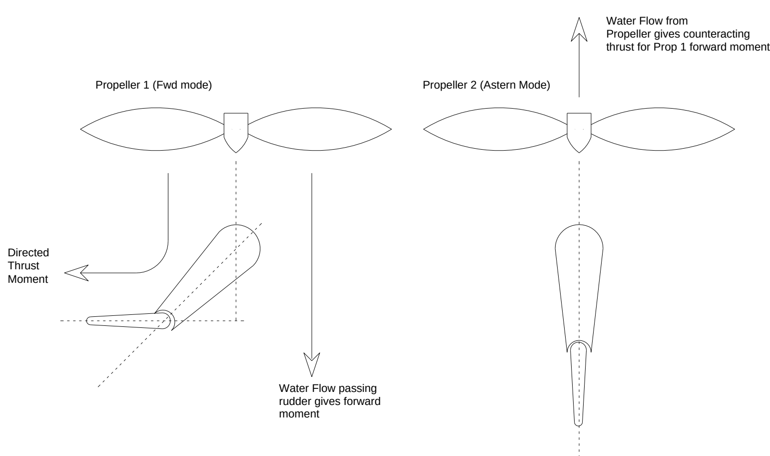
The systems generally depend upon single electrically operated solenoids for each action, clutch in, clutch out. Unless the solenoid is activated it is not possible to determine if is going to act when commanded.

In the event of failure of either main propulsion chains multiple actions of the hydraulic solenoids of the operational unit will be required in order to hold the vessel on location while disengaging vital equipment and in manoeuvring to a safe location. Any failure during this period could leave the vessel without propulsion capability, a condition which is contrary to Main Class rules, or the propeller could be fully clutched in and drive-off could occur.

Single Stern Thruster,

The original vessel designs such as those shown above did not make use of rudders in the dynamic positioning system though rudders were available for steering purposes.

It has been successfully demonstrated that vessel position may be maintained on a twin screw vessel using standard linked rudders with no stern thruster. Simple plate rudders with a maximum rudder angle of 35º restrict the vessel's position keeping envelope but so long as the environmental conditions are within these limits there is no observable degradation for the vessel's on positioning stability.



Rudders: Balancing Forces

Articulated flap rudders such as Becker or Tjenfjord high-lift rudders can achieve lateral thrust efficiency as high as 40% by increasing the effective deflection of water flow over the rudder plates.

In both cases however, the rudder efficiency factor means that water flow not deflected provides forward thrust and a means must be found to counter this force.

The standard twin screw arrangement twin screw is shown in the illustration. In order to be effective in a standard AHTS configuration both propulsion trains must be operational.

In order to obtain a degree of redundancy against propulsion unit failure at least one tunnel thruster is typically installed.

In consequence of the wording of certain Classification Society rules with respect to the use of rudders in DP systems it has become standard in many vessel designs to include two stern thrusters and ignore the rudders. The Ulstein UT 755 design is an example of this arrangement.

The offshore service industry has always been and will remain a highly competitive one. Capital expense can be considerably reduced in AHTS construction if a stern thruster can be omitted and a number of recently constructed vessels have reflected this. Many of these designs have elected to power the stern thruster with a diesel sets, making the stern unit independent.. Such designs however come with additional overheads in design which have to be considered: fuel distribution, piping, classification of machinery spaces and so on.

Recent designs have opted for traditional shaft generator arrangements such as the classical UT design but have opted to make the stern thruster motor switch between the shaft generator sets according to availability.

In any design employing this philosophy a number of factors require serious consideration:

i. Synchronisation of Electrical Distribution

ii. Shaft Generator Capacity

iii. Engine Load Absorption

iv. Thruster Propeller Torque

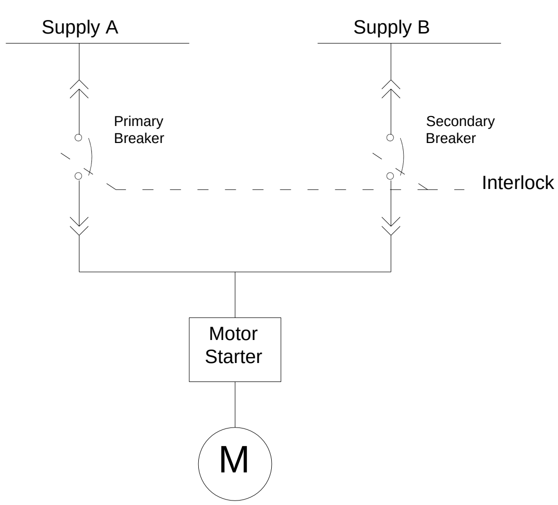
v. Co-ordination of Switchgear Control

vi. Switchgear Failure: Mechanical

vii. Switchgear Failure: Electrical

viii. Electrical Disturbance due to heavy load variation

Typically shaft generator distribution systems are segregated with the main propulsion units permitted to operate in droop mode or, under electronic control, speed regulated. In part due to the variance of load from the main shaft the units will not be synchronised. In consequence the frequency of the electrical distribution may vary by up to several Hertz. As motor speed is proportional to input frequency any motor being switched between unsynchronised distribution systems is therefore liable to place an instantaneous electrical shock load on the system assuming the load.



Basic Bus Transfer Circuit

If the Thruster is being operated at medium to high load it would not be unreasonable to expect significant torque load on the thruster shaft. At the instant where power is removed the thruster will immediately begin to slow down, the braking effect will be increased according to the level of shaft torque. The motor will quickly drop away from synchronous speed.

At the instant where power is removed, the electrical field in the thruster motor begins to collapse, creating a back-emf in the motor coils.

The combined effect of the difference in synchronous speeds, motor slowdown and back-emf is potentially four to five times that of the motor full load current

Each shaft generator powers one stern thruster, each taking 50% bow lateral thrust . The loss of one shaft generator will result in the loss of one bow thruster. The remaining bow thruster will therefore be required double its load.

The most significant failure within the propulsion and manoeuvring electrical distribution system considered by the FMEA must be the loss of the shaft generator by reason of failure of its prime mover: the main propulsion diesel engine. A highly dynamic situation is therefore taking place at this juncture: The remaining engine is undergoing a dynamic load change. The shaft generator is assuming the increased load from the Bow Thruster. At this same point a significant transitional load is placed on the shaft generator from the stern thruster motor as it transfers onto the operational network.

The rating of the shaft generator and the design of its safety systems must take these factors into account to ensure that the system can take all of these loads without causing the generator protection circuits to trip and cause total loss on manoeuvring capability.

The possibility of failure to transfer, due to control or mechanical failure in the switchboard main breaker must also be considered.

Solid state automatic bus transfer switches are used for high speed load transfer in military applications where virtually bumpless transfer of load following supply failure is vital. In commercial applications these devices are generally not considered and standard, spring loaded, breakers must be used. Whilst highly reliable, the potential failures inherent in these breakers, and the control mechanisms required to operate them, must be considered.

Automatic air circuit breakers generally employ spring powered mechanisms to provide for high speed open and close operation of the main contacts. The spring mechanisms are solenoid operated. Table 1 details potential failures which may be found in standard protection breakers.

The control action is double stroke; in order to prevent the possibility of closing onto a fault the primary supply feed breaker must be opened followed by the secondary breaker closure to restore supply to the motor. Failure risk of transfer is consequently increased.

The switching concept remains a subject of some controversy. At least one Classification Society and on Major Contractor make specific reference to automatic transfer and restart of thrusters following supply power failure and advise that restart cannot be taken into account as a redundancy feature in FMEA studies. It has not been determined if the switching thruster principle falls into this category.

Table 1 Potential Breaker Failures

Reasons why breakers and contactors fail to trip
Practical Power System Protection,
Brown & Ramesh, Newnes 2004

1. Open-circuited DC shunt trip coil
2. Loss of circuit DC trip supply
   - Trip fuse blown or removed or
   - Trip MCB open
3. Loss of station DC trip supply
   - Battery and/or charger failure
   - Battery and/or charger disconnection
4. Burnt out DC shunt trip coil
5. Failure by open circuit of control wiring or defective relay contact
6. Breaker mechanical jammed
   - Trip bar solid
   - Trip coil mechanically jammed
   - Trip coil loose or displaced
   - Broken mechanism
   - Lack of regular/correct maintenance
   - Main contacts welding
   - Contacts arcing – loss of vacuum or SF6 gas pressure

Conclusions

In recent years technological improvements have resulted in the development of a number of new power and control methodologies for thruster and propulsion systems which have significant cost advantages over traditional systems.

The inherent complexity of these new designs necessitates a higher level of understanding of their functional operation than is the case with traditional systems in order to accurately predict failure modes. In consequence, greater use of holistic techniques over individual component analysis is required in the preparation of any system FMEA where these systems are employed.

Classification Society Rules were largely written with the operational characteristics of the individual components which made up traditional designs in mind. The characteristics of new designs may no longer fall clearly in the same broad scope and specifications which rely upon this scope for design reference may no longer be adequate.

Failure to address the particular characteristics of each component in the preparation of design specifications may result in design shortfalls which can be costly to remedy while continuing to fail to achieve the original design intent.