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Recommendations for Training of Crews Working on Diesel-Electric Vessels Equipped with Azimuth Thrusters

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ABSTRACT: This study addresses the problem of training the officers, which are assigned to an electrical-driven vessels equipped with azimuth thrusters. A pair of omnidirectional thrusters in combination with power plant system containing several diesel generators imply a potential for a variety of different emergency scenarios, which also includes partial or full loss of control or blackout. These fault scenarios were classified in the article with predefined risk levels depending on the area, time limitation, mode of operation and fault itself. Mutual responsibilities and action algorithms for bridge and engine teams in a step-by-step manner have been developed for each scenario. Personnel behavioral differences in both expected and unexpected emergencies have also been studied.

1 INTRODUCTION

Azimuth thrusters are widely used in the maritime industry, specifically on tugs, offshore and passenger vessels. They are renowned for providing vessels with exceptional maneuverability.

Azimuth propulsion performs best in automated low and zero-speed tracking applications such as auto-tracking and dynamic positioning, as system can apply necessary steering forces at any speed in any directions.

However, it also has some drawbacks. Higher complexity leads to two apparent problems:
– Vessel with azimuth thrusters is much more complicated in manual handling.

Higher propulsion system complexity leads to a larger possibility for technical problems.

Many technical problems related to seals and bearings cannot be solved in a day and, apparently, do not appear in a day. They require correct assessment of visible symptoms, possible defects location and timely corrective maintenance.

When it comes either to steering system or power supply system faults, it is more situational and often requires immediate actions from both bridge and engine room teams.

Therefore, simulator training can help to build up a habit for specific actions and a communication flow between teams in case of such emergencies.

2 STEERING MODES HIERARCHY

A typical azimuth thrusters system has a specific procedural flow given in fig. 1.

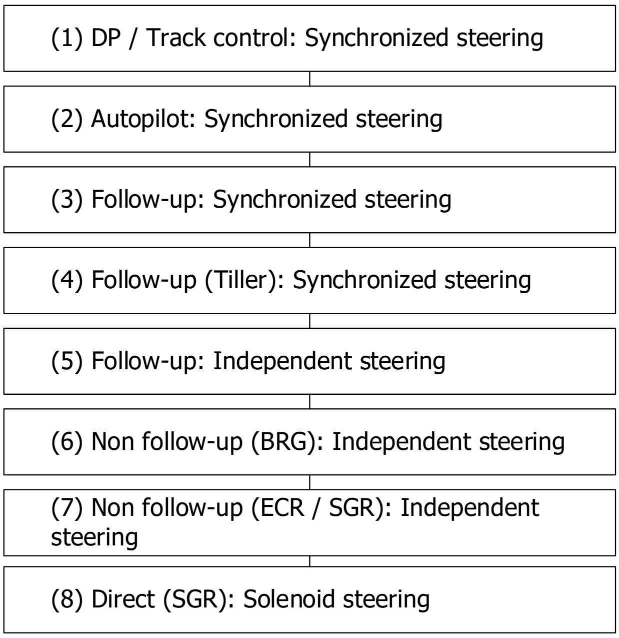

Figure 1. Steering modes hierarchy.

Modes (1) and (2) usually require routine monitoring and minimum intervention from an operator, except parameters adjustment, based on ship behavior.

However, simple things like steering angle limitation along with reduced speed may lead to temporary loss of steering in poor weather conditions. Also in synchronous (both thrusters engaged in steering) auto tracking mode vessel speed might be unstable. This problem can be treated with setting the system into asynchronous mode, where one of the thrusters is pushing only straight ahead. From the other hand, on the minimum speed of 1.5-2.5 knots, increase of rudder limit above conventional 35° can dramatically improve the ship’s stability on track.

Modes (3) and (4) are commonly used at high and moderate speeds to change heading manually. In this case, rudder limits have to be checked prior to maneuver to avoid abrupt turning, as all produced thrust will be directed to a given angle.

Mode (5) is a maneuvering mode, which requires specific skills from an operator. Manual maneuvering technics and precautions on thrusters’ allocation is discussed in several publications including Kobylinski (2013), Ververk (2002) and Nowicki (2014). *This stipulates the first stage of officers training, dedicated to gaining a manual handling skill for the bridge staff.*

Non-follow up (6) is the closest to emergency mode, when a thruster does not respond to manipulator. Generally, there are might be three options available for the operator:

- NFU Steering angle;
- NFU RPM;
- NFU Pitch angle.

Simply wrong sequence of actions during a transfer from one control system to another (i.e. from DP to a conventional autopilot) may lead to a situation when one of the thrusters is stuck on a certain azimuth angle.

This situation has to be assessed immediately and resolved with use of NFU control buttons.

Modes (6)-(8) are emergency modes, which require constant communication with an engine team. Non-follow up and direct solenoid steering can only save a vessel from imminent danger, after that a better solution has to be found in order to regain control of the vessel.

3 RISK BASED APPROACH

There is no danger in the loss of steering alone. However, depending on the situation, loss of steering may lead to a navigational incident such as grounding, collision or various heavy weather damage (i.e. loss of cargo due to heavy rolling resulted from vessels inability to keep a safe heading).

In relation to groundings and collisions, intuitional approach can be used.

As the RISK is a product of a LIKELIHOOD (LH) and a SEVERITY (SV), we should define these two components first.

Apparently, being closer to a hazard with no steering means bigger likelihood of running across that hazard. There are several factors influencing the LIKELIHOOD.

Let’s name the first factor HAZARDS DENCITY (HD). Even if the initial CPA (second factor) is non-zero there is still a risk to hit an object in dense traffic or narrow waters. Although, if it is a ship, it will most likely try to deviate from our way to give us sea room as necessary, which somewhat reduces the RISK.

However, the most critical is the time factor or TCPA to the closest hazard, which almost straightforwardly specifies how much time we have to solve the problem to avoid grounding or collision.

In the most general cases, the SEVERITY of collision or grounding can be related strait to a ship’s velocity. The higher the velocity the more damage may be caused.

In order to obtain correct LH value HD, CPA and TCPA shall be inversely proportional:

$$LH = \frac{1}{HD} \cdot \frac{1}{CPA} \cdot \frac{1}{TCPA} \cdot ST\,, \tag{1}$$

where ST – hazard movability index.

Basing on the kinematic energy equation

$$E = 0,5 \cdot mU^2,$$

where m – ship’s mass; U – ship’s speed, although mass can be assumed as constant and thus will not affect the RISK for the particular vessel, severity can be given as

$$SV = U^2, \tag{2}$$

In table 1 RISK level is given in each line for a possible collision with a stationary object.

Table 1. Risk assessment factors

Likelihood				Severity	Risk
HD nm	CPA nm	TCPA hours	Stationary	Speed	
10	1	2		1	0.05
5	0.5	1	0.5 - NO	5	2
2	0.25	0.5		10	40
0.5	0.1	0.25	1.0 - YES	20	1600

These factors form multi-dimensional RISK. However, to get better visual representation lets define HD = 1, CPA = 1 for a stationary target and calculate the RISK matrix.

RISK levels can be described as follows:

BLACK (risk > 400) – immediate actions required to avoid an accident or to minimize its consequences. Speed has to be reduced in any possible way. Assessment of possible catastrophic consequences to be done.

BLUE (risk > 200) – immediate actions required to avoid an accident or to minimize its consequences. Speed has to be reduced in any possible way.

RED (risk > 100) – Speed has to be reduced to a level where additional means of steering (retractable or side thrusters) can be utilized. As soon as safe heading is achieved, assess options for emergency anchorage. Try to regain the steering with main means of propulsion.

YELLOW (risk < 100) – additional means of steering can be utilized. Assess options for emergency anchorage. Try to regain the steering with main means of propulsion.

Table 2. Risk matrix: loss of steering

Risk		TCPA, hours			
		1	0.75	0.5	0.25
Speed knots	1	1	1.33	2	4
	5	25	33	50	100
	10	100	133	200	400
	20	400	533	800	1600

4 POWER MANAGEMENT AND BLACKOUT PREVENTION

There is a variety of possible faults that may happen to the steerable thrusters (IMCA 2011 & 2012), which goes all the way from power generation to a directed thrust delivery.

This stipulates the second stage of officers training, dedicated to gaining a power management skill for the engine staff. This also includes changeover and synchronization procedures between generators and system restart after blackout.

Generally speaking, a blackout can be avoided by utilizing two different approaches (IMCA 2000). The first one is used on conventional DP II/III class vessels, which usually have from four to six generators. During DP operations, a vessel usually has an open bus bar tie breaker, which splits power delivery in two equal groups, feeding two separate groups of thrusters.

Such approach advantages are elimination of total blackout in case of any single electrical or mechanical fault, greater reliability and less diesel-generator (DG) restarting time in case of partial blackout. Disadvantages are high fuel consumption at low loads, low power plant flexibility, in addition blackout on one side leads to inability to operate a certain group of thrusters and apparently reduces the steering ability.

The second way of providing electrical power continuity without splitting bus bars is the application of power plant advanced protection system.

The primary function of protection schemes is to isolate faulty circuits and limit damage to equipment. The greatest threat to any system is the short circuit fault, which can alter system operation in a sudden and possibly violent manner. Electromagnetic forces generated by large fault currents can cause mechanical damage to transformer and machine windings and the intense heat associated with arcing has caused fire at fault locations. In DP and other operations, even greater emphasis must be placed on the need to maintain supplies for propulsion. The arguments for and against operating with bus sections connected have been discussed earlier and are still the subject of much debate. Operation of the power system with bus sections connected offers many operational advantages with only slight risk of complete blackout. The risk cannot be considered negligible, however, and operators choosing to take advantage of this mode of operation may wish to consider installing one of the higher specification bus-bar protection methods. There are four types of protection that perform this task:
- zone protection;
- directional protection;
- protection by time discrimination;
- optical arc detection.

Such approach allows the power plant to be more flexible in most of known ships' operation modes but requires more sophisticated and expensive power management and protection equipment comparing the split bus bars operation.

Engine team actions in case of full or partial blackout are given on figure 2.

5 EMERGENCY STEERING

In a wider scope of the problem it is not only solenoid steering from the thrusters' gear compartment, but also all possible emergency actions taken by deck and engine departments, and communication between them. *Which is the third stage of training.* This includes:
- control transfer from autopilot to feedback and non-follow up modes on the bridge;
- full or partial control transfer from Bridge to ECR (one group of thrusters is controlled on the Bridge, another – in ECR);
- troubleshooting and equipment restart on the ECR side;
- ensuring steerage and maneuverability or emergency anchoring on the Bridge side;
- transferring the control back to Engine room.

Introducing realistic scenarios and time limits related to existing navigational hazards helps to improve deck and engine officers' trouble shooting and crisis management skills.

On the working vessel, these scenarios usually are only limited to a table talk. Which is understandable, as the vessel schedule, mode or area of operation might not allow to carry out a proper training.

However, hands-on experience is extremely important when it comes to emergencies. Crew shall not only know what to do, but be able to act in a quick and efficient manner. This can only be achieved with dedicated simulator training.

For the purpose of simulator training vessel specific action algorithms can be really useful as a step-by-step to-do list and communication protocol, which has to be discussed and agreed within Bridge and Engine teams.

There are several events related to steering that may substantially affect vessel's controllability, which also have previously occurred in the industry:

– thruster starts to rotate freely;
– thruster goes to full power load unintentionally;
– thruster freeze on certain azimuth;
– thruster stops due to failure.

Apparently, if a thruster's pitch or RPM is at zero or even below some critical value any steering with such thruster will be ineffective.

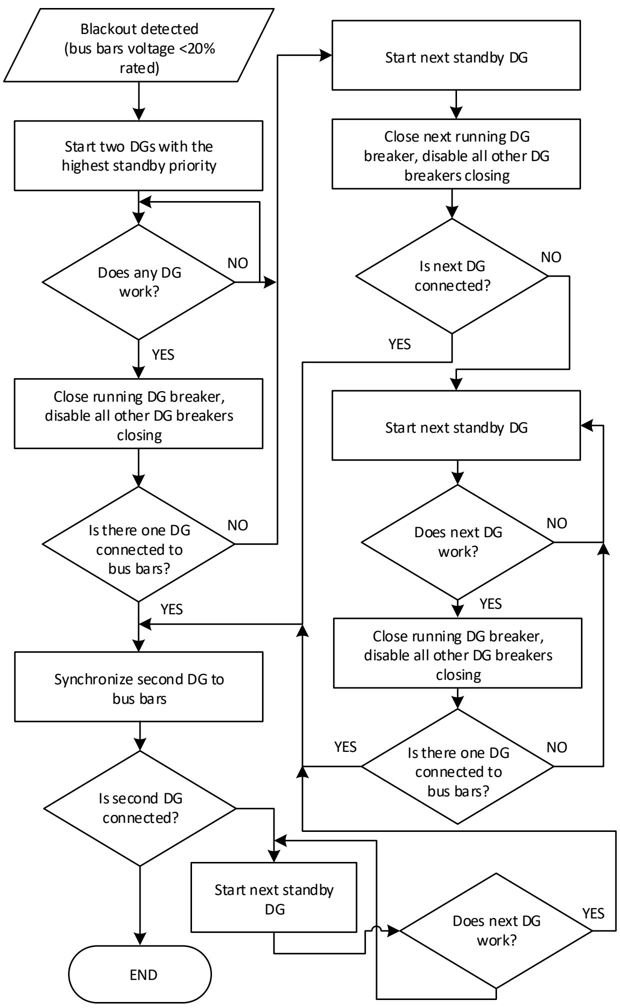

Figure 2. Flowchart on power restore after full blackout.

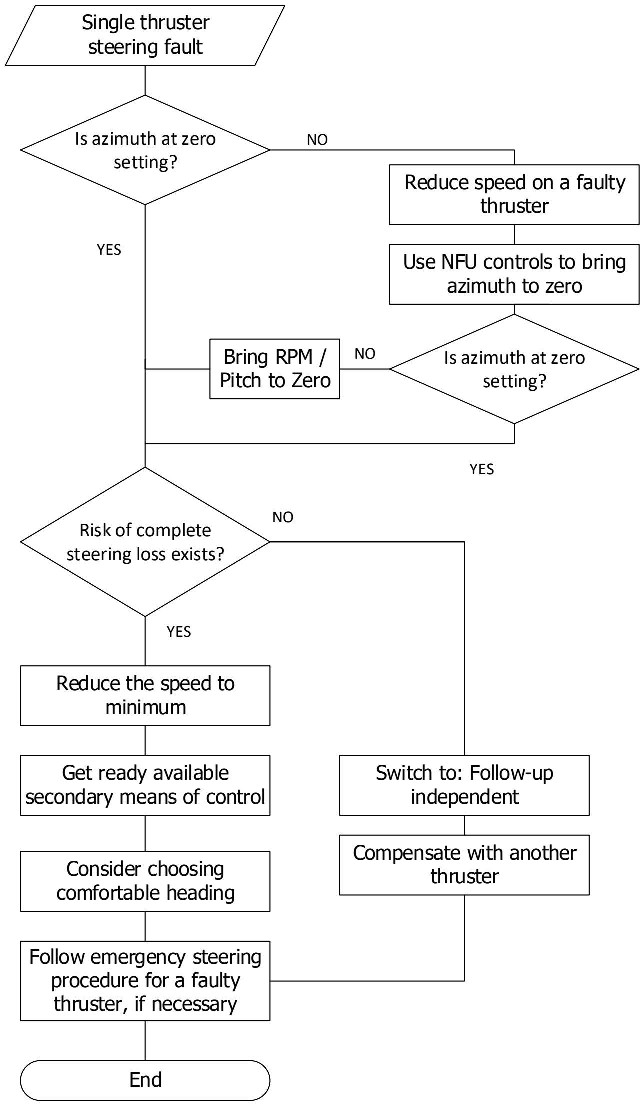

Figure 3. Actions flowchart for a single thruster failure

The latter has two different perspectives. When the steering mechanism works normally and thrust is lost, heading control will be also lost.

However, when thruster's azimuth cannot be controlled, the very first action required is to set thrust to zero.

Actions flowchart for a single thruster fault is shown on figure 3.

Required actions shall also be chosen with regard to existing risk level. For instance, if a vessel is steaming at 20 knots the very first action in case of any serious steering fault is to slow down appropriately in order to reduce possible harm and to give an engine team more time for troubleshooting.

Another consideration is that the vessel cannot effectively use additional means of control such as side thrusters, retractable thrusters or anchors at high speed. If the steering ability is seriously degraded, the deck officer has to ensure that the vessel is going slow enough in order to deploy an additional thruster or to use anchors as necessary.

6 BEHAVIORAL ASPECTS

Team reaction on faults and communication in the process of training changes dramatically.

There are several factors, which were observed during practical exercise.

Bridge and engine control room familiarization obviously has the greatest effect on response time. This also includes knowledge of warning and alarm sounds and indicators, and same important knowledge of how to silence the alarm buzzers. This recalls another important subject of alarms standardization an ergonomics, but usually a team has to deal with whatever is already installed.

Secondly, communication in between bridge and engine team has to be clear and precise in order to provide the best response time.

Not only language barrier may be a problem, but is also awareness on both ends of the phone line.

It is a good practice to have a toolbox meeting (briefing) between deck and engine teams prior to critical operations and practice emergency scenarios as a team, including VHF and phone communication.

Also, it is recommended to five a training to the same teams that will actually work together. It does help the crew to feel more comfortable in the future, if difficulties occur.

Finally, practicing all the stages of emergency gives both teams (bridge and engine) clear understanding of what may happen and how to deal with it. This builds up the operator's ability to recognize how a critical situation develops and what are the best ways to keep it from escalating or at least to minimize the harm.

7 CONCLUSIONS

A diesel-electric vessel equipped with azimuth thrusters have complicated steering and power supply systems architecture, which stipulates many possible faults, but also many troubleshooting alternatives. Knowledge of these alternatives can help to avoid incidents related to loss of steering or power.

As offered in the article, the best way to get hands-on experience on dealing with a steering and power systems faults is the Maritime Resource Management training, which includes both bridge and engine teams.

Suggested MRM training should consist of three stages:

- azimuth thrusters manual handling training for deck officers;
- power management and troubleshooting for engineers;
- emergency steering training for both teams involved in same scenario.

Generic steering system failure risk assessment method and emergency actions flowcharts are provided in this article.

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