INTERNATIONAL STANDARD

ISO 22822

First edition
2023-09

Large yachts — Quality assessment and acceptance criteria — Dynamic positioning on large yachts

Grands yachts — Évaluation de la qualité et critères d'acceptation — Positionnement dynamique sur les grands yachts

Reference number
ISO 22822:2023(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 12, *Large yachts*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Dynamic positioning (DP) systems are common on ships and platforms in the offshore oil and gas industry. System reliability and positioning accuracy are of vital importance for ensuring safe operation at sea. These aspects are therefore an integral part of the vessel design, the operational procedures and the personnel requirements. The DP system reliability is expressed in the vessel class notation. The specific DP notations as defined by classification societies are usually derived from the IMO definitions for equipment Class 1, Class 2 and Class 3, indicating the level of redundancy in the DP system.

The application of DP systems on large motor yachts is a more recent trend. There is a need for a clear definition of the specific capabilities and the necessary equipment for large yachts with a DP system. The intended use of a DP system on board a large yacht is different from application in the offshore industry. The DP system on a yacht is intended for recreational use. The use of the DP system is considered recreational when the DP operation is not mission critical, its duration is relatively short (hours, rather than days) and the weather conditions are relatively mild.

Large yachts — Quality assessment and acceptance criteria — Dynamic positioning on large yachts

1 Scope

This document specifies the minimum requirements for dynamic positioning (DP) systems on large yachts intended for recreational use (i.e. not mission critical, short duration, mild weather). This document provides minimum requirements for equipment, as well as a calculation method to quantify the DP stationkeeping capability and guidance on testing and personnel requirements.

2 Normative References

There are no normative references in this document.

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
dynamic positioning system
DP system
complete installation necessary for dynamically positioning a large yacht

Note 1 to entry: The dynamic positioning (DP) system includes a *power system* (3.2), *thrusters* (3.3) and a *DP control system* (3.4)

[SOURCE: MSC.1/Circ.1580: 2017, 1.2.11 — modified, "vessel" replaced by "large yacht", and second sentence condensed into Note 1 to entry.]

3.2
power system
components and systems necessary to supply the *dynamic positioning system* (3.1) with power

Note 1 to entry: The power system includes prime movers and associated systems, generators, switchboards, cabling, UPS systems and power management systems.

[SOURCE: MSC.1/Circ.1580: 2017, 1.2.20 — modified, second sentence condensed into Note 1 to entry.]

3.3
thruster
devices providing thrust force to control the position of the large yacht

Note 1 to entry: Thrusters can include dedicated thrusters, such as transverse tunnel thrusters and auxiliary thrusters, as well as the main propulsion if controlled directly by the *dynamic positioning system* (3.1).

3.4
dynamic positioning control system
DP control system
control components and systems, hardware and software necessary to dynamically position the large yacht

Note 1 to entry: The DP control system includes a computer system, a control station, sensors and all necessary cabling and network connections.

[SOURCE: MSC.1/Circ.1580: 2017, 1.2.10 — modified, “vessel” replaced by “large yacht”, and second sentence condensed into Note 1 to entry.]

3.5
sensor
device including at least one position reference system, one heading sensor and one wind speed and direction sensor

Note 1 to entry: Optional sensors can include additional position reference systems, as well as additional types of sensors.

3.6
joystick control
system offering manual position and heading control of the vessel from the dynamic positioning control station

3.7
dynamic positioning operator
DP operator
DPO
crew member with the specific task to operate the *dynamic positioning (DP) system* (3.1) and monitor its correct operation from the DP control station

Note 1 to entry: DP operators have received an internationally standardized DPO training and certification.

3.8
dynamic positioning class notation
DP class notation
code to indicate the level of redundancy present in a *dynamic positioning system* (3.1)

Note 1 to entry: Class notations are generally derived from the IMO equipment class notations Class 1 (no redundancy), Class 2 (all components redundant) and Class 3 (all components redundant and physically separated). Examples of the classification society guidelines can be found in References [2] and [3].

3.9
dynamic positioning capability plot
DP capability plot
graphical representation of the results of a static dynamic positioning capability analysis

Note 1 to entry: For each wind direction the plot shows the maximum wind speed at which the vessel can maintain its position and heading, using the available thrusters to counteract the environmental loads. Examples of calculation methods to determine such plots can be found in References [4] and [5].

4 Application

This document provides a common frame of reference that can be used by yacht designers, equipment manufacturers, yacht builders and yacht owners. It is noted that this document is not intended as a replacement for specific dynamic positioning (DP) class notations, as provided for commercial ships by classification societies.

The DP system on board a large yacht may have the following modes of operation:

— Automatic position and heading control. This mode of operation may be used when staying at a stationary position in open water, without the use of an anchor.

— Manual joystick control. This mode of operation may be used for low speed manual manoeuvring of the ship, for example in a port.

— Automatic heading control at anchor. This mode of operation may be used to avoid oscillating motions of the ship (fish-tailing) when moored on a single anchor at the bow.

The recreational use of a DP system on a large yacht can be described as follows:

— for operation in mild weather conditions;

— for relatively short duration operations;

— when no other systems or operations rely on the functioning of the DP system;

— special attention should be paid to passenger safety.

Notable differences with DP systems on commercial vessels can be summarized as follows:

— Large yachts with a DP system do not have a specific DP class notation. The intention of this document is only to provide a uniform definition of the required equipment for large yachts with a DP system, as well as a calculation method to quantify the DP stationkeeping capability.

— DP systems on large yachts do not require redundancy of equipment. This means that a single failure in any of the components can result in a complete failure of the DP system. This level of redundancy is similar to DP-1 systems on commercial vessels.

— DP systems on large yachts do not require specialized personnel. Ships with a DP class notation have specific personnel requirements, such as the presence of a DP system operator (DPO).

The calculation method to analyse the DP capability of a large yacht consists of the following:

— Show that the thruster configuration has the capability to independently create longitudinal and transverse thrust forces, as well as yawing moments (F_X, F_Y, M_{XY}). These thrust forces can be generated in positive and negative directions. The specific thruster settings applied to achieve these loads should be indicated [propeller revolutions per minute (r/min), rudder angles, azimuth angles, ..., etc.].

— Static calculations to determine equilibrium of mean environmental loads and mean thruster loads. Wind loads shall be considered, while current and wave loads may be ignored. Calculations are performed for all wind directions. The results are presented in the form of a polar plot, showing the maximum wind speed at which the vessel can maintain its position.

— Optional time-domain simulations may be performed to investigate aspects such as stationkeeping accuracy, DP control settings, fuel consumption, noise and vibrations.

5 Minimum equipment requirements

5.1 General

A large yacht with a DP system shall be equipped with the following systems and components:

— power system;

— thrusters;

— DP control system;

— position and heading sensors;

— wind speed and direction sensors.

This list corresponds with the minimum equipment requirements, as given in Reference [1].

5.2 Power system

The power system either directly drives the thrusters on board the vessel, or it generates the electrical power to drive thrusters. Furthermore, electrical power is generated for all other electrical systems on board the vessel. Diesel-electric configurations (system with generators, switch boards and electrical engines) offer the highest operational flexibility. Alternatively, generators connected to the main engine can be used.

5.3 Thrusters

The thrust force and direction required by the DP control system is generated by the thrusters. During DP operation, the thrusters are controlled directly by the DP control system.

The thruster configuration shall be designed such that thrust loads can be generated independently in the longitudinal and transverse directions, as well as a yawing moment. Azimuthing thrusters offer the most flexibility to generate the required forces, while vessel control may be more complicated using main propellers and rudders.

The response of the thrusters shall be sufficiently fast to accurately control the vessel position and heading. In general, electric thrusters are preferred for DP operation, due to their accurate thrust control and fast response. Thrusters that are driven directly by a diesel engine are usually of limited use for DP application, due to a slower response to a dynamically varying thrust demand.

5.4 DP control system

The DP control system typically includes a state estimator (e.g. a Kalman filter), a controller [e.g. a proportional-integral-derivative (PID) controller] and a thrust allocation algorithm. The DP control system determines the required action of the thrusters, based on the measured vessel position and heading.

The state-estimator determines the slowly varying motions of the vessel in the horizontal plane (surge, sway, yaw), ignoring wave frequency oscillating motions. The low frequency motions are input for the controller, which determines the total required forces (F_X, F_Y, M_{XY}) necessary to keep the vessel at its required position and heading. The allocation algorithm distributes the total required forces over the available thrusters, based on a power optimization.

5.5 Sensors

The large yacht shall be equipped with the following sensors:

— position measurement sensors, e.g. a GPS receiver;

— heading measurement sensors, e.g. a compass;

— wind sensor, measuring wind velocity and direction.

The sensor placement should be such to enable accurate measurement. For example, the wind sensor should be placed on a high position on the vessel, to enable undisturbed wind measurements.

The following sensors are optional:

— additional position measurement sensors, such as an alternative satellite navigation system, or an acoustic position reference system.

These optional sensors usually improve the performance of the DP system, for example with regard to accuracy of stationkeeping.

6 DP stationkeeping capability

6.1 General

The DP stationkeeping capability of a large yacht with a DP system can be assessed using static calculations. In these calculations, the mean thrust forces and the mean environmental forces acting on the vessel shall be evaluated. The calculation approach described in this chapter is intended for recreational use of DP systems on large yachts. The calculations are less extensive than the analysis typically performed for commercial vessels with a DP system. For example, only wind loads are considered, and no analysis of failure cases is required.

The DP stationkeeping capability of large yachts is assessed in three steps, as illustrated in 6.2 to 6.4. Vessels that meet the requirements in steps 1 and 2 can be identified by the notation “DP-R”, indicating that they have a DP system for recreational use. Step 3 is optional, allowing for more detailed analysis of the vessel DP performance.

The notation “DP-R” indicates that a large yacht has a DP system for recreational use (i.e. not mission critical, short duration, mild weather). It means that the vessel has a suitable thruster configuration and all necessary equipment on board. The term “DP-R” is not intended as a replacement of specific class notations as used for commercial vessels with a DP system.

6.2 Step 1 - Thruster configuration analysis

During automatic stationkeeping, the DP system relies on the available thrusters to independently generate thrust forces in the longitudinal and transverse directions, as well as yawing moments. The first step in the DP capability analysis is to determine if the thruster configuration of the vessel is capable of generating sufficient thrust in all directions.

The results of the step 1 analysis shall include the following:

— Thruster settings (r/min, rudder angles, azimuth angles, ..., etc.) to achieve a pure longitudinal thrust force F_X. Settings for positive (forward) and negative (aft) total forces shall be given.

— Thruster settings (r/min, rudder angles, azimuth angles, ..., etc.) to achieve a pure transverse thrust force F_Y. Settings for positive (to port side) and negative (to starboard) total forces shall be given.

— Thruster settings (r/min, rudder angles, azimuth angles, ..., etc.) to achieve a pure yawing moment M_{XY}. Settings for positive (bow to port side) and negative (bow to starboard) moments shall be given.

— The response times of all individual thrusters controlled by the DP system shall be listed. This includes response times of propeller revolutions per minute (zero to maximum), rudder angles (minimum to maximum) and thruster azimuth angles (0 degrees to 360 degrees). The response times shall be sufficiently short to respond to the dynamic forces and moments required by the DP system.

Annex A includes an overview of different thruster types that can be controlled by a DP system. It also includes some examples of thruster configurations.

6.3 Step 2 - DP capability plots

The DP stationkeeping capability of the vessel shall be quantified by determining for each wind direction the maximum conditions in which required position and heading can be maintained.

The DP capability analysis in step 2 shall include the following:

— Calculation of the environmental loads acting on the vessel. For large yachts with a DP system, only wind loads shall be considered. To simplify the calculation procedure current and wave loads are ignored.

— Calculation of the individual thruster loads and thruster settings (r/min, rudder angles, azimuth angles, ..., etc.) necessary to counteract these total environmental loads.

— A safety factor is applied to the calculated thruster loads, to account for dynamic effects and uncertainties in the calculated environmental loads and thruster loads.

— Graphical presentation of the results in the form of a polar plot (footprint plot).

Annex B includes explanations on the calculation of the environmental loads and the thruster forces. It also provides an example of the graphical presentation of the analysis results.

6.4 Step 3 - Advanced DP capability analysis (optional)

The results of the static DP capability calculations in step 2 do not include any dynamic effects in the environmental loads or the thruster response. This means that the calculation results do not contain any information on stationkeeping accuracy. Time-domain DP analysis should be carried out to address the following additional issues:

— Stationkeeping accuracy during crabbing, or during manoeuvres in confined areas, such as ports, channels, near bridges and in locks.

— The effect of different control settings (low/medium/ high) on the DP stationkeeping performance.

— Analysis of fuel consumption, exhaust emissions, or noise and vibrations.

Attention should be paid to the time-domain simulation model used in the analysis. It is recommended to use hydrodynamic simulation software commonly applied for offshore industry applications.

7 Testing and trials

The performance of the DP system shall be verified during sea trials, after delivery of the vessel. The following tests shall be performed:

— Manual joystick control

The vessel DP system shall be set to manual joystick control. A set of manoeuvres is performed to show that the vessel can be moved in all directions independently. The vessel is moved in longitudinal direction (forward, aft) and in transverse direction (starboard, port side). Finally, an in-place vessel rotation is performed (clockwise, counter clockwise).

— DP stationkeeping

The vessel DP system shall be set to automatic position and heading control. The vessel should maintain its position and heading, in calm water, but also in the presence of wind, waves, or current. After changing the position or heading set-point, the vessel should move to its new position and heading without significant overshoot or oscillations.

— Heading control at anchor (optional)

The vessel can be moored using an anchor at the bow. The vessel DP system may be set to automatic heading control, or the vessel may be free to weathervane. The active DP system can be used to avoid fish-tailing or large oscillations, in calm water, but also in the presence of wind, waves, or current.

During the life time of the vessel, the performance of the DP system shall be verified annually, by repeating the above tests.

8 Personnel and operational requirements

During DP operation a crew member shall always be present at the DP console.

Commercial ships with a DP system have dedicated personnel on board to operate the DP system. The DP operator (DPO) has received special training and certification to perform these tasks. The DP system on board a large yacht is intended for recreational use (i.e. not mission critical, short duration, mild weather). For this reason, the presence of a DPO is not required. Instead, the DP system is operated by the nautical crew on board the yacht.

For large yachts with a DP system, it is recommended to use the DP system only in open water conditions, without other vessels in the direct vicinity. In this manner, the risks in case of a failure or malfunction of the DP system, or one of its components, can be limited. During DP operation in confined areas, or with other vessels in the direct vicinity, the crew member at the DP console shall be ready at any moment to take over manual control of the ship, in case of failure or malfunction.

Special attention should be paid to the safety of the passengers. Swimmers should not be allowed in the water when the DP system is active.

Annex A
(informative)

Description of thruster configurations

A.1 Definition of the actuator types

A.1.1 General

Different actuators (thrusters) on the vessel can be used for different purposes, such as main propulsion, or low speed manoeuvring in port. The thrusters listed in A.1.2 to A.1.4 can only be considered in the DP stationkeeping analysis if they can be directly controlled by the DP system.

A.1.2 Main propulsion

The following thruster types can be applied for main propulsion:

— Main propellers and rudders

This configuration offers good propulsive efficiency and good manoeuvring of the vessel at forward speed. For DP stationkeeping, this set-up is less useful, due to the limited possibilities of independent generation of longitudinal and transverse thrust forces and the relatively slow response of the main propeller revolutions per minute and rudder angles.

— Azimuthing thrusters

This configuration offers good propulsive efficiency and good manoeuvring of the vessel at forward speed. This set-up is also good for DP stationkeeping, due to the accurate control of the thrust force direction and magnitude. Ducted thrusters offer high bollard pull, but are limited in maximum forward speed. Podded propulsors are suitable for high forward speed, but usually have slower response during DP operation.

— Water jets

This configuration is suitable for high speed vessels. This configuration is difficult to apply for DP stationkeeping, due to the limited control over the thrust magnitude and direction. Noise and fuel consumption can also be a concern.

A.1.3 Transverse thrust

The following thruster types can be applied to generate a sideways thrust force:

— Bow tunnel thrusters

Tunnel thrusters at the bow can effectively generate transverse thrust during low speed manoeuvring and DP stationkeeping. Their effectiveness can reduce significantly with increasing forward speed. Thruster ventilation can occur in high waves, or at low vessel drafts.

— Stern tunnel thrusters

Tunnel thrusters at the stern can effectively generate transverse thrust during low speed manoeuvring and DP stationkeeping. Their effectiveness can reduce significantly with increasing forward speed. Interactions with the main propulsors can also reduce their effect.

A.1.4 Auxiliary thrusters

The following thruster types can be applied to generate a thrust force that can be controlled in magnitude, as well as horizontal direction.

— Retractable azimuthing thrusters

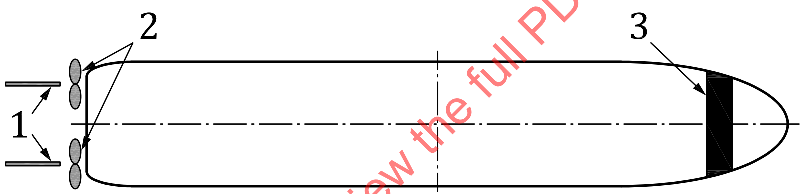
Azimuthing thrusters can effectively generate transverse and longitudinal thrust force during DP stationkeeping. The response is generally fast, due to their relatively small size. Operation of retractable thrusters is not always possible in very shallow water.

— Pump jets

Azimuthing pump jet thrusters can effectively generate transverse and longitudinal thrust force during DP stationkeeping. Since the thruster is built inside the vessel hull, it can also be operated in very shallow water. Noise and fuel consumption can be a concern.

A.2 Examples of thruster configurations with limited DP capability

Figure A.1 shows an example of a thruster configuration which is very common for large motor yachts (configuration "A"). The vessel has two main propellers with rudders. For low speed manoeuvring, a bow tunnel thruster has been added.



Key

1 rudder

2 main propeller

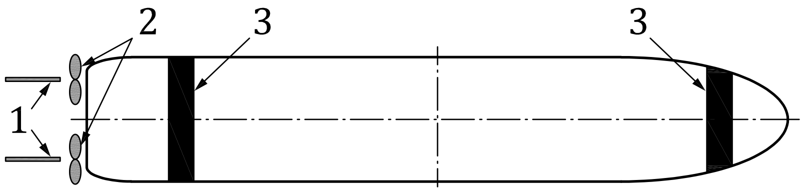
3 tunnel thruster

Figure A.1 — Thruster configuration "A"

This configuration can result in limited DP capability, because the main propellers and rudders offer limited possibilities for independently generating longitudinal and transverse thrust forces at the stern of the vessel.

A.3 Examples of thruster configurations with improved DP capability

In this clause, some examples are given of thruster configurations which usually offer an improved DP capability for large motor yachts. Figure A.2 shows a modified thruster lay-out (configuration "B"). The vessel has two main propellers with rudders. For low speed manoeuvring, a bow tunnel thruster and a stern tunnel thruster have been added.



Key

1 rudder

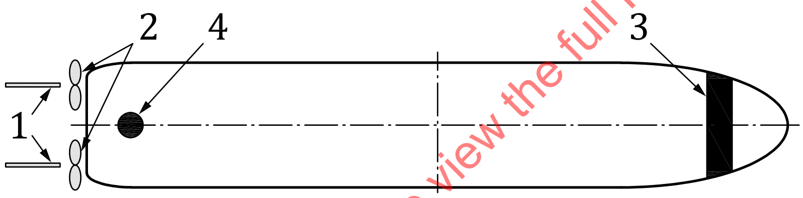
2 main propeller

3 tunnel thruster

Figure A.2 — Thruster configuration "B"

This configuration can result in improved DP capability, because the bow and stern tunnel thrusters can generate a transverse thrust force and yawing moment, independent from the longitudinal thrust generated by the main propellers.

Figure A.3 shows another modified thruster lay-out (configuration "C"). The vessel has two main propellers with rudders. For low speed manoeuvring a bow tunnel thruster has been added. For DP stationkeeping, a stern auxiliary azimuthing thruster has been added. The main propellers and rudders are not active during DP operation.



Key

1 rudder

2 main propeller

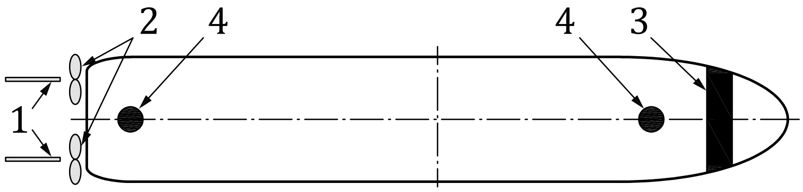
3 tunnel thruster

4 azimuthing thruster

Figure A.3 — Thruster configuration "C"

This configuration can result in improved DP capability, because the bow tunnel thruster and stern auxiliary thrusters can generate a transverse thrust force and yawing moment. The stern auxiliary thruster is also used to generate the longitudinal thrust force.

Figure A.4 shows another modified thruster lay-out (configuration "D"). The vessel has two main propellers with rudders. For low speed manoeuvring, a bow tunnel thruster has been added. For DP stationkeeping, a stern auxiliary azimuthing thruster and a bow auxiliary azimuthing thruster have been added. The main propellers are rudders are not active during DP operation.



Key

1 rudder

2 main propeller

3 tunnel thruster

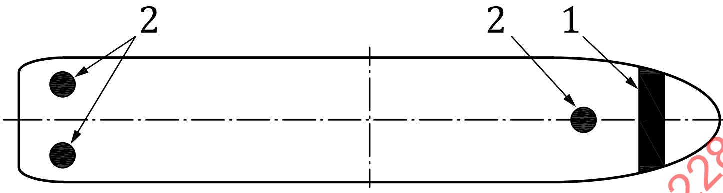
4 azimuthing thruster

Figure A.4 — Thruster configuration "D"

This configuration can result in improved DP capability, because the bow tunnel thruster, the stern auxiliary thruster and the bow auxiliary thrusters can generate a transverse thrust force and yawing moment. The stern and bow auxiliary thrusters are also used to generate the longitudinal thrust force.

A.4 Examples of thruster configurations with good DP capability

Figure A.5 shows a thruster lay-out designed for sailing conditions, as well as DP stationkeeping (configuration "E"). The vessel has two azimuthing thrusters for main propulsion. For low speed manoeuvring a bow tunnel thruster has been added. For DP stationkeeping, a bow auxiliary azimuthing thruster has been added.



Key

1 tunnel thruster

2 azimuthing thruster

Figure A.5 — Thruster configuration "E"

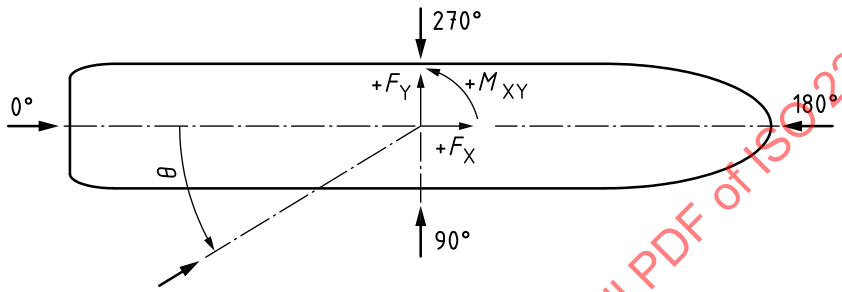
The stern azimuthing thrusters offer accurate control of the thrust force and direction at the stern of the vessel. The bow tunnel thruster and bow auxiliary thruster offer accurate control of the transverse (and longitudinal) thrust at the bow, independent of the main thrusters. This thruster configuration also offers some redundancy. For example, DP stationkeeping is still possible in case of failure of one of the stern azimuthing thrusters, or one of the bow thrusters.

Annex B
(informative)

Description of DP capability plots

B.1 Definition of the system of axes

The system of axes used for the calculation of the wind loads was taken from Reference [2]. The definition is shown in Figure B.1.



Key

F_X	longitudinal wind (or current) force	M_{XY}	yawing wind (or current) moment
F_Y	transverse wind (or current) force	θ	wind (or current) angle of attack (going to)

Figure B.1 — System of axes according to OCIMF

B.2 Formulae to calculate the wind loads

Formulae (B.1) to (B.3) to calculate the mean wind loads on the vessel were taken from Reference [6]. These formulas are as follows:

$$F_X = \frac{1}{2} \cdot \rho_{air} \cdot V_{wind}^2 \cdot A_F \cdot C_X \tag{B.1}$$

$$F_Y = \frac{1}{2} \cdot \rho_{air} \cdot V_{wind}^2 \cdot A_L \cdot C_Y \tag{B.2}$$

$$M_{XY} = \frac{1}{2} \cdot \rho_{air} \cdot V_{wind}^2 \cdot A_L \cdot L_{pp} \cdot C_{XY} \tag{B.3}$$

where

L_{pp}	is the length between perpendiculars (m);
A_F	is the frontal wind area, (m^2);
A_L	is the side wind area, (m^2);
ρ_{air}	is the air density, (kg/m^3);
V_{wind}	is the mean wind velocity, (m/s) at a reference height of 10 m above water level;

F_X is the longitudinal wind force, (N);

F_Y is the transverse wind force, (N);

M_{XY} is the yawing wind moment, (Nm);

C_X is the dimensionless longitudinal wind load coefficient, (-);

C_Y is the dimensionless transverse wind load coefficient, (-);

C_{XY} is the dimensionless wind yawing moment coefficient, (-).

The dimensionless wind load coefficients can be determined by wind tunnel testing or CFD calculations. Alternatively, wind load coefficients of a similar vessel can be used. The vessel length and wind areas can be determined from the vessel general arrangement plan.

B.3 Formulae to calculate the thrust loads

The thrust magnitude and direction of the individual thrusters is determined by a thrust allocation algorithm. The allocation algorithm distributes the required total forces and moments (F_X, F_Y, M_{XY}) over the available thrusters, often based on a power optimization.

Thruster interaction effects (thruster-hull, thruster-thruster, thruster-current) can reduce the total generated force, thus affecting the vessel stationkeeping capability. In the DP capability analysis for large yachts with a DP system, it is not necessary to include thruster-interaction effects, provided that regions of strong interaction are avoided by defining forbidden zones for azimuthing thrusters. Background information on thruster-interaction effects can be found in Reference [8].

The thrust forces generated by the individual thrusters can be calculated based on their maximum (bollard pull) thrust values. It can be assumed that a quadratic relation exists between the thrust and the propeller revolutions per minute. Formulae (B.4 and B.5) can be used:

$$T = T_{max} \cdot \left(\frac{r}{r_{max}} \right)^2 \tag{B.4}$$

where

T is the generated thrust (kN);

T_{max} is the maximum bollard pull thrust (kN);

r is the propeller revolutions per minute (1 r/min);

r_{max} is the maximum propeller revolutions per minute at bollard pull thrust (1 r/min).

The consumed power can be calculated based on the maximum power values of the individual thrusters. The following relation between power and propeller revolutions per minute can be used:

$$P = P_{max} \cdot \left(\frac{r}{r_{max}} \right)^3 \tag{B.5}$$