ITTC Quality System Manual
Recommended Procedures and Guidelines

Procedure

Dynamic Positioning System Model Test Experiments

7.5	Process Control
7.5-02	Testing and Extrapolation Methods
7.5-02-07	Loads and Responses
7.5-02-07-03	Ocean Engineering
7.5-02-07-03.6	Dynamic Positioning System Model Test Experiments

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Table of contents

Dynamic Positioning System Model Test Experiments

1. PURPOSE OF PROCEDURE

The purpose of this procedure is to ensure that model tests of dynamic positioning (DP) systems are conducted according to the best available techniques and to provide an indication of improvements that might be made. The DP systems addressed in this procedure have the main purpose of station-keeping. The procedure is also to ensure that any compromises inherent in dynamic positioning system tests are identified and their effects on the measured results are understood. In general, DP model tests are employed to investigate the effects arising from the simultaneous action of waves, wind and current, combined with multiple thrusters, and to provide systematic data for the development of reliable DP simulation tools (Sørensen, 2011).

The test methods and procedures strongly depend on the objectives and the focus of tests. If the focus, for instance, is on the global behaviour of a floating platform/ship in the horizontal plane, it is acceptable to make some simplifications on the thrusters. On the other hand, if the objective is to investigate the hydrodynamic interactions between thrusters, special attention must be paid to those thrusters. Coanda effect and the influence of the first-order wave motions on the behaviour of thrusters must be considered. Coanda effect is the phenomenon in which a jet flow attaches to a nearby surface and remains attached to it even when this surface curves away from the initial jet direction. All observed phenomena during the model tests shall be documented for further investigations.

For offloading approaching tests, where the model experiences large horizontal motions, the degradation of the environmental conditions due to the change of model position in the basin and reflection from the walls should be considered. Waves, wind and current are usually calibrated in the test area of the basin. It should be noted that the set-up in offloading tests may cover a relatively large area and, therefore, the wind and wave conditions should be checked at several locations, in addition to the centre of the set-up. It is desirable to measure wind and waves in the surrounding areas where the model can possibly move, since the change of the nominal conditions would affect the DP behaviour. In tandem offloading tests, wind, current and wave shielding effects may affect the response of the DP shuttle tanker. These effects should be considered in both tests and simulations (de Wilde et al., 2010, Giorgiutti et al., 2015).

Model values, including the thruster forces, are scaled to full scale by applying Froude's law of similitude. Model tests of DP systems are typically conducted in the scale ratio between 40 and 60. In general, scale effects have a negligible effect on the overall response of the floaters in mooring and in DP model tests, especially for ship-shaped bodies. However, for slender column structures, such as semisubmersibles, special care should be taken in the extrapolation of drift forces which can be significantly influenced by viscous effects. In extreme waves, extrapolation of ventilation effects should be considered with care, making the applicable hypothesis clear.

2. PARAMETERS

In general, the following model test program should be carried out for floating structures equipped with DP systems:

- Resistance and propulsion tests to obtain reliable speed-power predictions.
- Wind tunnel tests to determine wind resistance coefficients.

- Wind tunnel tests or towing tests to determine the current resistance coefficients.
- Thruster-hull interaction tests to determine thrust degradation.
- Thruster-current interaction tests.
- Thruster-thruster interaction tests to determine the performance of thrusters acting in the vicinity of other thrusters.
- In addition, dynamic thrust production, including force and direction subject to limitations in power plant, revolution speed (positive and negative), azimuth direction control, maximum azimuth speed, and maximum rate of change of thruster revolutions per second (RPS), should be addressed.

2.1 Model Parameters

The geometry of the model should be scaled according to Froude’s law. Aspects on the preparation of the model are provided in Procedure 7.5-02-07-03.14 Floating Offshore Platform Model Construction.

2.2 Environmental Parameters

Parameters related to the simulation of environmental properties include water depth, basin dimensions, calibrated wave, current and wind characteristics, combined environmental characteristics and relative directions. Combined environmental conditions are described in Procedure 7.5-02-07-03.1 Floating Offshore Platform Experiments.

2.3 Operation of Thrusters

Thrusters are operated under complex conditions with respect to inflow and outflow, which affect the efficient operation of thrusters. In the operation of thrusters, the following aspects need to be accounted for: (1) thruster degradation due to current, (2) thruster-hull interaction (including Coanda effect), (3) thruster-thruster interaction, (4) thruster degradation due to interactions of the thruster flow with waves and platform/ship motions, and (5) limitation on the physical characteristics of the propulsion devices. The power limit in model scale might not scale up correctly due to the relatively higher friction losses inside the thruster model compared to the prototype. Detailed discussion and relevant references on interactions and associated scale effects in DP systems can be found in ITTC (2014).

2.3.1 Thruster-Current Interaction

When thrusters are operated in current, the current affects the thruster-hull interaction due to changes in the flow direction and in the pressure field.

In low current velocity conditions, the influence of current in terms of relative current-drift velocity is not significant for azimuth thrusters and main propellers. For waterjet thrusters, it may also be assumed that the unit thrust is barely affected by the current flow over the inlet and outlet regions. For high relative current-drift velocities, i.e., high current conditions or forward speeds, greater thruster-current interaction effects may be expected. Model tests also show that the azimuth angle and the presence of other thrusters have a significant influence on the performance of the thruster under current inflow (Ottens and van Dijk, 2012, Li et al., 2018).

2.3.2 Thruster-Hull Interaction

Thrust degradation due to thruster-hull interaction depends on the hull shape and the location of the thruster. Friction, flow interactions between the thruster race and the hull, and the deflection of the thruster race in the presence of structural elements, i.e., the Coanda effect, will cause thrust losses. See, for instance, Cozijn and Hallmann (2014), Tiana and Kinnas (2014).

2.3.3 Thruster-Thruster Interaction

The thruster-thruster interaction always leads to thrust degradation, which occurs when:

- the jet flow of one thruster interacts with another thruster
- as a consequence of the Coanda effect, one thruster race may be deflected and flow over another thruster. For semi-submersibles, the Coanda effect should include the flow against the opposite pontoon.

The most effective way to avoid or minimize the thruster degradation is to avoid the jet of one thruster interfering with other thrusters. Except for the case of the Coanda effect, this can be achieved by specifying forbidden operational regions in the thrust allocation algorithms of the DP system. These conditions should be clearly reported.

2.3.4 Thruster-Wave Interaction

The thruster-wave interaction can be in the form of:

- degradation due to the oscillating flow caused by waves and platform/ship motions
- ventilation
- ingestion of air

The wave-induced oscillatory flow motion in the proximity of the inlet region of a thruster and/or a main propeller modifies the pressure field, affects the generated thrust, and leads to degradation. These conditions should be clearly reported.

2.3.5 Ventilation and Ingestion of Air

Ventilation occurs when a thruster or a propeller partially or totally emerges. A heavy loaded propeller/thruster may experience a decrease in pressure on the propeller/thruster blades, especially when the effective submergence of the propeller becomes small due to the relative vertical motion of the platform/ship in waves. The decrease in pressure can lead to air suction when the propeller is operated in the proximity of the free surface.

Ventilation can cause sudden changes in thrusters' torque and power, leading to thruster racing – a rapid increase in RPS when the thruster is partially or completely out of water (due to the relative vertical motion in waves). These conditions should be clearly reported.

2.3.6 Limitation on the Physical Characteristics of the Propulsion Devices

Degradation in the dynamic thrust production, including force and direction, may appear due to limitations in power plant, revolution speed (positive and negative), azimuth direction control, maximum azimuth speed, and maximum rate of change of thrusters' RPS. Degradation is also caused by viscous effects that may occur in thruster operation such as thruster-thruster, thruster-hull, thruster-current, thruster-wave and other interactions. All these interactions are accounted as thrust deductions. Viscous thrust degradation should be carefully analysed, especially when extrapolation from model to full scale is to be performed.

2.4 DP Control System

The DP control system involves DP controller, filter and thrust allocation.

The control algorithm of a DP system has several functions, and the control modes are dependent on the particular marine operation and the vessel/platform type. The DP functions should be determined according to the specifications of the full-scale system. The control algorithm should filter the first-order wave induced motions to ensure that thrusters only counteract low-frequency and mean environmental disturbance components, avoiding excessive thrust modulations.

The control algorithm accounts for instantaneous wind forces and moments based on measurements of wind speed and directions. It determines the horizontal thruster forces and the yaw moment necessary to regain position and distributes the required thruster forces over the available thruster system.

2.4.1 State Estimation and Filtering

An observer is the state estimation of position and velocity and sensor noise filtering. The observer can be a Kalman filter or a nonlinear passive observer. The filtering of motions is important to increase control efficiency. The Kalman filter is an estimator that minimizes errors covariance under the assumption of a statistical knowledge of noise processes (Kalman, 1960, Kalman and Bucy, 1961, Balchen et al., 1980, Sørensen et al., 1996). Nonlinear passive observers may also be used for state estimation and filtering (Fossen and Strand, 1999, Besançon, 2007).

2.4.2 DP Controller

There are many linear and nonlinear controllers. The proportional-integral-derivative (PID) and the linear quadratic regulator (LQR) controllers are commonly used. The required thrust can be calculated as a single-input-single-output (SISO) control (Fay, 1990, Partington, 2004). For instance, a PID multivariable controller for surge, sway and yaw may be modelled as:

$$\begin{Bmatrix} T_x \\ T_y \\ T_z \end{Bmatrix} = \begin{bmatrix} D_x & P_x & 0 & 0 & 0 & 0 & I_x & 0 & 0 \\ 0 & 0 & D_y & P_y & 0 & 0 & 0 & I_y & 0 \\ 0 & 0 & 0 & 0 & D_\psi & P_\psi & 0 & 0 & I_\psi \end{bmatrix} \vec{e}$$

where:

$$\vec{e}^T = \left\{ \dot{e}_x \quad e_x \quad \dot{e}_y \quad e_y \quad \dot{e}_\psi \quad e_\psi \quad \int e_x dt \quad \int e_y dt \quad \int e_\psi dt \right\}$$

is the vector of motions composed of the motions in surge (e_x), sway (e_y), yaw (e_ψ), and their corresponding derivatives and integrals. T_x, T_y, and T_z are the thrusts and moment of the propulsors in surge, sway and yaw, respectively. P_X, P_Y and P_ψ are the proportional gain factors, I_X, I_Y and $I_\psi$are integral gain factors, and D_X, D_Y and D_ψ are derivative gain factors.

The LQR controller involves an algorithm that minimizes a cost function with weighting factors (Halvorsen, 2008). Lately, nonlinear DP controllers have also been implemented by DP vendors (Torsetnes et al., 2004). Alternative control strategies can be applied to tandem offloading DP operations. In these cases, position error tolerance windows can be considered in the DP control.

2.4.3 Thrust Allocation

Thrust allocation is an essential part of the DP control system. Thrust allocation requires a set of equations to distribute horizontal forces and moment among thrusters (Johansen and Fossen, 2013, Arditti et al. (2014).

The thrust allocation process may involve azimuth thrusters, tunnel thrusters, main thrusters and rudders. For azimuth thrusters, the thrust forces as well as the azimuth angles should be determined.

The lateral thrusters can be grouped close together in one forward and one aft location. The Lagrange multiplier method with penalty functions is usually implemented.

The thrust allocation logic considers the limitation of actual thruster capabilities, the forbidden zones of azimuth thrusters, and the failure of thrusters.

The selected thrust allocation algorithm should be well documented as this will have a major impact on the extrapolation of the static and dynamic DP capability to that in full scale. It should be noted that the thrust allocation algorithm usually differs from the full-scale specifications. The DP control algorithm has limited information about thruster effects such as saturations, limited rate of rotation of variable-direction thrusters, or systematic effects, for instance, singular thruster configurations (Veksler et al., 2016). Efforts should be made to match the full-scale system and algorithm as close as possible to avoid, for example, position loss.

2.5 Test Duration

Test duration is dependent on the requirements of a specific model test. For instance, for DP tests to assess the capabilities of a large tanker under waves, wind and current, the test duration corresponded to 1.5 hours full-scale (Pinkster and Nienhuis, 1986).

3. DESCRIPTION OF PROCEDURE

3.1 Model and Installation

The model should be prepared with the propulsion devices, thrusters such as tunnel thrusters and azimuth thrusters, rudders, and the control system.

The DP control system requires electronic and mechanical devices to be positioned inside the hull or above main deck. The design of the model must consider the effect of these devices on the model’s internal arrangement and loading conditions. Due to the volume restrictions and the size of the devices, some changes in positions and diameters of thrusters may be necessary. Some simplifications in cases of multiple devices, for example, two bow thrusters modelled as one, are acceptable. Significant scale effects may be expected when large deviations/simplifications are adopted due to, for instance, not accurate representation of thruster-hull, thruster-thruster or thruster-current/wave interactions.

Details on the model preparation, ballasting and tolerances can be found in Guideline 7.5-02-07-03.16 Model Construction of Offshore Systems.

The as-built model shall be documented.

3.2 Thruster System and Verification

The thruster system consists of main propellers, rudders and thrusters.

Prior to installing the thrusters on the model, their open-water characteristics should be available. For each thruster, its thrust-RPS relationship may be determined by carrying out open-water thruster tests at zero forward speed according to Procedure 7.5-02-03-02.1 Open Water Tests or other means.

In order to determine the thruster-hull and the thruster-thruster interaction effects on the DP system, thruster interaction tests may be conducted beforehand. These tests are typically carried out on a captive model in calm water. The total loads on the vessel are measured and compared with the open-water results.

The azimuth angle or rudder angle should be varied by the controller according to the calculated value.

The response of the thruster system to the controller in terms of RPS and angle needs to be verified prior to tests.

3.3 Measurement Systems

The main measured quantities include:

- 6 DOF motions of the model
- Wave elevations, wind and current velocities
- RPMs of thrusters
- Azimuth angles of thrusters

Model motions are measured by optical position systems or inertial positioning systems. A basin-fixed coordinate system is typically used for model’s position tracking and a model-fixed system is used for motion measurements.

Velocities may be calculated as time derivatives of positions. Wave elevations are measured by wave probes at various locations in the basin. Wind velocity needs to be measured on the model or at a fixed location in the basin, close to the model.

The thruster system is driven by electric motors which are controlled by the DP controller. The propeller rate of revolution measured by tachometers is used as a feedback. The azimuth and rudder angle are measured directly.

Propeller thrust and torque may be measured. It is also desirable to measure the delivered thrust and torque for each thruster, especially for investigations on thruster-thruster and hull-thruster interactions.

3.4 Data Reduction and Analysis

Test data for a DP system in regular and irregular waves including the thruster data should be subjected to analyses described in Procedure 7.5-02-07-03.2 Analysis Procedure for Model Tests in Regular Waves and Procedure 7.5-02-07-03.13 Analysis Procedure for Model Tests in Irregular Waves.

4. DOCUMENTATION

A report on the DP test should contain at least the following information:

- List of test objectives
- Summary of the test
- Description of test facilities and instruments
- Basic assumptions, coordinate systems and sign convention;
- Model description including balancing report
- Description of experimental set-up
- Description of DP system, its control and calibration
- Target and actual environmental conditions, calibration procedures and results
- Instrumentation calibration procedures, results, and statement sheets
- Description of test program, procedures and parameters
- Description of data acquisition and data analysis procedures
- Description of data analysis results and discussion
- Analysis about the accuracy and uncertainty estimations
- Tabulated and graphical results for DP capability

The test report should also include photographs.

5. UNCERTAINTY ANALYSIS

Many parameters cause uncertainties in dynamic positioning tests. Sources of uncertainties can be found in Qiu et al. (2014).

Furthermore, uncertainty analysis should be performed in accordance with Procedure 7.5-02-01-01 Guide to the Expression of Uncertainty in Experimental Hydrodynamics and Procedure

7.5-02-06-05 Uncertainty Analysis for Free Running Manoeuvring Model Tests.

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