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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 procedure is also to ensure that any comprises 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.

Model tests of DP systems are typically conducted in the scale range between 1:40 and 1:60.

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 the ship on the horizontal plane, it is acceptable to make some simplification 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.

Scale effects may play a role in some physical phenomena, for example, viscous effects. However, scale effects in general have a negligible effect on the overall response of the floaters in mooring and in DP model tests.

Effects such as Coanda effect and the influence of the first-order wave motions on the behaviour of thrusters must be considered. 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 shall be taken into account. Waves, wind and current are usually calibrated for a certain optimal area on the middle of the basin. It is desirable to measure wind and waves in the surrounded areas where the model can possibly be since the changing of the nominal conditions would affect the DP behaviour. The set-up in offloading tests may cover a relatively large area and therefore the wind and wave conditions should be checked at locations in addition to the center of the set-up. 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.

2. PARAMETERS

In general, the following model test programs 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.

- 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 RPMs, should be addressed.

2.1 Model Parameters

The geometry of the model should be built to scale as for the normal model tests based on Froude's law. Aspects of preparing the model can be found in the ITTC Recommended Procedures for Floating Offshore Platforms Experiments (7.5-02-07-03.1).

2.2 Environmental Parameters

Parameters related to the simulation of environmental properties such as water depth, basin dimensions, calibrated wave, current and wind characteristics, combined environment characteristics and relative directions on combined environments can also be found in the ITTC Recommended Procedures for Floating Offshore Platforms Experiments (7.5-02-07-03.1).

2.3 Operation of Thrusters

Thrusters operate under complex conditions with respect to inflow and outflow, which affect 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, (3) thruster-thruster interaction, (4) thruster degradation due to waves including ventilation effects due to emergence, and (5) limitation on the physical characteristics of the propulsion devices.

2.3.1 Thruster-Current Interaction

When thrusters operate in current, the current affects the thruster-hull interaction, due to changes in the flow directions and pressure fields.

In low current velocity conditions, the influence of current in terms of relative current-drift velocity is not significant for azimuthing thrusters and main propellers as long as the thrust of a propeller does not vary dramatically at low speeds. For water jet 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 of the model, i.e., high current conditions or forward speeds, greater thruster-current interaction effects may be expected.

2.3.2 Thruster-Hull Interaction

Thrust degradation due to thruster-hull interaction depends on the hull shape and the location of thrusters. Friction and flow interactions between the thruster race and the hull and the deflection of the thruster race in presence of structural elements, i.e., the Coanda effect, will cause thrust losses.

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 the 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 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 the case of the Coanda effect, this can be achieved by specifying forbidden operational regions in the thrust allocation algorithms of the DP system.

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
- ventilation
- ingestion of air

The wave-induced oscillatory motion in the proximity of the inlet region of thrusters and main propellers modifies the pressure field, affects the generated thrust, and leads to degradation.

2.3.5 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 thruster RPMs.

2.4 Ventilation and Ingestion of Air

Ventilation occurs when a thruster or a propeller partially or totally emerges. Heavy loaded propellers may experience a decrease in pressure on the propeller blades, especially when the effective submergence of the propeller becomes small due to the relative vertical motion of 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 and air suction can cause sudden changes in torque and in power of thrusters. They will lead to thruster racing, a rapid increase in the number of revolutions per unit of time when the thruster is partially or completely out of water due to the relative vertical model motion in waves.

2.5 DP Controller and FilterAlgorithm

The control algorithm of a DP system has several functions and the control modes are dependent on the particular marine operation and the vessel type. These DP functions should be decided in cooperation with the client. It filters the position error to ensure that thrusters only counteract low frequency and mean environmental disturbance components. Thrusters should react as little as possible to wave-frequency position errors since they lead to unacceptable thrust modulations.

The control algorithm, consisting of PID type feedback controller and various feedforward controller like wind feedforward, accounts for instantaneous wind forces and moment based on wind speed and directional measurements. It determines the horizontal thruster forces and yaw moment necessary to regain position, distribute the required thruster forces over the available thruster system, and allocate thrust signals to the individual thrusters.

2.5.1 State Estimation and Filtering

An observer is the state estimation of position and velocity and sensor noise filtering. The observer can be Kalman filter or nonlinear passive observer. The filtering of motions is important to increase control efficiency. The Kalman filter is an estimator that minizes errors covariance under the assumption of a statistical knowledge of noise processes. Nonlinear passive observers may also be used for state estimation and filtering.

2.5.2 DP Controller

There are many linear and nonlinear controllers. The PID controller, the proportional-integral-derivative control, is commonly used. The required thrust can be calculated in the simplified form as single-input-single-output (SISO) control. Note that the multivariable controller is normally used due to the hydrodynamic coupling between sway and yaw.

The linear-quadratic regulator (LQR) is often used in optimizing the controller. It is concerned with operating a linear dynamic system at minimum cost, where the cost is described by a quadratic function. The LQR algorithm is essentially an automated way of finding an appropriate state-feedback controller. Lately, nonlinear DP controllers have also been implemented by DP vendors.

Alternative control strategies can be applied to tandem offloading DP operations. In these strategies, position error tolerance windows can be taken into account in the DP control.

2.6 Thrust Allocation

Thrust allocation logic is a basic part of the controller of a dynamic positioning system. Thrust allocation requires a set of equations to distribute the two force commands and one moment command from control equations among the thrusters.

Thruster allocation logic considers azimuthing thrusters, tunnel thrusters, main thrusters and rudders. For the azimuthing thruster, the amount of thrust as well as the azimuthing should be determined.

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

The allocation logic covers the strategies for the limitation of thrusters' capability and for the forbidden zones of azimuthing thrusters. Thruster failure is also considered in the thrust allocation logic. The selected thrust allocation routine, including low level thruster control and azimuth control, if relevant, should be well documented as this will have a major impact on the static and dynamic DP capability.

2.7 Test Duration

Test duration is dependent on the requirements of the specific model test.

3. DESCRIPTION OF PROCEDURE

3.1 Model and Installation

The model is prepared with special equipment such as tunnel thrusters and azimuthing thrusters. The thrusters shall be controlled by a closed loop DP-control system. This requires some electronic and mechanical devices to be positioned inside the hull or above main deck. A correct design of the model must take account of the internal arrangement and also eventual changes of loading conditions. Due to the volume restrictions and the size of the devices, some minor changings on the position and diameters of tunnel thrusters may be necessary. Some simplification in cases of double devices (i.e. two bow thrusters being modeled by a single one) is acceptable. All changes done on the model shall be documented.

A model equipped with the thruster system and control system should be ballasted with solid weight to achieve the correct mass, center of gravity (COG) and radii of gyration. Longitudinal radius of gyration is calibrated by oscillation tests. The metacentric height (GM) is checked by a heeling test. The roll natural period is adjusted by free roll decay tests in still water.

3.2 Measurement Systems

Model motions are measured by opto-electronic position systems which consist of onshore cameras viewing active or reflective targets onboard the model. Velocities are calculated as time derivatives of position. Wave elevation is measured by means of wave probes at various positions in the basin. Azimuth and tunnel thrusters are driven by electric motors. The propeller rate of revolution is measured by tachometers and changed by the dynamic positioning control algorithm. The azimuth angle is measured directly. Measured signals often include propeller thrust and torque.

The main measured quantities are:

- 6 DOF motions of the model;
- Wave elevations, wind and current velocities;
- RPMs of thrusters;
- Azimuth angles of the azimuthing thrusters;
- Propeller thrust and torque.

Also, it is desirable if the laboratory can measure the delivered thrust and torque for each thruster, especially for investigations on thruster-thruster and hull-thruster interactions.

The wave and current are typically scaled according to the Froude scaling law. All wind speeds are with reference to a height of 10 m above the sea surface.

3.3 Thruster System and Calibration

The thruster system consists of main propellers, rudders and thrusters. Each of the thrusters is operated according to the thruster RPM. The azimuth angle or rudder angle is varied according to the calculated value by controller. In order to produce the required thrust, the relation between RPM and the thrust of a thruster has to be known. From the calibration the thrust-RPM characteristics is obtained. The thruster forces used in the DP model tests are based on the propeller open water diagrams (bollard pull). The propeller thrust can be measured directly.

Prior to installing the thrusters on the model, their open-water characteristics should be determined in separate tests. In order to derive the thruster-hull and the thruster-thruster interaction effects on the DP system, the thruster interaction tests need to be conducted beforehand. These tests are typically carried out on a captive vessel in still water. The total loads on the vessel are measured and compared with the open-water results.

3.4 Use of Numerical Models

Numerical models may be used to generate data for the comparison with the DP tests. The numerical models should be validated by direct comparison of generated data with results from:

- Known solutions of simple cases
- Generally accepted model tests or experiments specifically for verification
- Full scale data available from installation

3.5 Test Procedure

- A basin fixed co-ordinate system is used for vessel's position tracking and a model fixed system is used for motion estimation.
- The cross-angle between the main wave and current directions has limitation owing to the test facilities.
- The thrust-hull interaction and the thruster-thruster interaction are complicated and need to be well estimated.
- The DP control system and power distribution algorithms usually do not match the actual condition perfectly. However it is desirable that the model system is matched with the full-scale system and algorithm as closely as possible.

3.6 Data Reduction and Analysis

Test data for a DP system in irregular waves including the thruster data should be subjected to the spectral and statistical analysis:

- Mean values;
- Significant values;
- Extreme (minimum and maximum) values;
- Mean (zero-up crossing) period;
- Peak period;
- Power spectrum and spectral characteristics (m_0 to m_4 spectral moments, significant amplitudes, periods, confidence levels);
- Response functions based on cross-spectral analysis.

3.7 Extrapolation to Full Scale

All test results of the model tests are presented as prototype values. Model values are scaled to full scale by applying Froude's law of similitude.

Conversion from the model to prototype values follows the Froude scaling law using scaling factors that assume potential flow, i.e., viscous scale effects on the hull are small. It is assumed that scale effect on wave drift damping can be neglected, and the relative contribution from skin friction damping will be low.

In extreme waves, viscous effect and ventilation effect are important and should be considered.

3.8 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, axis system and sign convention;
- Model description including balancing reports;
- 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
- Analysis about the accuracy and uncertainty estimations;
- Tabulated and graphical results for DP capability;
- Conclusions on model behavior; and
- Comparison of the predicted results from the analytical/numerical studies.

Normally, the test report should also include photographs and video films.

4. UNCERTAINTY ANALYSIS

Uncertainty analysis should be performed in accordance with 'Uncertainty Analysis in EFD, Uncertainty Assessment Methodology' as described in QM 4.9-03-01-01 and 'Uncertainty Analysis in EFD, Guidelines for Uncertainty Assessment' as described in QM 4.9-03-01-02. In addition to the above an example 'Uncertainty Analysis, Example for Resistance Test' is provided in QM 7.5-02-02-02.

5. REFERENCES

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