MARIN

Shaft dynamic loads and responses at extreme manoeuvring and ventilation of mechanical azimuthing thrusters

SHARES JIP

In the last years during the boom of the global shipbuilding industry, a considerable amount of mechanical azimuthing thrusters (typically pushing arrangements with ducted propellers and pulling arrangements with open propellers) were manufactured and delivered for various applications on different types of vessels, covering wide ranges of operational profiles. Recently, rather large number of gear and bearing failures were reported with those thrusters only after being used in service for half or one year, irrespective of the thruster manufacturers and the ship operators. Obviously the operation of those mechanical azimuthing thrusters have exceeded the design constraints and limits, which were based on the present understanding of hydrodynamic loads on the thrusters and their shafting systems, including gears and bearings. At least two possible reasons have been identified and blamed to have resulted in those mechanical damages. One of them is the extreme manoeuvring with the azimuthing thrusters, including interactions, typically for offshore structures both during transit and at dynamic positioning. The other is the thruster ventilation, which occurs both in DP and also in high speed sailing conditions when located close to the free surface. In both cases, large hydrodynamic loads variations and shafting responses occur, leading to the high level transient dynamic loads on the propeller blades, which transmit through the propeller hub and shaft to the underwater gears, the pinion shaft and its bearings.

The scale of the damage is so large that it worries not only the thrusters manufacturers, the gear makers and the ship operators but also the classification society who defines the rules for designing, manufacturing and operating for safe, reliable and durable thrusters. In serving the shipbuilding, shipping and offshore industries by thorough studies and research in order to gain insights on the dynamic loads, we propose this Joint Industry Project (JIP) on dynamic loads and SHAft RESponses - SHARES. By participating in this JIP, we SHARES our mutual knowledge, our expertise and our experiences in solving the present problems.

OBJECTIVE

The objective of this JIP is to achieve the thorough, complete and deep understanding of the present problems by investigating the vessel operations with thrusters; by measuring and monitoring the full-scale thrusters; by correctly analysing and simulating the shaft dynamic responses and by accurately testing and measuring the shaft dynamic loads in model scale, leading to the sound solutions for the gear and bearing problems of the mechanical azimuthing thrusters.

SCOPE OF WORK

The scope of work of the SHARES JIP consists of the following 5 work packages which are closely linked to each other:

WP1 Operation studies and investigations

In this work package, we will choose a few vessels with/without damaged thrusters to carry out operation studies and investigations by interviews, meetings and seminars with the captains and personnel on board in order to understand the way the thruster are used in practice for DP, transit and high speed operations. This WP will try to map the operation experience and perceptions of risk on damaging the mechanical thrusters among officers, operators and owners who operate vessels with azimuthing thrusters, and to identify the limits related to extreme manoeuvring and thruster ventilation, aiming at describing and closing the gaps between how the thrusters are used in practice and what the assumptions and limits are set by manufacturers and classification societies.

This study will identify what dynamic loads are avoidable and what are not.

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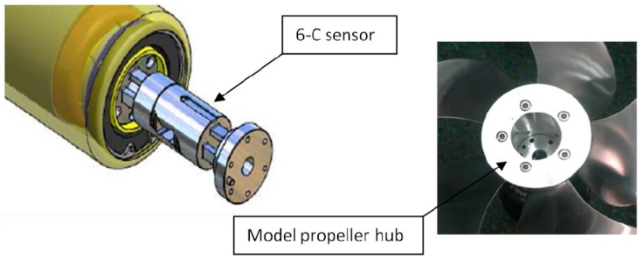
For avoidable loads, together with the results and the studies from other WPs of this JIP, the findings of this WP will be finally derived into the guidelines on designing and operating azimuthing thrusters in extreme manoeuvring and ventilation conditions for the operators, the owners, the designers and the manufacturers, in order to avoid unnecessary high dynamic loads. For un-avoidable dynamic loads, the results of this WP will be used to detail the model testing and investigation programs in order to define the magnitude of the unavoidable dynamic loads the and load characteristics for dimensioning the mechanical shafting systems.

WP2 Shaft dynamic response and modelling

When investigating dynamic forces and moments on thrusters and their shafting systems, dynamic loads can never be separated from the response of the systems. Simulating correctly the responses of the mechanical systems in order to understand the dynamic loads is extremely important to get the insight of the problems. This WP aims at investigating the responses of the shafting systems of typical mechanical thrusters, including shaft torsion loads, bending loads, gear meshing and hammering characteristics; identifying and deriving the similarity law on shafting responses simulation in model scale; building and testing the model shafting systems with different dynamic responses in order to simulate the responses in full scale.

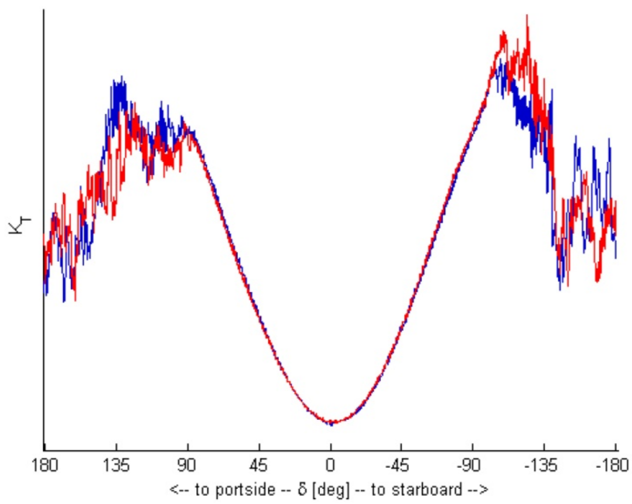
During the investigations, existing and well-validated computer software on thruster shafting systems (typically from classifications as partners of this JIP) will be used to analyse the dynamic responses of both typical full-scale thrusters and also the model-scale thrusters with modelled shafting systems. The results of this study will be used as instructions on building the model scale shafting systems and on analysing and interpreting the model test results. The unique 6-component shaft sensor with high accuracy, as shown in the following figure, will be used throughout all of the model tests in the present JIP. The dynamic characteristics of the sensor will be studied and tested within this WP. Combining with specifically-built shafts, the prescribed shafting dynamic responses can be built and used in the model tests. When needed, another 6-component shaft sensor with high accuracy, but with different dynamic response characteristics, will be built.



An example of the 6-component sensor on the propeller shaft

WP3 Dynamic loads tests during extreme manoeuvring and interactions

Until now, there is very limited knowledge on the possible transient impact loads on the propeller blades and the shaft of an azimuthing thruster when the thruster is set to any possible angles in any possible advance speeds and movements – ahead, astern, drift aside, etc. The only practise at this moment for using multiple thrusters is the forbidden zone, which is pre-defined for each thrusters. Those forbidden zones are defined neither based on the dynamic loads on the thrusters nor the possible damages to their mechanical parts and shafting systems, but mainly on the degradation of the effective thrust due to interactions. The interaction effect on shaft loads remains unknown and un-explored. In addition to the interactions, steering the azimuthing thrusters to a certain large angle during manoeuvring at low or high vessel speed may result in unexpected high level dynamic loads variations, with high load spikes and hysteresis dynamic characteristics, as an example shown in the following figure.



An example of dynamic loads on the propeller shaft of a thrusters

The objective of this WP is to determine the dynamic loads on the propeller blades, the shafting system and the total thruster unit by dedicated model tests with advanced measuring devices and sensors of high accuracy. The measured loads will be associated with the operation conditions and the flow conditions for:

- Open water operation at all azimuth angles and speeds;
- Behind operation at all azimuth angles and speeds;
- During interactions among thrusters;
- During extreme manoeuvring;
- And at dynamic positioning with multiple thrusters.

Besides the 6-component sensor on the shaft, one blade will be instrumented with blade sensor to record the blade forces. For selected tests at selected areas, Particle Image Velocimetry (PIV) will be used to identify the details of the flow in order to associate it with the measured dynamic loads, especially during the thruster-thruster interactions.

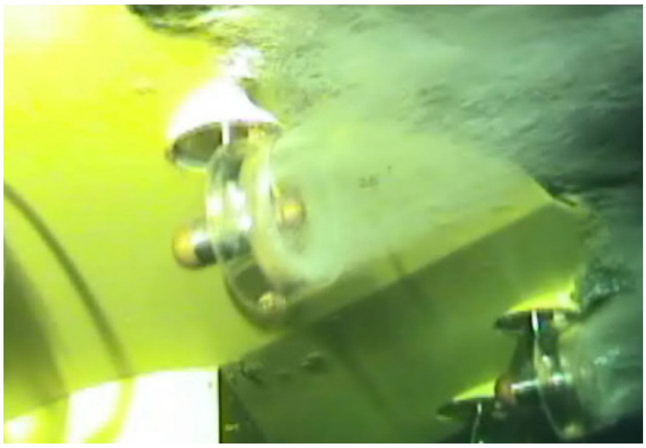
Two representative thruster configurations will be tested within this WP:

- A pushing type thruster with ducted propeller
- A pulling type thruster with open propeller

WP4 Dynamic loads tests during ventilation

Thruster ventilation is an important issue nowadays, not only due to the sudden loss of the thrust and torque during e.g. dynamic positioning, but also the high dynamic loads fluctuations on the blades and shafts. It is well known that the propulsor looses suddenly both thrust and torque within a single propeller revolution when ventilation starts, followed by a few high impact load peaks in the coming revolutions during the recovery to fully-wetted again. The following figure shows a typical thruster ventilation in a rough sea.

The objective of this WP is to understand thruster ventilation mechanism, to investigate the ventilation inception (onset) criteria, and to measure the dynamic loads on the blades, in the shaft and for the total thruster unit, by means of model testing in atmospheric as well as in vacuum conditions with cavitation on the propeller blades at MARIN's Depressurised Wave Basin (DWB) with capacity of wave making system from two sides.



An example of thruster ventilation test in a sea way

For the mechanism of ventilation inception (onset), we will make use of an oscillating open water set-up for different submergence of the thruster at different amplitudes and frequencies. High speed underwater video camera will be used during the tests to view the flow and the inception of the ventilation. In addition, the videos will be synchronized with the loads measured on the propeller blades and the shaft. Selected tests will also be carried out in the waves in the renovated DWB in vacuum conditions with waves, in order to simulate ventilation in a more realistic condition with cavitating propellers. The finding of this study will lead to the better understanding of thruster ventilation and the criterion of ventilation inception, and will result in the guidelines for preventing ventilation from occurring.

By carefully designing the sensors on the propeller shaft and blade, working together with WP2, the sudden loss of thrust and torque at the beginning of the ventilation and the recovery with high transient dynamic load peaks will be captured and recorded. At the same time the response of the shafting system to this dynamic loads will be analyzed too. These dynamic loads tests shall be carried out in the following conditions at different pre-defined shaft response characteristics:

- Oscillating open water set-up
- Open water set-up in vacuum and waves
- In a seaway installed to a ship model

The two typical thruster configurations used in WP3 will be investigated for the ventilation mechanism and the dynamic loads for this WP.

WP5 Full-scale measurements and monitoring

The objective of this WP is to monitor the operation of the thrusters in full scale in a long time period, say half to one year, measuring the dynamic torque on the input shaft of the thrusters during all possible operations of the vessels. An at the same time, the speed, the power, the draught, the motions of the vessel and the thruster RPM and steering angles will be registered. We will select a few vessels for the monitoring, preferably the vessels experiencing thruster mechanical failures. The measured data will be synchronized and the transient dynamic loads events will be carefully analysed, including the operation condition of each thrusters.

In order to validate the model tests results and verify the ventilation inception phenomenon in real life, dedicated full scale sea trial on selected vessels will be carried out with ventilation observations. In addition to forces and moments measurements as carried out for the thrusters monitoring, video recordings on board of those vessels during the sea trial will be carried out by borescope with high speed video cameras for the ventilation events.

This WP is strongly linked, not only, with WP3 and WP4 for the model tests, but also with WP1 on the operation studies. The results of this WP should contribution to the set-up of the operational guidelines too.

DELIVERABLES

- Operational guidelines
- Model tests results analyses and reports
- Sea trial and monitoring reports

PARTICIPANTS

The SHARES JIP aims at the following participants:

- Ship and offshore structure operators
- Oil companies
- Thruster and gear manufacturers
- Classification societies
- Engineering and design offices

BUDGET

The estimated budget for each work package will be roughly:

WP1 Operation studies and investigations	50,000 Euro
WP2 Shaft dynamic response and modelling	100,000 Euro
WP3 Dynamic loads during extreme manoeuvring	375,000 Euro
WP4 Dynamic loads during ventilation	375,000 Euro
WP5 Full-scale measurements and monitoring	(phase 2)
Total estimated budget for SHARES JIP	900,000 Euro

CONTRIBUTIONS AND SCHEDULE

The total budget of the SHARES JIP is expected to be around 1 million Euro. The contributions from the participants are (excluding VAT) 60,000 Euro for operators and oil companies; 50,000 Euro for thrusters and gears manufacturers and for classification societies, engineering and design offices, and other small companies. Expected participants are over 15. Should more companies participate, then cost of each participant will be reduced. MARIN contribution is 150,000 Euro.

The project has been started April 1 2012 and the duration will be about 2 years. A slight extension in time is foreseen (till October 2014)

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