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Review

Simplified method of torsional vibration calculation of marine power transmission system

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A R T I C L E I N F O

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A B S T R A C T

The paper presents two estimation methods to calculate the natural torsional vibration mode of marine power transmission system. Additionally, the method of forced vibration analysis (torsional stress level amplitude estimation) is discussed. A typical propulsion system of merchant ship is made up of slow speed main engine connected directly to the propeller by a relatively short shaft line. All classification societies require calculation of the propulsion system operating parameters, but they have no simplified formulas. Torsional vibrations of the marine power transmission system are usually most dangerous for the shaft line and the crankshaft. Numerical algorithms based mostly on Finite Element Method (FEM) are unobtainable and not easy to use by the ship crew and unspecialized engineers. Estimation method of the torsional vibration of the system was being investigated by the authors. Modelling method of more difficult propulsion system parameters like propeller added water polar moment of inertia was presented. Short description of the advantages and disadvantages of the undercritical and overcritical propulsion system was introduced. A discussion about the calculation results was included in the final part of the paper. The presented calculation method was verified by comparison with the detailed FEM calculation and measurements on real ships.

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1. Introduction

Reliability of the marine power transmission system is closely correlated with the safety of navigation at sea. Two-stroke, slow speed main engines have been installed mostly on merchant ships since the late 70s (oil crisis). The engines are connected to a directly driven propeller by a relatively short shaft line. The power output delivered from one cylinder of the typical engine has been increased in the last forty years. Therefore nowadays engines have less cylinders and the engine room is smaller (cargo space is larger). The propulsion system described above has a lot of advantages (mainly efficiency) but is the source of a relatively high vibration level. What is more, rough sea can be a source of added ship vibration, especially for big container carrier [1–3]. Vibrations may have a dangerous influence on crew comfort, ship equipment strength and consequently on the ship safety. Therefore, many authors examine the vibration characteristics and vibration control of complex ship hull structures [4]. But still, the propulsion system is a main source of ship vibration and methodology of power transmission system analysis is very important from designers' point of view.

All classification societies require calculation regarding the propulsion system operating parameters but they do not provide simplified formulas. There are several numerical algorithms (mostly based on the Finite Element Method – FEM) for shaft line alignment [5] and vibration analysis. But these numerical algorithms are unobtainable and not easy to use for ship crew as well as other unspecialized engineers. They are too complicated, time-consuming and expensive. According to the authors, there is a lack of simplified calculation method for unspecialized engineers; for instance in the well known classification societies [6–8] we can find only general rules for that kind of analysis without any simplified equations. For instance, the chief of marine engineers should have possibility to check the torsional vibration analysis and measurements performed by specialized calculating and testing engineers.

Torsional vibrations of the marine power transmission system are usually most dangerous for the shaft line and the crankshaft [9]. The model of the power transmission system (performed for the sake of calculation) is usually isolated from the ship hull, thus being the basic assumption for these kinds of methods. All connection between ship hull and crankshaft – shaftline system are omitted in case of model for torsional vibration analysis. Therefore, there is no problem with boundary conditions, because model hasn't got any boundary conditions. The FEM model of a typical marine propulsion system prepared for torsional vibration analysis is shown in Fig. 1. Each reciprocating crank is modelled by single polar mass moment of inertia as well as intermediate shaft, propeller shaft and propeller. Crankshaft is modelled by first nine elements; element No. 10 and 11 presents shaftline; propeller is shown as element No. 12.

Torsional vibration are the result of the pulsing torque of the reciprocating combustion engine [10] as well as unsteady propeller power output and the torsional elasticity of the power transmission system. All system components such as: crankshaft, intermediate shaft, propeller shaft, optional couplings and gears have to transmit the static and additionally dynamic torque. Research methods of the torsional vibration have been developed since the 1950s [11,12]. Despite such an intense research several elements still need to be investigated, for instance: propeller damping, cylinder damping, polar moment of inertia of propeller added water mass as well as the characteristics of specific shaft line elements such as: dampers, gears, elastic couplings. What is more, torsional vibration is one of the main sources of coupled longitudinal vibration and dynamic excitations (on the thrust bearing) of the ship hull and deckhouse.

2. Modelling method

Usually, the reciprocating and rotating masses of the engine including crankshaft, intermediate shaft(s), propeller shaft and propeller are modelled as a system of rotating masses (inertias) connected by the torsional spring. An example of a model for torsional vibration analysis of propulsion system with6 cylinder main engine has been shown in Fig. 1. The power transmission system model with one degree of freedom in each node is usually sufficient [13]. There is no problem with any boundary conditions. Therefore, a more detailed model of the power transmission system is not required for