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Parametric study to identify the cause of high torsional vibration of the propulsion shaft in the ship

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ABSTRACT

Since torsional vibration can lead to fatigue failure of the propulsion shaft in a ship, it should be restricted from the first step of the design through calculation and verified at the sea trial test step through measurement. Considering that the torsional vibration of the shaft is a system characteristic, it is strongly related to the vibration modes at the natural frequencies of the shaft. Therefore, the actual torsional vibration problem can occur due to the variation of parameters such as those of the vibration system, including mass of inertia, damping, and stiffness, which differ from the design.

In this research, the root cause analysis of the high torsional vibration which occurred in the actual ship is described through a parametric study performed using numerical analysis. Parameters that can increase the torsional vibration of the propulsion shaft are selected, including coupling stiffness, shaft stiffness, coupling damping, and shaft damping. Through the torsional vibration calculations with variations of these parameters, the extent of the effect of these parameters on the torsional vibration of the propulsion shaft is investigated and the cause of the increased torsional vibration is identified.

1. Introduction

The torsional vibration of the propulsion shaft is very important for the functioning of the ship with respect to the stability of the propulsion shaft. Since serious vibratory torque can lead to torsional fatigue failure, it is restricted in the specifications issued for various ship classes such as those by DNVGL [1], ABS [2] and Lloyd [3].

In order to avoid fatigue failure of the shaft, the propulsion shaft system should be designed to have a sufficient fatigue safety factor using representative methods such as the Goodman, Soderberg, and Gerber methods.

Lloyd [3] suggests the limit of the vibratory torque of the engine transferred to the gear box to 33% of the maximum torque. D.o.D [4] restricts the torsional vibration with vibratory torque as well as stress in accordance with MIL Std 167-2, Type-3. In MIL 167-2, the vibratory torque of the diesel engine transferred to the gear box should be less than 25% of the maximum torque of the engine. In addition, the maximum vibratory stress should be less than 1/25 of the ultimate tensile stress for the steel shaft and 1/6 of the fatigue limit for the non-steel material shaft.

IACS suggested the design criteria of the vibratory torque for the crank shaft and intermediate shaft in accordance with IACS M53 [5] and M68 [6], respectively.

Therefore, the propulsion shaft should be designed to satisfy the previously referred to specifications, and the design should be verified through calculation as well as measurement.

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In order to reduce the torsional vibration, many studies have been performed. Park et al. [7] performed the optimal design of the crank angle in order to reduce the excitation force in a diesel engine. He suggested a non-equally divided crank angle that differs to that for the commercial engine and found that the horizontal and vertical moments were reduced by about 70% when the non-equally divided crank angle was applied after optimization. Huang [8] researched the torsional vibration of the shaft with an imbalance. He concluded that the synchronous torsional vibration accompanying small higher harmonic components were excited when the shaft had an imbalance. In addition, it was found that the bisynchronous components were considerably more remarkable than other harmonic components and the torsional vibration of the shaft could result in lateral vibration when the speed of rotation was near or equal to half the natural frequency of the torsional vibration. Ren et al. [9] researched the torsional vibration for the electrical induction motor. In this research, it was found that the induction motor had large torsional vibration when the motor was started due to the negative damping of the rotor winding. Lee et al. [10] studied the torsional vibration for a speed increasing geared rotor-bearing system. In their research, it could be found that some vibration modes might yield coupled lateral and torsional mode characteristics when the gear mesh stiffness increased above a certain value.

From the above studies, it was found that the torsional vibration of the system can increase for various reasons.

Even though the vibratory torque is sufficiently low with respect to the typical specification, the shaft can be fractured when its design is not robust. When mechanical designs such as the fillet, chamfer, and keyway are not properly applied, the shaft can develop a high stress concentration factor. Therefore, many studies related to the design of the shaft have been performed.

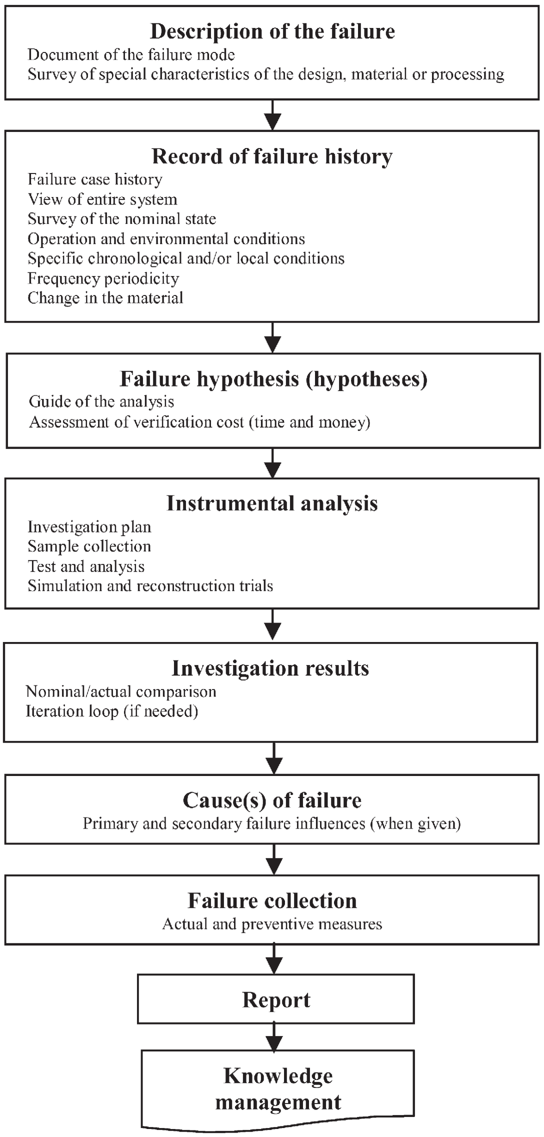

Fig. 1. Performance of a failure analysis.