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Guidelines for the Identification of Vibration Issues and Recommended Remedial Measures on Ships

1. Introduction

The most efficient way to meet vibration criteria is to undertake a vibration analysis and apply appropriate controls during the design stage. After the vessel is built there are less options readily available to rectify vibration problems in hull structures and the cost of fixing such problems is much more expensive in-service than if incorporated into the design from the preliminary design stage. Therefore, careful consideration should be given to incorporating vibration reduction elements during the design stage by either using experience with satisfactory service history or by employing analytical methods.

Having mentioned the above, this guidance is limited to identifying vibration problems in hull structures on newly built or in-service vessels and lists a few common remedial actions to make improvements to address those problems. It is recommended that consideration be given to employing experts in the measurement, evaluation and resolution of issues should vibration problems in hull structures be present.

This document is an IACS Recommendation which is a guideline and not necessarily a direct matter of class, but which IACS considers would be helpful to offer some advice to the marine industry. Further, this Recommendation may be utilized to supplement the IMO GBS requirements, i.e. SOLAS II-1/Reg. 3-10, the functional requirement 3.2.1.11 in Resolution MSC.296(87) GBS verification guidelines, and CSR Part 1 Ch 10 Sec 2 [3.1.1]. As these guidelines are recommendations they are not mandatorily applied.

2. Terminology

Damping: The dissipation of energy with time or distance. In this document, damping generally refers to dissipation of vibrating energy in structures.

Hard Mounting: Rigid attachment of a machine to its sub-base or foundation.

Isolation: The coupling of a vibrating structure (e.g., machine) to another structure (e.g., foundation or hull) by means of resilient or compliant supports that prevent the transmission of the vibration from the vibrating structure to the coupled structure.

Resonance: (1) The phenomenon of amplification of a free wave or oscillation of a system by a forced wave or oscillation of exactly equal period. The forced wave may arise from an impressed force upon the system or from a boundary condition. The growth of the resonant amplitude is characteristically linear in time. (2) Of a system in forced oscillation, the condition that exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system.

Vibration: The variation with time of the magnitude of a quantity which is descriptive of the motion or position of a mechanical system, when the magnitude is alternately greater and smaller than some average value. Also referred to as structure-borne noise.

Vibration Level: Measure of the amplitude of vibration. Most commonly given as acceleration in mm/s^2 or velocity in mm/s.

3. Sources of Vibration

The most basic forces of interest are those generated by engines, propellers, and shafts. Other common sources of vibration include: gears, screws, thrusters, fans, compressors, pumps, pipes, and valves. Flow generated vibrations may also occur.

3.1 Machinery Excitation – Unbalanced or misaligned machinery, particularly propulsion machinery such as the main propulsion engines, is the major source of excessive vibration and can develop excitation forces in the frequency range of interest for both the equipment and structure in the vicinity of the machinery. These frequencies of excitation match either the rotation rate, or twice the rotation rate.

3.1.1 Diesel Engines – Diesel engines, whether low, medium or high speed – two or four stroke, generate significant force and moment coupled vibration excitation. The diesel firing forces, which depend on rotation rate and the number of cylinders, are impulsive in nature, which causes components of vibration at many harmonics of the firing frequency. Low-speed propulsion diesel engines are typically more of a concern than high-speed diesel engines because their low excitation frequencies are more likely to lie in the range of a hull natural frequency. As a result, diesel engines, and other reciprocating machinery, may develop forces and moments, which are sufficient to create excessive ship vibration. These forces/moments may excite the machinery itself, the ship foundation on which it is attached, the hull girder, or other structures within the vessel.

The excitation of a reciprocating engine can be divided into two parts:

- Unbalanced inertial forces
- Firing forces/moments

The unbalanced inertial forces are associated with the rotating or reciprocal masses. The frequencies of resulting forces are multiples of shaft rotation rate.

A 4- stroke engine has twice as many ‘firing’ harmonics as a 2- stroke engine. Analytical calculations of diesel engine generated forces are not easily undertaken and should be left to the diesel engine vendor.

3.2 Propulsion and Shafting Excitation – The basic design purpose of the propulsor is to generate steady thrust to the vessel. In addition, this propulsor generates undesired fluctuating dynamic forces and moments due to its operation in a non-uniform wake and due to passage of the blades close to hull and appendages.

3.2.1 Hull Pressure vs. Bearing Forces – Propellers generate two types of fluctuating forces. These are hull pressure forces and bearing forces. The hull pressure originates from the hydro-acoustic pressure variations caused by the passage of a propeller through non-uniform inflow or wake. These hull pressure forces are affected by propeller-hull clearance in the vertical and horizontal directions, by blade loading, and by changes in the local pressure field around the blades.

Bearing forces are caused by fluctuating forces on the blade during a propeller rotation which generate both vertical and horizontal forces on the shaft. These vertical and horizontal forces produce lateral and axial forces and moments on the support bearings and thrust bearing. The frequencies of these forces and moments are the same as for the hull pressure, shaft rate, blade rate, and multiples.

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The thrust bearing forces provide an excitation to the propulsion system in the longitudinal direction; the fluctuating torque produces shaft torsional vibration. The blade frequency vertical bearing force, when combined with same frequency vertical hull pressures, provides the overall vertical excitation of the hull in the vertical direction. Similarly, the combined horizontal forces excite the hull in the horizontal direction. Dynamic unbalance of any component of the system (propeller, shaft, coupling, gear, and engine) will increase the resulting hull vibration levels.

3.2.2 Cavitation – Where there is the occurrence of cavitation, (the sudden formation and collapse of low-pressure bubbles in liquids by means of mechanical forces, such as those resulting from rotation of a propeller), there is a significant increase in the hull pressure forces. Again, the frequencies of these propeller impacts are shaft rate, blade rate, and 2× and 3× multiples of the blade rate.

3.2.3 Thrusters – Another significant vibration source may be the bow or stern thruster(s). These units can be located relatively close to accommodations and can cause high vibration. As discussed above for the prime propulsor, inflow and propeller design control the induced vibration levels.

4. Structural Response

Generally, it is important to ensure that the natural frequencies of the fundamental hull girder vibration modes do not coincide with the excitation frequencies from any of the major excitation sources (propellers/main engines). This is normally ensured by global vibration calculations during design stage. However, increased vibration levels caused by hull girder modes excited by machinery or propellers can sometimes be experienced during sea trial or operation. The natural frequencies of the hull girder modes are influenced by the draft, trim and load distribution along the hull girder.

Substructures, like decks, machinery platforms, or the deckhouse, of sufficient mass and flexibility also need to be considered in a vibration-related survey. These substructures have their own natural frequencies, which should not coincide with primary excitation frequencies. The natural frequencies of these substructures are usually higher than that of the whole hull. However local structural elements like plates, bulkheads, parts of the deck, rudders, and machinery platforms may have natural frequencies which are close to the excitation frequencies. Massive equipment installed on platforms may have a large influence on the resulting natural frequency.

5. Vibration Assessment

If observations regarding vibration are made, it is helpful to remember that vibration levels experienced as “uncomfortable” are normally well below vibration levels necessary to create structural problems.

If found necessary based on vibrations experienced by the surveyor or personnel during the vessel trials or operation, vibration measurements should be considered. Changes in the text plan might be necessary or a test plan should be developed which includes evaluation of relevant measurement locations and vessel operating conditions. This may include measurement positions suitable for describing global vibration behavior of hull girder and deck house, as well as local positions in accommodation and machinery areas. Locations should include the potentially ‘worst locations’ (e.g., closest to sources or places expected to have maximum vibration).

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Vibrations can in all cases be expected during maneuvering or during operation far outside of normal operation range for the vessel. Such temporarily experienced vibrations are normal and should not be considered problematic.

There are several international standards which address vibration, measurement procedures and evaluation. It is recommended to use the following standards, although not limited to them, as guidelines:

- ISO 20283-5:2016, Mechanical Vibration – Measurement of Vibration on Ships – Part 5: Guidelines for Measurement, Evaluation and Reporting of Vibration with Regard to Habitability on Passenger and Merchant Ships
- ISO 8041:2005, Human Response to Vibration – Measuring Instrumentation
- ISO 5348:1998, Mechanical Vibration and Shock – Mechanical Mounting of Accelerometers
- ISO 20283-2:2008, Mechanical Vibration – Measurement of Vibration on Ships – Part 2: Measurement of Structural Vibration

6. Measurements

The following summarizes some typical measurement types that may be relevant in case of severe vibrations. For all vibration related issues where measurements are considered, it is important that a proper measurement procedure is established by personnel with vibration expertise.

6.1 Global Structures – If vibrations are of a global nature, e.g. longitudinal vibrations in the deck house, it may be relevant to carry out measurements to establish the vibration behavior of the hull girder or deck house. Reference is made to ISO 20283-2.

6.2 Local Structures – Local structure includes plates and stiffened panels in deck or bulkheads. For local deck areas in the accommodation vibrations are normally only a problem for human comfort. This is further discussed in Recommendation 132. Reference is also made to ISO 20283-5. Vibrations in plates or panels in way of bulkheads, e.g. tank boundaries, can be a cause of structural damage.

If severe or critical local vibration exists, vertical, transverse, and/or longitudinal measurements are taken at the suspect location in order to determine the need for corrective measures. If the problem is established as highly localized resonant vibration of plating panels, piping, etc., then the vibration survey likely needs to go no further. It is usually obvious in such cases how natural frequency changes, through local stiffening, can be effectively accomplished to eliminate the local resonant conditions.

6.3 Semi-global structure – If vibrations are of a semi global nature, e.g. including an entire deck or coupling between decks, vertical and transverse vibration bending shape measurements can be taken using a significant number of points necessary to determine the mode shapes at low frequencies while avoiding local resonances. These types of measurements are made by use of a reference transducer at the stern along with a portable transducer. Torsional modes may require phased deck-edge measurements.

6.4 Vibration source measurements – Some of the following measurements may be relevant investigating the source of any excessive structural vibrations in hull or accommodation areas. Often measurements of machinery vibration or propeller pressure pulses are taken simultaneously with measurements of relevant structural positions. In cases with variable rpm on relevant machinery or propellers, such measurements are normally carried out as a run-up.

6.4.1 Local Machinery and Equipment – Vertical, transverse and/or longitudinal measurements are taken on non-rotating parts of the machinery where there is evidence of large vibration amplitudes. Types of machinery and equipment include diesel generator, electric motors, air compressors, ballast pumps, etc. Vibration measurements are normally taken at the bearing position and /or foundation.

6.4.2 Shell Near Propeller – If necessary, the measurements of hull surface pressure are taken in order to confirm design estimates, to obtain design data or to investigate hull pressure forces or potential cavitation problems.

To minimize the effect of plate vibration, all transducers in the hull plating are located as close as possible to adjacent frames or partial bulkheads.

6.4.3 Main Engine and Thrust Bearing –, Vertical, transverse, and longitudinal measurements are taken in order to determine the need for corrective measures. In some cases, measurements to establish an operational deflection shape (ODS) of the engine can be relevant. ODS measurements are carried out either with simultaneous measurement with numerous fixed sensors or more commonly with one fixed sensor and one or more roaming sensors. Such measurements are time consuming and with high demand to equipment and postprocessing tools. However, they may be a helpful tool for troubleshooting cases.

6.4.4 Lateral Shaft Vibration – If this measurement is conducted, vertical and transverse vibration measurements are made on the shaft. Additional measurement points may be taken. These measurements are made throughout the normal operational range of the ship.

In order to eliminate possible error, shaft run-out is checked by rotating the shaft by the turning gear and recording the first-order signal. This signal is phased, and the shaft vibration measurement corrected accordingly.

6.4.5 Torsional Shaft Vibration – If this measurement is conducted, torsional vibration measurements are taken either at the free end of the propulsion machinery, using a suitable torsional vibration transducer, and/or on the main shafting, using strain gauges. Alternatively, depending on the system characteristics, a mechanical torsiograph, driven from a suitable position along the shafting or free end, may be used for this purpose.

7. Remedial Measures

A foundation for critical vibration sources (e.g., large reciprocating machinery) typically is fitted with a thick foundation top plate, stiff floors, and local gussets between these two members in way of attachment points in order to provide damping of the vibratory forces. This is true whether the machinery is isolation mounted or not.

7.1 General Approach – The test report should describe the operating conditions for measurements, including weather, sea state, speed, rpm, water depth under keel, and other pertinent data. The report should show the locations of measurements and overall rms value in mm/s or mm/s^2. For additional information the spectrum and/or single peak level with corresponding frequency could also be recorded. As the vibration control treatment designs evolve, drawings and other design information should be reviewed by one familiar with the design of treatments to verify that the treatment design adequately reflects vibrational considerations mentioned in the report.

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Just as in developing a vibration-sufficient ship design, there exist three possibilities for correcting a vibration-deficient one in normal practice:

i) Reduce vibratory excitation

ii) Change natural frequencies to avoid resonance

iii) Change exciting frequencies to avoid resonance.

Most of the excessive diesel engine excited hull vibration can usually be corrected by the following provisions:

i) Mechanical or electrical moment compensators against engine external moments, or

ii) Engine lateral stays of weld, hydraulic or friction type against engine lateral vibration, or

iii) Axial damper against crank shaft vibration, or

iv) Dynamic absorber against fore-and-aft vibration of deckhouse.

The detail information necessary for the installations of above provisions is typically provided by engine or equipment manufacturers.

7.2 Structural Modifications – The most cost-effective approach for eliminating structural resonances is usually to shift natural frequencies through structural modifications such as adding panel stiffeners.

7.3 Propeller or wake modifications – For cases where the pressure pulses or shaft forces from the propellers are the source of excessive vibrations, it may be a solution to modify the propeller design or to manipulate the wake in order to reduce the excitation forces.

7.4 Machinery modifications – For vibration caused by unbalanced or misaligned machinery, the 'treatment' in these cases is to correct the mechanical problem. This represents another basic design function often carried out by the equipment vendor, who usually takes responsibility for the proper selection of vibration dampers, torsional couplings, and flexible shaft couplings.

7.4.1 Top stays - For vibration caused by e.g. main engine H-moment, the solution may be to add (or in some cases remove) top stays. Active top-stays can in some special cases be relevant.

7.4.2 Moment compensator – The excitation by main engine forces can in many cases be limited by installation of a moment compensator. This can be a solution for both 1st order, 2nd order, H-moment and X-moment excitation.

7.4.3 Resilient Mounts – If there is no inherent mechanical problem, resilient mounts may provide some abatement. However, isolation mounting provides no vibration reduction below the systems natural frequency and may amplify the vibration in the vicinity of the system resonance. Resilient mounts need careful design for two reasons. Vibration levels of the machinery itself are actually higher on resilient mounts than that if the machinery is hard mounted. Another concern is that the excitation frequencies of the machinery should not coincide with isolation system's natural frequencies. To avoid such a coincidence, the selection of the resilient mounts should be made with consultation of experts or the equipment manufacturer accompanied with calculations of natural frequencies of a 'machinery-resilient mount' system (six degrees of freedom calculations). The lower the

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natural frequency (softer resilient mounts), the lower the vibratory effect will be on the foundation and adjacent structures.

7.4.4 Foundation – Designing a stiff foundation structure is the most important approach to prevent excessive machinery induced vibration. The incorporation of a stiff egg-crate like framing and flooring system is preferable and should be a relatively light system of floors in either the longitudinal or transverse direction only. Transverse plating of a foundation should be a continuation of rigid floors; longitudinal plating should be incorporated into longitudinal stiff girders. The structure of thrust bearing foundations is also important, especially for systems with a Cardan shaft (universal joint).

8. Verification of Countermeasures

It is important that proper verifications are carried out to determine the effectiveness of the vibration treatment measures. This can include re-measurement of affected areas and/or calculations or documentation of the effect of the modifications carried out. The extent of necessary follow-up needs to be evaluated from case by case. The performance of vibration control treatments is ultimately dependent on the quality of the implementation. Seemingly trivial deviations from the detailed design, or inadvertent errors due to unfamiliarity with vibration control treatment materials and constructions, may compromise vibrational performance. Hence re-measurements will often be requested.

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