Research Note

Noise and Vibrational Analysis onboard Marine Platforms and Automated Report Generation

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Introduction

Noise and Vibration (N&V) onboard marine platforms, is of keen interest for multiple military and non-military applications. A marine platform consists of convoluted sources of N&V, determined by numerous onboard structures and installations as well as specific activities of crew and passengers. Noise and vibrations have a major impact on the operations and wellbeing of equipment and humans onboard [1]. The N&V analysis typically has three major motivation – wellbeing of humans onboard due to excessive exposure, fatigue failure of equipment and structures onboard due to continuous exposure and finally the high levels of underwater radiated noise that is a cause of concern for both acoustic stealth for military platforms to avoid detection by sonars deployed by their adversaries and also acoustic habitat degradation for the marine species [2]. In the past few years, national and international organizations have established limits for noise and vibration exposure. In 1981 the IMO set the standards for N&V onboard merchant ships [3]. Since then, numerous studies and research made observations and conclusions that improved the conditions of crew onboard commercial and military ships. Separate classification societies and regulatory authorities like IMO, DNV, IMO, ABS and other organizations collect information and update the standards. The globalized nature of commercial shipping, these standards cannot vary from country to country.[4] The need for a uniform standard and at the same time the concerns of socio-economic diversity among nations and varying resource & know-how availability to be able to implement such a global standard makes it a complex issue.

The concept of noise and vibrations cannot be generalized for ships. Each ship has different structure, machinery, load etc. and these are the few factors on which the amount of noise and vibrations generated depends. Noise and vibration are best minimized during the design process. [5]

N&V Ship is a noise and vibration engineering company which works in the fields of shipbuilding and marine industry. They offer their skills and expertise in noise and vibration to ship owners, shipyards, repair yards, design and engineering offices, naval architects or any actor of the marine industry.[6]

Projected growth in the blue economy is expected to bring an expansion in noise generating activities, notably the construction of offshore wind turbines and other marine infrastructure, geophysical surveys using sonar usage and vessel traffic. Unlike other marine pollutants such as microplastics or persistent organic pollutants, underwater noise is ephemeral and quickly disperses in the environment. If effective, interventions to reduce noise pollution could lead to a rapid easing if this pressure on acoustically sensitive organisms.

VIBRATIONAL ANALYSIS: Working or living onboard vessels can impose a series of low and high frequency mechanical vibrations, as well as single impulse shock loads on the human body. Low frequency vibrations are also imposed by vessel motions, which are produced by the various sea states in conjunction with vessel speed. High frequency vibration is often caused by rotating machinery. The imposition of higher frequency vibrations induces corresponding motions and forces within the human body, creating discomfort and possibly resulting in degraded performance and health.[7]

One of the challenges in the design of modern ships is the avoidance of excessive elastic vibration of the hull structures in response to external or internal forces. Such vibration may cause discomfort and interfere with performance of crew duties. Severe vibration may lead to structural damage and negatively influence operation of mechanical and electrical equipment on board. Typically, propellers excite the most significant vibration. Flexural vibration can also be excited by forces from reciprocating, and to a lesser degree, rotational machinery, and by external forces of sea waves impacting a vessel.

Looking at the sources of vibration, it is easiest to start at heavy pieces of mechanical equipment and work ‘backwards’. The most basic forces of interest are those generated by engines, machinery, propellers, and shafts. These forces vary with engine load, the speed and draft of the ship and with environmental conditions. Other common sources of vibration include gears, screws, hulls, thrusters, fans, compressors, pumps, pipes, and valves. It is assumed that shafting, torsional, whirling, lateral, and axial vibration analyses are carried out as part of the standard design, either by the equipment vendor or a third party. Selecting low vibration machinery and minimizing propulsor/thruster excitation are the better approaches to avoiding excessive vibration levels. Foundations for shaft bearings should be stiff enough to prevent excessive low frequency vibration. The strategy of selecting low vibration machinery is so critical due to a limited or restricted ability to change the hull size and shape later in the design. 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 – both for the equipment and structure in the vicinity of the machinery. These frequencies of excitation match either the rotation rate, or twice the rotation rate.

Hydrodynamic vibration excitation is a flow-related phenomena within the frequency range of 1 to 80 Hz that indicates whole body vibration. The sources of this vibration are generally hull shape, hull appendages, and openings, tunnels or chests subjected to interactions with flow. Vibration excitation induced by hydrodynamic sources is typically unintentional and should be avoided.

For the global response, one can consider the hull as a beam (of varying stiffness) floating in water and vibrating in a ‘free-free’ mode. As mentioned before, propulsors and engine excitation create moments and forces which can induce vertical, horizontal transverse, longitudinal, and torsional vibration of a hull, which acts as a whole beam. If the excitation frequency from a particular force is close to or coincides with a natural frequency of the vertical, horizontal, longitudinal, or torsional mode then the whole-body vibration may be significant. The normal practice is to calculate a few natural frequencies of the hull, once information about the hull structure and weight distribution becomes available. The main goal of this calculation is to check how close the excitation frequencies come to the computed natural hull frequencies.

Local structures may exhibit a vibration response independent of the ‘whole’ body response. These substructures, like decks, machinery platforms, shafting systems, or the superstructure, of sufficient mass and flexibility need also be considered in the vibration analysis process. These substructures have their own natural frequencies, which again should not coincide with primary excitation frequencies. The natural frequencies of these substructures are usually higher than that of the whole hull. The frequency depends on the structural stiffness, mass distribution, and on the method of attachment of substructure to the main structure (boundary condition). [8]

There are three approaches to developing vibration modeling. The most accurate and time-consuming is to build a Finite Element Analysis (FEA) model. The second approach would involve an empirical analysis. Simplified methods exist to determine the vibrations of 'free-free' beams, framed panels, cantilever structures, etc. The final method is to use historical data from a close prototype vessel and account for differences in excitation frequencies and machinery. This type of scaling may also be risky but can be used as a first-cut to indicate likely problem areas. With any of the approaches listed above, the first objective is to predict the structural resonances. If these are sufficiently clear of any of the exciting frequencies, it may not be necessary to carry out a 'forced' response analysis. If a coincidence is likely, a 'forced' analysis can be used to determine if the response is within the allowable limits.

MEASUREMENT AND ANALYSIS:

Finite Element Analysis: The primary tool currently in use is Finite Element Analysis (FEA), requiring software, qualified analysis personnel, and necessary time for modeling. Using FEA, the whole structure is divided into a large number of small and simple elements; plates, beams, masses, etc. These elements are connected and all together form the model of a realistic structure.

Vibration Calculation by Empirical Methods: The empirical approach varies with set ship types: tankers, bulk carriers, or cargo ships. The common parameters for all approaches are length, width, displacement, draft, and distance between the bottom and the main deck. Other major parameters are the cross-sectional moment of inertia and mass of a vessel with entrained water. This approach may be very useful in the early design stage and offers an opportunity to avoid the coincidence of natural and exciting frequencies. For example, it might be possible to change the number of propeller blades or shaft rpm early in the design stage. There also exist empirical methods to compute the hull response to propeller hydrodynamic pressures.

NOISE ANALYSIS: Noise challenges are especially difficult to address in smaller vessels. The most problematic vessels are those possessing highly-loaded propulsors and thrusters, for example those with towing and dynamic positioning systems. Other noise deficiencies are related to excess noise from the indoor climate systems. Sound is measured by a pressure sensing device, usually a microphone, connected to a Sound Level Meter (SLM) or an acoustic analyzer. The range of noise levels which can be measured on the modern vessel is between 30 and 130 dB(A). The lowest may be measured in a compartment on a larger vessel far from the engine room; the highest could be in an engine room supplied with a high-speed diesel engine or gas turbine.[9]

Noise sources may be located outside the vessel or installation. Propellers, thrusters, waterjets, and other hull protrusions fall in a category of 'hydro-acoustic' sources. Excessive noise levels from propulsors are basically connected with their cavitation. Typical shipboard noise sources include the main and auxiliary engines, pumps, compressors, fans and other equipment located in a machinery space. These sources generally generate significant noise and vibration, particularly in close proximity to the engine space. The main engine's intake and exhaust systems also often generate high noise levels at on-deck stations and, sometimes, inside the vessel's manned compartments. As a distributed system, the heating, ventilation, and air conditioning (HVAC) system may be an important noise contributor to manned compartments and work spaces. Ventilation systems can be of concern, particularly on deck or in machinery spaces with the internal equipment secured. While not as distributed as an HVAC system, piping systems can be an important contributor to noise in compartments near the machinery space, (i.e., the control room).

MEASUREMENT AND ANALYSIS:

Source-Path-Receiver Modeling: Noise is transmitted from a source location to a receiver area over the air media (airborne) and/or through the structure (structure-borne) before it reaches a receiver area of interest. This receiver area can be inside or outside the vessel, in the equipment room, or remote from the equipment. The airborne source level and airborne paths are the most critical factors affecting noise within a machinery space itself and the compartments directly adjacent. However, structure-borne sources and the structure-borne paths are responsible for carrying the acoustic energy everywhere else on the vessel.

Analytical Tools: Several noise prediction/analysis software tools currently exist. With these tools, the user can predict the octave band, an overall A-weighted noise level in all rooms of interest, vibration levels of all structural elements of the model (decks, bulkheads), and airborne and structure-borne noise contribution for every room of interest. This type of software can aid the user in the evaluation of noise contributions from every source over every path (including propulsors and inflow which may also be influencing factors) and determine the physical reasons for excessive noise levels, ultimately detailing the optimal way for noise reduction. [10]

REGULATORY ORGANIZATIONS

The international organizations that control the noise inside the ship are two United Nation's agencies : International Labor Organization (ILO) and the International Maritime Organization (IMO). The noise code given by IMO applies to all ships in service and is designed to prevent potentially hazardous noise levels on board ships and to provide with acceptable working environment for people on board.

IMO is a specialized agency of the United Nations responsible for regulating shipping. The IMO's primary purpose is to develop and maintain a comprehensive regulatory framework for shipping and its remit today includes safety, environment concerns, legal matters, technical cooperation, maritime security and the efficiency of shipping. IMO is the source of approximately 60 legal instruments that guide the regulatory development of its member states to improve safety at sea, facilitate trade among seafaring states and protect the maritime environment. The most well known is the International Convention for the Safety of Life at Sea (SOLAS).

The similar organization responsible in India is Indian Register of Shipping (IRS)**.** It is an internationally recognized, non-profit, independent ship classification society. Today IRS acts on behalf of the Maritime Administration of the Indian government as the sole authority for final assignment of Load Lines in Indian flag vessels. IRS provides independent third party technical inspection and certification services for all types of ships, marine craft and structures. It carries out statutory design appraisal, surveys and certification work on behalf of flag states, when so authorized by the governments of such states via the International Maritime Organization Conventions and Codes. [11]

APPLICATION

SILENV: The Transport and Research and Innovation Monitoring and Information System (TRIMIS) supports the implementation and monitoring of the Strategic Transport Research and Innovation Agenda (STRIA) that outlines future transport research and innovation (R&I) priorities to decarbonize the European transport sector. The project SILENV was taken up whose purpose was to reduce ship generated noise and vibration pollution. The SILENV project proposed a global approach to investigate all of these noise related annoyances and suggested ways to limit the noise. SILENV's final main deliverable is a "green label" for ships which declares ship's noise and vibrational level as bearable. The team of researchers surveyed noise pollution level on board ships, in the environment of ports and in the water. As a result, the team proposed a "green label" applicable to most types of ships. Since the beginning of the SILENV project, three report have been produced covering the three principal topics of the SILENV project: N&V on board ships, noise pollution in the environment of ports and noise radiated in the water. The main result of this project is the definition of the N&V green label applicable to the most prevalent type of ships. This is the first important step in the N&V abatement process.

The potential impacts of the decrease of N&V ships are:

1. Improvement of health and safety for sea workers especially fishermen.
2. Improvement of comfort for the users of maritime transports.
3. Reduction of noise pollution for populations living around ports and close to inner waterways.
4. Reduction of underwater noise pollution and its effects on the marine ecosystem.

The green label will be used as a reference by members of SILENV consortium in their respective activities: measurement, design, ship classification, N&V consulting. [12]

FUTURE SCOPE

Real time analysis of noise and vibrational data could help detect faults and problems efficiently on the spot and also help us prevent fatigue failures. An automated report generation technique could be useful to check if the noise and vibrations generated are under the threshold value or not. This threshold value is given by the regulatory organizations(for example IMO, ABS etc.). If the noise and vibrations generated are not under the regulated value then the report should contain various measures and techniques to bring it under control.

We could use AI and ML in report generation by monitoring the previous performance of the ship and the new changes made as well.

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[9] ISO 20283-2 Mechanical vibration – Measurement of vibration on ships, Part 2 Measurement of structural vibration provides a standard guideline for the measurement of global ship vibration .

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[11] ("Indian Register of Shipping - Wikipedia," 2019)

[12]("Ships oriented Innovative soLutions to rEduce Noise & Vibrations," 2019, pp. 1–3)