Research Note-1

Analysis of URN based on Vessel Hull Vibrations

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Pollution in the ocean is not just about the dumping of harmful chemical, physical or biological substances into the sea, but also about the increased ambient noise. Ocean ambient noise results from both natural and anthropogenic(human-induced) acoustic sources. The latter are closely related to maritime shipping and seismic exploration by the oil/gas industry. Studies show that the Underwater Radiated Noise (URN) due to shipping activity has resulted in an increase of at least 20 dB of ambient noise compared to pre-industrial levels [1]. Sound generated by ships is primarily due to hydrodynamic flow, interaction between hull and water and propeller cavitation, is generally in the low frequency range [2]. Low frequency noise i.e., less than 1,000 Hz could affect several marine mammal species, specifically the big whales, whose auditory range overlaps [2, 3].

The science of underwater acoustics began in 1490, when Leonardo da Vinci wrote the following, [4] "If you cause your ship to stop and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you." The sinking of Titanic in 1912 and the start of World War I provided the impetus for the next wave of progress in underwater acoustics. This was when active ASDIC and passive sonar was developed.

Major Sources of onboard vibrations

1. **Machinery Vibrations** These are the vibrations produced by internal machinery components like engines and motors. On the basis of vibration type these can be categorized into three
    a) **Torsional Vibration**: The main propulsion system of a ship consists of the main engine, which is connected to a propeller by a shaft. The shaft is again, not a single component. Usually, a marine shaft consists of an intermediate shaft and a propeller shaft, which are connected by means of coupling flanges. The presence of connections, like coupling flanges, thrust block, engine connection flange, and the cylinder-piston system in the main diesel engine creates torsion in the rotating shaft system. In other words, the

rotatory motion of the diesel engine creates an ‘excitation’. So, the entire propulsion system can be simplified, for vibrational analysis into a series combination of shafts and discs.

b) **Axial or Longitudinal Vibration:** One of the most interesting cases of machinery vibration, and perhaps the one most likely to cause forced vibrations, is axial vibration of the propulsion system. Axial mode of vibration makes the propulsion system behave like a horizontal multiple degrees of freedom spring-mass system.

c) **Lateral or Transverse Vibration:** This mode of vibration occurs in the direction perpendicular to the axis of rotation of the shaft. The intermediate and tail shafts can be considered as beams, with the shaft bearings as support points. Due to the bending of the shafts, the center of gravity of the shaft does not coincide with the ideal centerline of the shaft, therefore when the shaft rotates, the centrifugal force on the center of gravity would cause it to shift further away from the ideal centerline, resulting in a vibratory motion called whirling of shafts.

2. **Hull Girder Vibrations** These are the structure borne vibrations transmitted to hull of the vessel. Major contributors to it are-

    a) **Low speed main diesel engine** has always been the primary source of vibrations in the hull girder. The excitation from diesel engine can be considered to comprise of periodic forces and three periodic moments that act on the foundation of the engine. Gas pressure force and Inertia Forces. the force along the axis of the shaft is cancelled out by the periodic thrust.

    b) **Hull Wake**: Varying wake on the propeller due to the stern contour of the hull results in propeller induced vibrations better known as hull wake vibrations.

    c) **Propeller Cavitation**: Propeller cavitation results in formation of bubbles that implode on the propeller blade.

Vibrational Acoustics and transmission

Air Borne: This is produced due to longitudinal wave with contractions and rarefactions in the air. When air borne sound energy strikes a structure, it changes and converts to vibrational energy in the structure. The signatures of air borne sound energy and corresponding vibrational energy are somewhat similar but the waves are different in a few variables like, frequency response, speed, majorly depending on density and elastic properties of the structure material. When the wave passes through a structure it converts back to acoustic energy on the other side but most of the energy is lost in the structure.

Structure Borne: These are the waves being transmitted by the structure those are emitted by a source. Particularly talking of vessels, sources can be of three types, transient sources like moving parts of the engine, periodic sources; rotating parts like gears and wheels, and random sources. Wave propagation in the structure are much more complicated than air. In air we just have longitudinal waves where air particles are moving in the same direction. This kind of wave can also be in a structure, here we call it cross longitudinal waves. There are two more types of wave in a structure, shear wave and bending wave. Shear waves are the ones causing the torsion in the structure. Bending waves as the name suggest are the ones those are produced on bending of a structure to and fro from the mean position. Bending waves are excited easily and due to the transverse motion, they radiate the sound really well. Radiation happens when we have a big surface to radiate sound through bending waves, just like hull surface in a vessel. Most of the underwater radiated noise is transmitted to water through hull it acts as a big laminar plate with bending waves through it.

<u>Mindlin-Reissner Plate Theory</u>

The **Mindlin–Reissner theory** of vibrating plates is an extension of Kirchhoff–Love plate theory that takes into account shear deformations through-the-thickness of a plate. The theory was proposed in 1948 by Yakov Solomonovich Uflyand [5] (1916-1991) and in 1951 by Raymond Mindlin [6]. The Mindlin–Reissner theory is used to calculate the deformations and stresses in a plate whose thickness is of the order of one tenth the planar dimensions while the Kirchhoff–Love theory is applicable to thinner plates.

A differential equation describing the vibratory motion of plates was given by Mindlin.

$$\ddot{w} + \frac{c_p^2 h^2}{12} \nabla^4 w - \frac{4.3}{12} h^2 \nabla^2 \ddot{w} + \frac{3.3}{12} \frac{h^2}{c_p^2} \ddddot{w} = \frac{p}{\mu'} .$$

Here, cp= phase velocity of sound
W is the displacement of the neutral plane
h is the thickness of the plate
μ’ is the mass per unit area
P is the pressure exerted due to external forces

Hull as a 2D plate

Considering the Mindlin model where any laminar plate where the thickness is less than one tenth of the dimensions can be treated as a 2D plate and Mindlin equations can be applied to the same. Here applying the same analogy to vessel hull the structure can be treated as a 2D plate. Since there is a grid clamping the entire structure from inside, we need to divide the entire hull as a grid formed with clamping various sheets together.

Unlike simple structures the hull plates have linear increase of pressure with depth of water from outside. Internal pressure whereas depends on the positioning of various machinery components like engines and motors inside the vessel. Moreover, internal pressure may vary with the distance from each component. The same can be calculated by superimposing pressure functions from each component.

Future Scope

In the preceding sections, we have described, Mindlin mathematical model of vibrations. There are two methods which can help us in estimating URN:

a. Mindlin equations are a result of equating strain energy in the structure with the kinetic energy of vibrations, similarly if we have the formula for power radiated through the hull. Once we are able to calculate the vibratory forces on the hull due to different machinery, we can use them directly to calculate the noise radiated.
b. Second, we have enough literature which provides us with noise estimates of the machines onboard. Using those estimates and by using transmission path analysis we can estimate URN.
c. While applying Mindlin model to hull plates, dynamic pressure variation i.e. linearly proportional to depth outside and based on positioning of machinery components like diesel engine and motors inside has to be taken into account.
d. Vibration exciting functions from various machinery components can be superimposed vectorially in the Mindlin model for most accurate results.

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