AN INTRODUCTION TO SHIP RADIATED NOISE

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ABSTRACT: Radiated noise from ships is important for naval vessels, hydrographic survey ships and oceanographic ships. This article provides a broad overview of the major sources of radiated noise, transmission paths, and noise reduction methods. Its principal objective is to introduce the reader to the topic of radiated ship noise. Many of the procedures for estimating the radiated noise form ships have been derived empirically. This paper is written to provide a general overview of the topic, rather than a detailed technical discussion.

1. INTRODUCTION

Ship noise is a major part of the field of underwater acoustics. In naval operations the radiated noise is an important source of information, ie signal, for passive listening systems. Radiated noise is an important contributor to ocean ambient noise, and is a factor in oceanographic research and geophysical exploration. Ship noise reduction and control is an important factor in the performance of underwater acoustic systems and in the habitability of the vessel for the crew and passengers. Underwater radiated noise is also critical to many naval activities.

Seismic survey and oceanographic research vessels require low acoustic signatures, while many commercial vessels are subject to environmental legislation. In underwater warfare the increasing capability of the detection systems of modern weapons such as mines and torpedoes plus the improved performance of passive sonar systems is leading to stringent requirements as to ship radiated noise signatures. Specifications describing the permissible levels of underwater radiated noise and self-noise are important requirements in the acquisition of any major vessel.

This paper provides a brief introduction to the subject of radiated ship noise. It describes the major sources of radiated noise, transmission paths and noise control measures. It is written to provide a general overview of the topic, rather than a detailed technical discussion.

2. RADIATED NOISE

The four principal groupings of radiated noise sources are: machinery vibration caused by propulsion machinery and auxiliary machinery; propellers, jets and other forms of in-water propulsion; acoustic noise within compartments below the water line; and hydro-acoustic noise generated external to the hull by flow interaction with appendages, cavities, and other discontinuities.

Noise spectra are generally classified in two groupings; broadband noise having a continuous spectrum such as that associated with flow or cavitation; and tonal noise containing discrete frequency or line components, usually related to machinery. In addition to steady state noise, ship noise is also characterized by transient and intermittent noise caused by impact, machinery changes of state or unsteady flow that have particular spectral properties.

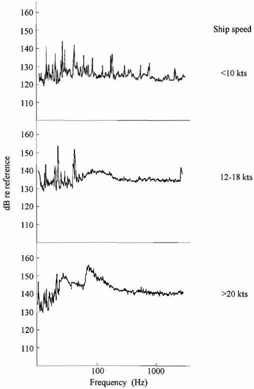

Figure 1. Diagrammatic radiated noise spectra for different speeds.

Generally, at speeds below the cavitation inception speed, main and auxiliary machinery are the principal components of radiated noise. Above this speed propeller cavitation becomes a major source, with discrete frequency components from machinery still being significant. Flow noise and cavitation from hull fittings may add a significant contribution at higher speeds. Figure 1 shows typical radiated noise spectra for different speeds. The approximate frequency ranges of different noise source groups are shown in Figure 2.

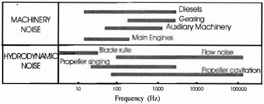

Figure 2. Approximate frequency ranges of noise radiated by ships and submarines.

3. SELF NOISE

Self-noise is the noise or vibration that a vessel produces at its own sonar, thus interfering with and prejudicing the performance of the sonar. As detection requirements become more demanding, the self-noise of the vessel must be reduced to maximize the vessel's own sonar performance.

At very low speeds self-noise is almost entirely due to machinery noise. The background at the sonar is a combination of the self-noise and ambient sea noise, which will vary with sea conditions. The relative proportion of the self-noise increases as the vessel speed increases, becoming dominant at moderate speeds. The turbulence of the vessel wake will be a strong contributor to self-noise on the aft sonar bearings. At speeds above the cavitation inception speed, propeller cavitation noise may be a contributory source, especially on aft sonar bearings and in shallow water. At the same time hydrodynamic turbulent boundary noise (flow noise) due to flow past the hull and sonar dome increases rapidly at higher speeds and tends to become dominant. At speeds above 20 to 25 kts local cavitation, at the sonar dome and hull adjacent to the dome, becomes important. Hull vibration at the natural frequencies of the hull can also be a significant source of self-noise, particularly on submarine flank arrays. The vibration response of the hull to broadband excitation can cause interference on hard mounted sonar arrays.

4. SOURCES OF MACHINERY NOISE

The major machinery sources of radiated noise are diesel engines (propulsion and generation); main bearings; propulsion turbines (steam and gas); turbo generators, forced draft fans; main feed pumps; and motor driven forced lubrication pumps. Other machinery which are lower intensity sources but are still significant are main circulation pumps; extraction pumps; turbo forced lubrication pumps; refrigeration and air conditioning plant; bilge pumps; servo air compressors and high pressure compressors.

Any fluctuation or impulsive force applied to a machinery structure by a working fluid, electrical flux or by motion of the working parts will give rise to noise and vibration. This may be in the form of either airborne noise, or vibration of the machinery mountings and other connection points, structure-borne noise.

The general sources of machinery noise are dynamic unbalance; fluctuating friction forces; journal surfaces not circular and center eccentric; impulsive loading due to impact between components; pressure variations in the working fluid, either periodic or impulsive; disturbances in the fluid flow of lubricating, cooling or working fluids; and rolling bearing noise due to inaccuracies in the races or rolling elements.

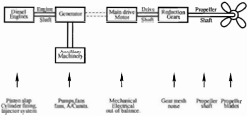

Figure 3. Schematic of machinery components of a diesel-electric propulsion system and associated noise sources (after [1]).

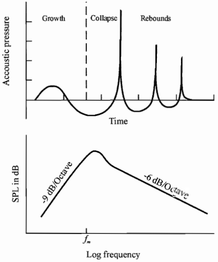

Figure 4. Cavitation bubble generation and collapse (after [2]).

Figure 3 is a schematic of the machinery components of a diesel-electric propulsion system and their associated noise sources. The propeller as a noise source is discussed in the next section.

5. PROPELLER NOISE

There are four main types of noise associated with propellers: cavitation; blade rate; singing and hull vibration.

The onset of propeller cavitation causes a rise in radiated noise levels of about 20 dB in the 80 Hz to 100 kHz band. As the propeller rotates water vapour is generated along the leading edge of the cavity and collapses along the trailing edge of the cavity. Figure 4 illustrates this process for a single cavitation bubble with the resultant idealized spectrum. There are a number of different forms of cavitation: tip vortex cavitation; hub vortex cavitation and face cavitation, either from the suction face or the pressure face. Cavitation is a function of the blade shape, the operating speed and the wake field.

Blade rate tonals and harmonics result from oscillating components of force or propeller thrust variations as the propeller rotates, caused by circumferential variations in the

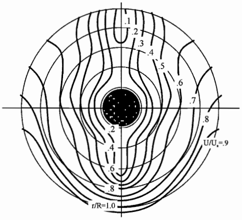

Figure 5. Propeller plane wake velocity contours for a single screw surface ship (after [2]).

wake inflow at the propeller plane. Figure 5 plots contours of equal velocity in the propeller plane of a single propeller merchant ship. The wake inflow speed varies from 10% to 90% of the free stream velocity during the propeller rotation. These velocity differences cause large fluctuations of angle of attack and associated lift forces, which lead to significant fluctuations in thrust and torque during each revolution of the shaft and, in turn, to high level, low frequency hull vibration. The most important design consideration in the uniformity of the wake and the relationship between the harmonic structure of the wake and the number and form of the propeller blades.

A singing propeller results when the vortex shedding frequency matches a blade structural resonance. The vortices are shed in the vicinity of the blade trailing edge, exciting the blade in a twisting mode. The shedding frequency is given by

$$\text{Frequency} = \frac{\text{Strouhal No.} \times \text{flow speed}}{\text{Cross section thickness}}$$

The Strouhal number is the dimensionless frequency, which relates the frequency of vortex shedding to the flow speed and a characteristic dimension, in this case the trailing edge thickness. Typically the Strouhal number is approximately 0.2.

Often the singing can excite the hull, which causes an intense airborne tone within the vessel. Singing is speed dependant, so the tone will only appear in a defined speed range. However, it is possible for there to be a number of tones excited in a number of different speed ranges.

The rotating pressure field exciting the adjacent hull plating causes hull vibration. This is then re-radiated both within the ship structure and into the surrounding water.

Propeller broadband noise is generated by the vibratory response of the propeller blades to turbulence ingestion and trailing edge vortices. In extreme cases this can lead to high levels of radiated noise at a large number of propeller natural frequencies simultaneously. Unlike singing this will occur over a wide speed range, with all frequencies being present at all times, only the relative intensity changes as the speed changes. The broadband excitation can also be transmitted along the shaft and into the hull, causing the hull to respond and radiate noise at its natural frequencies.

6. HYDRODYNAMIC FLOW NOISE

The flow over the complete hull of the vessel and its underwater fittings gives rise to noise, which can be divided into two types; boundary layer turbulence; and large scale irregularities of flow.

For a body moving through a fluid, the region close to the body is known as the boundary layer. It is relatively thin and well defined. It is usually a region of high turbulence; the turbulent eddies causing noise either directly from pressure fluctuations or indirectly through the vibrations excited in the hull plating. The boundary layer over the sonar dome is the most important self-noise source.

Other important noise sources associated with flow around a vessel are: cavitation from items such as sonar domes, shaft brackets, stabilisers etc; and wakes and vortices which are shed from appendages, particularly those whose shape approximates a hydrofoil at incidence to the flow. The associated pressure fluctuations can be detected directly and may also excite panel vibrations.

7. NOISE IN PIPEWORK

The flow of liquid in pipe work can be a significant source of noise. Vibration is transmitted through pipe walls and so care must be taken to isolate pipes and fittings from the main structure. Pressure pulsations are produced by the pumping element of the pump and transmitted through the suction and discharge lines.

Cavitation in pipe systems occurs where a flow restriction increases the flow velocity at the expense of static pressure. If the static pressure falls below the vapour pressure, bubbles form and these later implode in down stream regions with low velocity. Typical sources of cavitation are partially closed valves, orifice plates, rapid changes of direction and low suction pressures.

8. TRANSMISSION PATH EFFECTS

The effects of the transmission along different paths are expressed in terms of transfer functions that relate input at the source location to the output levels at the receiver location. There is usually more than one transmission path for each source; the available paths depend upon the location of the receiver and the type of the noise of interest.

The transmission paths for underwater radiated noise may be divided into three broad categories, dependant upon the medium of transmission; airborne, structureborne and fluidborne. Figure 6 shows the main sound transmission paths for a resiliently mounted diesel engine and figure 7 gives a simplified block diagram of these paths. Paths 1, 4 and 5 may be considered structureborne, path 3 is probably best described as fluidborne, while path 2 is airborne.

Radiated noise from sea-connected pumps can be transmitted via water paths inside the sea-connected pump piping. Also, noise that is generated outside the ship, such as propeller cavitation noise, follows a waterborne noise transmission path from source to receiver.

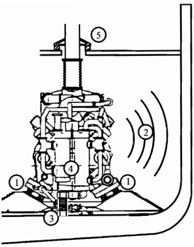

Figure 6. Sound transmission paths for a resiliently mounted diesel engine (after [3]).

For sonar selfnoise, the types of noise transmission paths are similar to those for radiated noise. However, once in the water, the paths for sonar selfnoise lead to the sonar systems and not the far field as for radiated noise. Some sources of selfnoise, such as flow noise at the sonar, do not radiate into the far field. In addition to the three paths above, it is sometimes necessary to consider only structureborne noise that enters the sonar sensors as vibration induced selfnoise.

When dealing with transmission paths it is usually more convenient to divide them up into elements that consist of either transmission within one medium or the transmission of noise from one medium to another. With this approach, transfer functions for transmission in a single medium (eg air, water, ship structure) can be combined with transfer functions that describe the transfer of noise from one medium to another (eg air/hull or hull/water) to construct transfer functions for the transmission of noise from source to receiver.

In Figure 8 some broad outlines for control measures for each path are given.

9. NOISE CONTROL

Noise control procedures may be divided into two categories; reduction of noise at the source and reduction of noise transmission by the different paths. Generally speaking reduction at the source is the preferred solution since it will have the least risk, will cause the least impact on overall vessel design and will normally minimize future maintenance of any noise reduction system. For noise sources that transmit direct to the sea (eg flow noise) this is the only option.

If reduction at the source is not possible or is insufficient to achieve the required results then noise reduction treatments to the transmission path need to be considered. As a broad guide the following measures are most likely to achieve a reduction in radiated noise levels: fitting noise reduction propellers; elimination of propeller singing; design for minimum blade rate noise; resilient mounting of machinery and pipe systems; good seating design; design and manufacture of all machinery for minimum vibration and optimum balance; and attention to hull smoothness and design of underwater fittings.

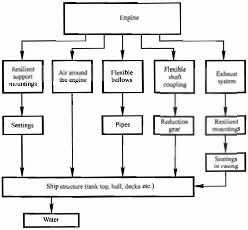

Figure 7. Simplified block diagram of sound transmission paths in Figure 6 (after [3]).

9.1 Noise Path Control Measures

The following factors should be considered in the reduction of structureborne noise transmission:

- Place machinery systems on common, rigid sub-bases or rafts, which are resiliently mounted
- Design machine foundations to maximize the impedance mismatch between the foundation and the resilient mounting
- Avoid cantilever or shelf foundations since moments are readily converted into bending waves
- The impedance of the isolation mounts should be much less than the impedances of both the machinery mounting point and the foundation
- Resilient mounts should be located at nodal points in the machine operational deflection shape.
- There should be no rigid structural paths between mounted machinery and the ship structure
- In two stage or compound resilient mounting systems the weight of the raft should be approximately the same weight as the mounted machinery
- The natural frequencies of the mounted machine in all six degrees of freedom should be well below the lowest frequency of significant excitation (less than half)
- Pipes should be attached with two straight flexible sections separated by a 90-degree elbow.

9.2 Airborne Noise Control

The following factors should be considered in the reduction of airborne noise transmission:

- Fitting of acoustic hoods
- Damping treatment application to machine sections with significant radiated noise

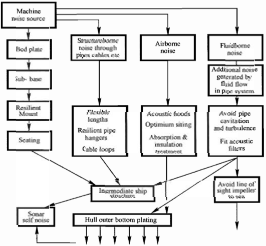

Figure 8. Schematic of transmission path control measures.

- Sound absorption treatment to compartments containing the noise source
- Avoid airborne noise shorts
- Minimise the number of penetrations in bulkheads
- Fit splitter silencers in air intakes or other openings to systems having a high airborne noise level

9.3 Fluidborne Noise Control

The following factors should be considered in the reduction of fluidborne noise transmission

- Fitting acoustic silencers or anechoic termination
- Pipes should be supported on resilient hangers
- Restrict the number of valves to a minimum and design valves to be fully open or closed
- Where orifices are required use cascade or multiple orifices instead of a single orifice plate
- Avoid siting valves in areas of low pressure
- Avoid sudden changes in pipe section
- Avoid ill-fitting gaskets and other projections into the flow
- Use multi-speed pumps to enable reduced load to be matched to reduced flow velocity

9.4 Hull Noise Control

Hull noise is primarily controlled by the initial design stage; however, the quality of hull maintenance can have a significant effect on overall hull noise levels. Aspects of hull noise control include:

- Bow shape – elliptical profiles and waterlines are preferred
- No abrupt change of shape in the vessel waterline
- Uniform flow into propellers
- Minimisation of appendages such as bilge keels, struts, domes etc
- Fairness of hull lines – welds should be ground flush
- Plate distortion should be avoided
- Align fitting with flow
- Hull paint should be as smooth as possible

9.5 Propeller Noise Control

Propeller cavitation, once it begins, will be the dominant noise source, masking other noise sources. All propellers will cavitate if sufficiently loaded. The high load may be due to high installed power, rapid increase in revolutions, crash stops or violent maneuvers. However, proper propeller design will avoid cavitation under normal operation and raise cavitation speed as high as possible. It is important that the propeller remains in good condition, as damage will increase the propensity to cavitate. Important considerations are:

- Optimum loading on each propeller
- Uniform flow into propellers
- Tip shape, and tip unloading
- Adequate clearance between tip and hull, boss and brackets, boss and rudder etc
- Maximizing propeller size for a given thrust
- Selection of blade section and pitch and camber variations to delay the onset of cavitation
- Optimise efficiency versus quietness

Propeller singing usually occurs well below the cavitation inception speed and can persist over a broad range of ship speeds. Singing is usually overcome by putting a sharp trailing edge on the propeller blades.

An alternative is to make the propeller from an alloy with high damping. Unfortunately these alloys have long-term maintenance problems.

It is essential that there is adequate clearance between propeller tips and the hull. Otherwise the strong pressure variations that occur as the blades pass may cause hull vibration. Whilst avoidance of the problem is obviously the most desirable solution, the problem can sometimes be reduced to acceptable levels by damping or isolating the hull plating in this region.

RECOMMENDED FURTHER READING

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