Radiated Noise of Research Vessels

A multidisciplinary Acoustics and Vibration problem

CAV Workshop
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• What makes noise?
  – Propulsion
  – Machinery
  – Hydrodynamic sources, transient sources and transducers

• How can you build and operate a quiet ship?
  – Propulsor and hull design
  – Noise control technologies
  – Operational awareness

• Why care?
  – Environmental Impact
  – Shipboard Habitability
  – ICES
  – Impact on Shipboard Mission Systems (self-noise)

• How to measure it?
  – Acoustic ranges, portable systems
  – Shallow water measurements
Radiated Noise Sources

• Sources
  – Propulsor Noise
  – Motor and Aux Machinery Noise
  – Sea connected systems (pumps)
  – Transient sources
    • incl. active acoustic transponders
  – Hydrodynamic sources

• Paths
  – Direct acoustic propagation
  – Shaft line propagation
  – Sound/structure interaction
  – Diffracted paths
  – Tanks
Figure courtesy of Noise Control Engineering
Machinery Sources

25 MW Alstom Generator

Measurements taken
30 Sept 1998

CORE MAGNETOSTRICTION 2E

SHAFT ROTATING 1R AND 2R

2E - Full load
2E - No load with excitation

Stator Core Radial

Bearing Cap Vertical - 3600 RPM

Frequency, Hz
5 to 15 Knots
Low Speed Limits

2E - Low Speed
1R
2X

Generator Rotational
2X - Rotor Mechanical

25 MW Alstom Generator Measurements taken 30 Sept 1998
Paths for Machinery Noise

- **Airborne**
- **First Structureborne**
- **Secondary Structureborne**
- **U/W Radiated Noise**
Pump generated fluidborne acoustic energy travels via piping systems.
Propeller Noise

- Cavitation typical dominates broadband ship signature

Mitigation:
- Design prop for maximum cavitation inception speed
- Restrict noise-sensitive operations to speeds less than cavitation inception

**Graph:**
- Frequency (Hz)
- SPL
- FRV-40 Goal
- 11 kts with Tip Vortex Cavitation and Suction Side Leading Edge Cavitation Inception at 10.5 knots
- 11 kts Noncavitating (design)
Non-propulsion flow-related noise

Hull and appendage cavitation
- Rudders, Struts
- Fairings, Bilge Keels

Bow wave transients
- Acoustic source
- Bubble sweepdown

Mitigation: good hydrodynamic design
Sonar Self-Noise Sources

- **Hull-mounted sonars**
  - Bow-area flow noise
  - Bow wave transient
  - Flow-induced structural excitation

- **Installation details**
  - window material and attachment mechanism
  - fairings

- **Propagation of external ship sources into sonar**
  - machinery / prop noise via hull grazing path
  - Bottom reflected path

\[ \text{SNR} = \left[ \text{SL} - 2\text{TL} + 20\log H_T H_R + TS \right] - \left\{ \text{NR} + (\text{NL}_0 - \text{DI}_R) \right\} \]
Impact - Environmental Noise

- Studies ongoing to assess impact of anthropogenic noise on marine mammals
  - general shipping noise
  - Local radiated noise
  - Science mission sources

<table>
<thead>
<tr>
<th>Sound Source</th>
<th>SPL dB re 1\mu Pa @1m</th>
<th>Ping Energy (dB re 1\mu Pa^2 s)</th>
<th>Ping Duration</th>
<th>Duty Cycle (%)</th>
<th>Peak Frequency (Hz)</th>
<th>Band Width (Hz)</th>
<th>Directionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underwater Nuclear Device (30 kilo-ton)</td>
<td>328</td>
<td>338</td>
<td>10 s</td>
<td>Intermittent</td>
<td>Low</td>
<td>Broad</td>
<td>Omni</td>
</tr>
<tr>
<td>Ship Shock Trial (10,000 lb TNT)</td>
<td>299</td>
<td>299</td>
<td>1 s</td>
<td>Intermittent</td>
<td>Low</td>
<td>Broad</td>
<td>Omni</td>
</tr>
<tr>
<td>Military Sonar (SURTASS/LFA)</td>
<td>235</td>
<td>243</td>
<td>6 – 100 s</td>
<td>10</td>
<td>250</td>
<td>30</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Research Sonar (ATOCS Source)</td>
<td>195</td>
<td>20 minutes</td>
<td>8</td>
<td>75</td>
<td>37.5</td>
<td>Omni</td>
<td></td>
</tr>
<tr>
<td>Acoustic Harrassment Device</td>
<td>185</td>
<td>185</td>
<td>0.5 - 2 s</td>
<td>50</td>
<td>10,000</td>
<td>600</td>
<td>Omni</td>
</tr>
<tr>
<td>Multibeam (Echosounder Hull-mounted)</td>
<td>235</td>
<td>218</td>
<td>20 ms</td>
<td>0.4</td>
<td>12,000</td>
<td>Narrow</td>
<td>Vertical</td>
</tr>
<tr>
<td>Research Sonar (RAFOS float)</td>
<td>195</td>
<td>120 s</td>
<td>small</td>
<td>250</td>
<td>100</td>
<td>100</td>
<td>Omni</td>
</tr>
<tr>
<td>Fishing Vessel 12 m long (7 knots)</td>
<td>150</td>
<td>CW</td>
<td>100</td>
<td>300</td>
<td>250-1000</td>
<td>Omni</td>
<td></td>
</tr>
</tbody>
</table>

Table from Hildebrand, "Sources of Anthropogenic Sound in the Marine Environment"
ICES Criteria for Fisheries RV’s

- Impact of research vessel noise on fish surveys
  - Based on estimates of “fish hearing” for various species
  - Impact to both acoustic and catch surveys
Radiated noise measurements in a harbor environment using a vertical array of omnidirectional hydrophones

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Overview

• Research Field Test
• Omni-directional measurements
• Beamforming
  – Far-field
    • Theory
    • Measurements
  – Near-field
Research Testing and Objectives

• Acoustic Research Detachment at Lake Pend Oreille in Bayview, Idaho
• Summer 2010 and 2011
• SEAJET
• In conjunction with near-field acoustic holography (NAH) testing
  – Validate NAH estimates
Problems with a shallow water harbor environment

• Multipath Environment
  – Surface reflections
  – Bottom reflections
  – Reflections off other underwater interfaces

• Near-field Environment
  – Proximity from hydrophone to source may prohibit far-field plane wave assumption
Hydrophone Array

14 Element Hydrophone Array
Top-view Geometry

A Few Array Locations (suspended by crane from barge)

Sources (varying depth)
Side-view Geometry

SeaJet

14 Element Array

Range

Reference Hydrophone

ITC 1001

Barge
Omni-directional measurements
Far-field beamforming theory

\[ p(r, \theta, t) = \sum_{i=1}^{N} \frac{A}{r_i'} e^{j(\omega t - kr')} \]

Far field assumptions:

- \( r \gg (N - 1)d \) so all \( r_i \) are approximately parallel
- \( \frac{1}{r_i} \approx \frac{1}{r} \) for all \( i \) where \( r \) is the distance from array center to source
- \( r = r_1 - \frac{1}{2} (N - 1)\Delta r \) where \( \Delta r = d \sin \theta \),
- so \( r_i = r_1 - (i - 1)\Delta r \)

Far-field beamforming theory

\[ p(r, \theta, t, \theta_0) = \frac{A}{r} e^{j(\omega t - kr)} e^{-j\left(\frac{N-1}{2}\right)k\Delta r} \sum_{i=1}^{N} e^{j[\phi_i + (i-1)k\Delta r]} \]

where \( \phi_i = i \frac{2\pi}{\lambda} d \sin \theta \)

multiplying a \( \sum_{i=1}^{N} e^{j\phi_i} \) to the unsteered FFT gives us the beamsteered data in the frequency domain
Calculated broadside beams

Changing the steered frequency affects the main lobe width as well as the number and size of the side lobes.
Calculated steered beams

\[ f = 1860 \text{ Hz}, \text{ steered to 10 degrees} \]

Steering the beam affects the direction in which the main lobe points and also affects the size and direction of the side lobes.
Calculated steered beams

14 Element Array steered in the direction of an oncoming plane wave
Far-field beamforming results

Bearing-time Record of MOo 62° with center frequency 3720 Hz
Far-field beamforming results

Averaged BTR over all times for MOo 62º with center frequency 3720 Hz

Amplitude

Vertical Angle [deg]

X: -53.5
Y: 10.55

X: -0.5
Y: 11.93

X: 68.5
Y: 11.6
Near-field beamforming theory and application

• Measure from geometric center of array
• Remove far-field assumptions and recalculate
• This will negate the plane wave assumption and account for spherical spreading from the source
• Vary ranges to find accurate range
References


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