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Effects of Sea Surface Forward Scattered Signals in Radiated Noise Measurement

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1. Introduction

Radiated from vessels including submarine, is a critical parameter in anti submarine warfare considering the vulnerability to detection by a threat. Radiated noise measurement range is used to identify the radiated noise signature of a vessel since its theoretical prediction is limited due to complexity of vessel's mechanical structure, operating condition and boundary condition[1-8].

The source level of tonal and broad band signature, are obtained by the intensity mean of received signals of hydrophone array[9]. However, rough sea surface adds the complication to the intensity mean estimate in relatively high frequency since the reflection and scattering occurs at the water-air boundary. In this study, how the sea surface forward scattered signals affects in radiated noise measurement is analyzed in frequencies of 1.5, 2.0, 5.0, 10 and 15 kHz.

2. Coherent Reflection Coefficient and Interference Acoustic Field in Rough Sea Surface

Figure 1 shows path difference of rough sea surface to mirror surface. Phase difference $\Delta\emptyset$ due to path difference is given as

$$\Delta\emptyset = k(2ysin\theta) \tag{1}$$

where, α, k, y and θ are boundary local curvature, wave number, instant wave height and grazing angle, respectively. Therefore instant interference acoustic pressure p_{rgh} is given as

$$P_{rgh} = -p_{mirror}\cos(2kysin\theta) \tag{2}$$

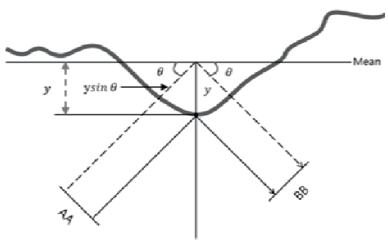

Fig. 1 Path difference of rough surface to mirror surface

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Coherent reflection coefficient R_{coh} is defined as mean value of p_{rgh} to surface wave height probability density,

$$\begin{aligned} R_{coh} &= <\frac{p_{rgh}}{p_{mirror}}> \\ &= -\int_{-\infty}^{\infty} cos(2kysin\theta)\frac{1}{h\sqrt{2\pi}}\exp\left(-\frac{1}{2}(\frac{y}{h})^2\right)dy \\ &= -exp\{-2(khsin\theta)^2)\} \\ &= -exp\left(-2R_{rgh}^2\right) \end{aligned} \tag{3}$$

where k: wave number, h: rms wave height, θ: grazing angle.

As shown in **Fig. 2**, the received sound pressure level L_{pT} is given as

$$\begin{aligned} L_{p_T} &= 20\log(p_T) \\ &= 20\log(|P_M|) - 20\log(R_1) \\ &+10\log\left(1 + (\frac{R_1}{R_2})^2 R_{coh}^2 + 2(\frac{R_1}{R_2})R_{coh}\cos(\omega\tau)\right) \\ &= 20\log(|P_M|) - 20\log(R_1) + \Delta TL \end{aligned} \tag{4}$$

where ΔTL is level difference between spherical spreading and interference field levels and defined transmission loss anomaly. Therefore received sound pressure level depends on R_{coh} and path time difference $\tau = (R_2 - R_1)/c$ for given source to receiver range. However R_{coh} is a function of frequency, wave height and grazing angle.

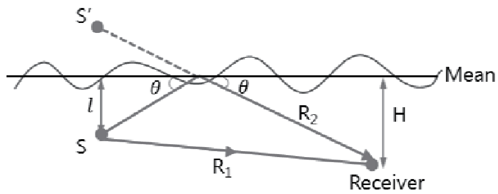

Fig. 2 Interference between direct and rough surface refection paths

3. Results and Discussions.

The estimate error ΔTL in eqn. (4), will depends on the R_{coh}. To examine the effects of R_{coh} to interference acoustic field in rough sea surface, experiment was conducted for two different wind speeds, five different frequencies and two different Tx-Rx horizontal ranges. **Table I** shows $|R_{coh}|$ variations with respect to sea surface grazing angle and frequency at each source depth, transmitter-receiver (Tx-Rx) range and Rx depth for one of four sea trials.

Table. I $|R_{coh}|$ variations with respect to sea surface grazing angle and frequency at each source depth, transmitter-receiver(Tx-Rx) range and Rx depth for Run #1.

	Date	Tx depth(m)	Tx-Rx initial~final range(m)	Grazing angle range of each Rx		$\lvert R_{coh}\rvert$ range of each frequency				
				Rx. Depth(m)	Grazing angle range(°)	1.5 kHz	2 kHz	5 kHz	10 kHz	15 kHz
Run #1	08.18	17	30-266	5	37-5	.32-.97	.13-.95	.00-.74	.00-.30	.00-.06
				15	47-7	.20-.95	.06-.91	.00-.56	.00-.09	.00-.00
				25	55-9	.15-.91	.03-.86	.00-.40	.00-.02	.00-.00
				35	60-11	.13-.88	.02-.80	.00-.02	.00-.00	..00-.00
				45	65-13	.11-.84	.02-.73	.00-.00	.00-.00	.00-.00

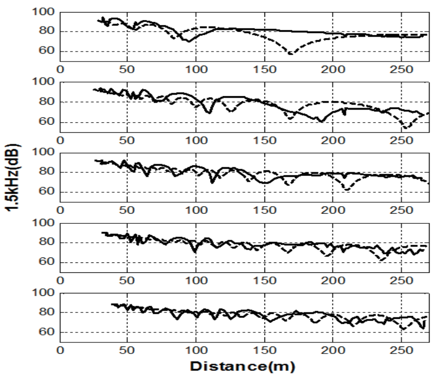

Fig. 3 Interference variation to range(R_1) of 1.5 kHz frequency of Run #1: receiver depth = 5, 15, 25, 35, and 45m; — measurement, - - - theory.

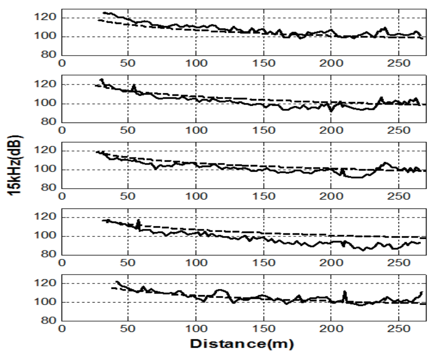

Fig. 4 Interference variation to range(R_1) of 15 kHz frequency of Run #1: receiver depth = 5, 15, 25, 35, and 45m; — measurement, - - - theory.

Figures 3 and 4 show interference field variations of 1.5 kHz and 15 kHz to range R_1, respectively. The lower frequency result of 1.5 kHz shows more distinct interference field than 15 kHz. Interference field is also more distinct in longer range. Experiment results match well theoretical results considering R_{coh} dependency on frequency and grazing angle.

4. Conclusions

In this study, how the sea surface forward scattered signals affects in radiated noise measurement is analyzed in frequencies of 1.5, 2.0, 5.0, 10 and 15 kHz.

In the higher frequency and the shorter range, the coherent reflection coefficient R_{coh} decreases. Therefore effects of surface forward scattering decrease in radiated noise measurement.

Acknowledgment

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