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Noise Measurements on Towed Hydrophone Arrays

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1. Introduction

Hydrophones towed from ships by their electrical cables are used for a variety of purposes in marine science, such as seismic reflection profiling in the band 10Hz to 3kHz, and tracking neutrally buoyant floats, which emit 10kHz pings. They may be used as receiving arrays for low frequency sonar in the future. Single omnidirectional hydrophones may suffice for pinger tracking. For profiling in deep water, arrays up to 100 metres long contain typically 100 receivers, whilst for prospecting work in shallow water as many as 24 arrays, each of the order of 100m long, may be towed as one "string" reaching 3km in total length. The hydrophone arrays are usually small pressure sensors in an oil-filled plastic tube. Towing speeds range from 3 to 12kts and towing depths are usually in the region of 3 to 15 metres.

The sub-bottom penetration of a reflection profiling system is ultimately limited by the noise levels at the hydrophone array output, whichever of the many available sound sources is used. The importance of noise is indicated by the fact that a 20dB reduction in noise level would be equivalent to a 100 fold increase in source energy, or with the same source energy would allow the speed of the ship to be doubled. In order to achieve the full potential benefit of a profiling system use must be made of the natural differences in temporal, spectral and spatial characteristics between the signals and noise, in addition to minimising noises at their sources, where possible. Over the past few years attempts have been made by N. I. O. to measure and isolate noises by spectral and correlation analysis and to compare the performance at sea of different hydrophone designs, including commercial ones loaned by other organisations. Whilst the work reported here was principally directed towards the improvement of seismic reflection profiling records, high frequencies were measured simultaneously and are of some value. Measurements were taken in several ships including R. R. S. "Discovery" and R. R. S. "John Murray", so that some data on the noise fields behind them has been gathered which may have significance for other towed acoustic equipments.

The main known and presumed noise sources include thermal and receiver amplifier noise discussed in standard texts, ambient sea noise reviewed by Wenz (1), ship noises (engines, propellor, auxiliaries, wake), flow noise reviewed by Haddle and Skudrzyk (2), flow-induced vibrations, acceleration forces (longitudinal and transverse) due to an unsteady tow, aeolian tones from the cable, radio and electrical interference and surface wave pressures. Many of these sources vary with the towing speed, some with the geometry, i.e., depth and distance from the ship, some on sensor spacing and some on the array directivity, so that we found it instructive to vary these parameters.

2. Results

Using one-third octave spectrum analysis over the range 20Hz to 40kHz, the noise spectrum level at a point (i.e., one pressure sensor) 85 metres behind the ship was measured at different speeds, Fig. 1. (Note that noise spectrum level is defined as the r.m.s. pressure in a 1Hz bandwidth, and the r.m.s. pressure in a wider band is greater by a factor equal to the square root of the bandwidth). Highest spectrum levels are observed at the lowest frequencies and levels generally fall at 5 to 10dB per octave until receiver noise is reached near 30kHz. Levels generally increase with ship speed except above 8kHz where sea noise is reached. A speed dependent transition between 50Hz and 300Hz is observed which indicates that different mechanisms are effective above and below the transition.

By altering the towing distance it was possible to show that the band from about 50Hz to 3kHz is mainly ship noise. On greasing the hydrophone, to reduce surface roughness and reduce drag, there was a significant reduction in noise level in the band 2 to 8kHz, suggesting that flow noise is dominant there. Between 8 and 20kHz sea-state noise appears to have been achieved and above 20kHz, system noise is reached. The noise spectrum levels below 50Hz are the most difficult to interpret. These measurements based upon third octaves for equal averaging periods inevitably give larger fluctuations at low frequencies; more recent Fourier analysis by computer has shown that there are many spectral lines, at the engine firing rate of 4.5 Hz and its harmonics and at 17Hz and its harmonics, mixed in with a broader band of more random noise, which may be flow noise or due to mechanical vibrations of the towing system. In heavy seas the violent jerking by the ship of the towing point introduces large low frequency surges, which can be partly eliminated by the use of a compliant link (bungee elastic).

Over the high frequency region there is a significant increase in noise level at 8kts compared with 6kts and this may coincide with a transition from lamina to turbulent flow.

By using longer arrays and more sensors, a measure of rejection of ship noise can be achieved, Fig. 2, which also demonstrates high sensitivity to "John Murray's" ship noise at 3, 6 and 9kHz, where the hydrophone spacing was 1, 2 or 3 wavelengths. A considerable proportion of the difference between the noisy stationary hydrophone below the ship and the quieter array towed at 7kts can be attributed to the Lloyd's mirror effect, which is also evident in Fig. 3, for one short array.

The "John Murray" is a very noisy ship. Over the wide frequency range 100Hz to 20kHz there is a 10 to 20dB increase in noise level beneath the ship when the clutch is engaged with the propellor at zero pitch.

Improvements in noise level with multiple sensor arrays can also be achieved at low frequencies, where directionality is poor, if the turbulent pressure fluctuations add incoherently. In Fig. 4, the noise levels of a commercial 150ft. long array with 9 sensors, a 50ft. array with 10 sensors, a 100ft. with 50 sensors and a 200ft. array with 100 sensors are compared with the noise levels of a 25ft. array with 10 sensors at 4kts. Noise rejection improves with array length and reduced sensor spacing.

In order to attempt to find how close the elements could usefully be placed, an array was towed containing hydrophones spaced at distances between 3" and 16ft. and then the noises were cross-correlated in pairs for the band 50-2500Hz. In general, two correlation peaks were observed, one always at zero lag with a coefficient of the order of 0.25, and the other with a correlation coefficient of 0.7 at a lag increasing with spacing at acoustic velocity, as would be expected for ship noise. The zero lag correlation could be due to either ship noise reflected from the sea bed or, less likely, high velocity vibration noise in the towing tube.

3. Conclusions

Further work must be done but a few preliminary conclusions can be drawn: (i) below 1Hz it is calculated that wave noises can predominate, especially in rough weather, (ii) from 1Hz to 50Hz longitudinal vibrations of the towing system and turbulent flow give a broad band base on top of which are sharp spectral lines at engine speeds and harmonics, (iii) from 50Hz to 5kHz ships' machinery and propellor noises are the most important, (iv) from 5kHz to 20kHz ambient sea noise can be reached except at high speeds when flow noise may be significant, (v) above 20kHz amplifier noise sets a limit with the present system, (vi) the boundaries between sources are ill defined and vary with speed, ship, depth of tow and length of hydrophone. (vii) R.F. interference and electrical interference can usually be reduced to negligible levels by the use of low impedance balanced signal leads with a screen which is electrically isolated in the sea from the sea, and "earthed" in the laboratory. (viii) Aeolian tones do not seem to be a problem with very shallow cable entry angles.

The preferred array would (a) be towed as far astern as possible, (b) be at least 100ft. long, (c) use acceleration-balanced sensors, (d) use sensor spacing of the order of 1m, (e) aim for neutral buoyancy throughout to minimise turbulence, (f) use a compliant accumulator in the towing system to reduce surging and transient low frequency noises, (g) continue the array tube at least thirty diameters beyond the last sensor and (h) have a low noise pre-amplifier to assist in achieving (vii) above.

As one either reduces the most dominant noise in a band at its source or else reduces its effect at the array terminals by other means, then another source of noise becomes significant in that band and a different approach is required. Present designs allow profiling with air-gun sound sources in the band 20Hz-300Hz at speeds of 10 kts., up to sea state 6 or 7.

4. References

1. G.M. Wenz, (1962) J.A.S.A. 34 (12) pp1936-1956.

2. G.P. Haddle and E.J. Skudrzyk, (1969), J.A.S.A. 46 (1) pp130-157.

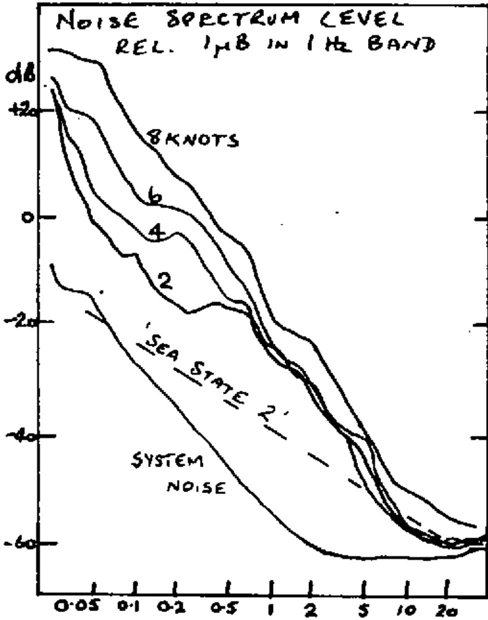

FIG. 1

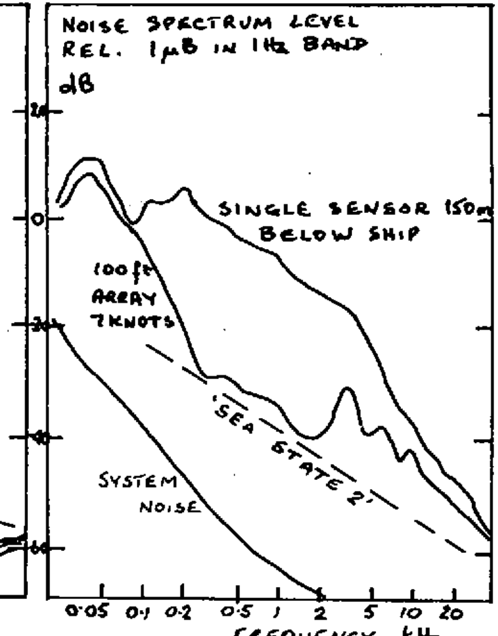

FIG. 2

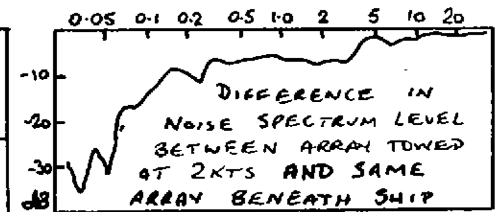

FIG. 3

DIFFERENCES REL. TO 25' (10)

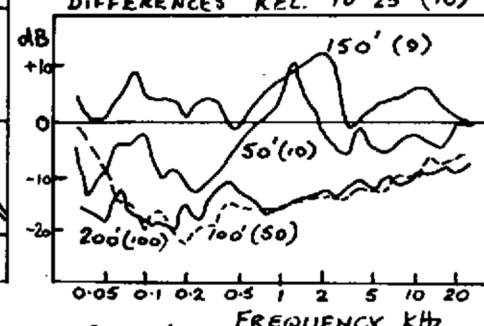

FIG. 4