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SHIP NOISE RELATED TO FISHERIES RESEARCH

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INTRODUCTION

Marine scientists need acoustically-quiet vessels for the same reason that astronomers need to site telescopes on mountain tops, that is, to prevent the information which they require from being obscured by other sources of the energy that they wish to measure.

The acoustic characteristics of vessels fall into two categories - internal noise and underwater-radiated noise. Internal noise is a major influence on the health and efficiency of personnel; underwater noise determines the effectiveness of acoustic sensors used for scientific purposes. Experimental acoustic investigations covering a wide frequency spectrum are most sensitive to ship noise, closely followed by acoustic surveys of fish abundance. Neither in its role of captor, nor of surveyor, should the vessel radiate a noise spectrum which will scare fish in its path. If it does, the quality of sampling will be affected indeterminately.

This paper examines the frequency spectrum, bandwidth and levels of noise from research vessels, particularly in relation to acoustic surveys.

POWER AND NOISE

Modern methods of fishing and the conduct of fisheries research both require powerful vessels. The prime source of power is invariably derived from diesel engines which produce vibration that is transmitted to the surface of the machines, then radiated in the form of airborne waves within the vessel. The airborne noise ranges in frequency from a few Hertz to several kiloHertz and research has quantified many of its effects on humans, so that legislation now controls and limits the levels. Vibration is also conducted to the vessel's hull, which is a potential underwater radiating surface. For a main engine delivering 1000 hp the equivalent electrical power is approximately 0.75 MW. Under normal weather conditions an acoustic power of 0.75 mW at 1 kHz (10^{-9} of the engine power) can be detected underwater at a distance of 1 km. It, therefore, takes only a tiny fraction of the engine's power, dissipated as vibration to produce large underwater signals.

Underwater noise can be measured against the speed of the vessel and related to instrument performance but evidence is still being collected on the effects of noise on fish[1].

DEFINITION OF NOISE

A simple definition of noise states that it is the cause of any unwanted output from a system regardless of the source. Therefore, any system user can define noise in a manner which distinguishes the signal that he requires from any other signals at the output of his system. Thus it is often the case that one man's signal is noise to another.

The noise spectrum level at any frequency is defined as the mean-squared pressure in a band 1 Hz wide, centred on the frequency. The concept of noise energy present in a 1 Hz bandwidth (the spectrum pressure level (SPL)) is used because noise is wideband (i.e. it extends over all frequencies, but the energy levels vary greatly with frequency according to the machinery, or the mechanisms of noise production and propagation). An illustration of the SPL noise signature over part of the low-frequency spectrum for a fisheries research vessel appears in Figure 1.

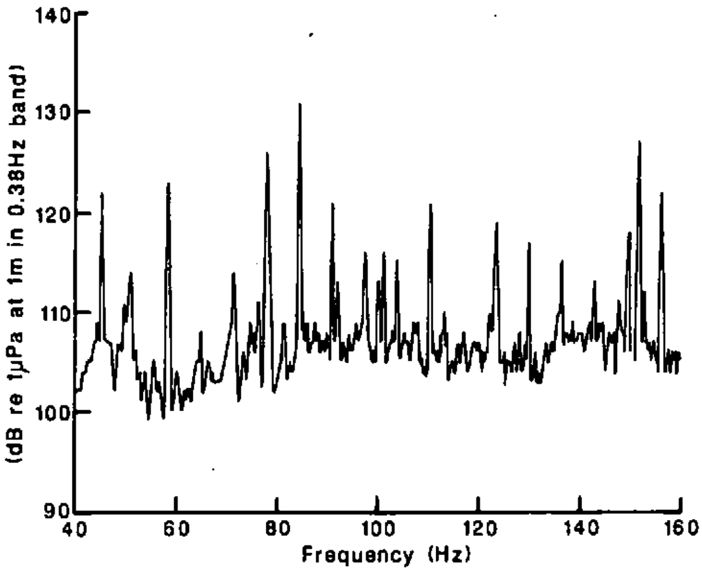

Figure 1 Narrow band levels. (Reproduced from Ministry of Defence unpublished data.)

FREQUENCY SPECTRUM

The full fisheries acoustics frequency spectrum is shown in Figure 2. This is much wider than hitherto because of the extension to 10 MHz which is necessary to sample plankton, but very little noise energy is radiated from vessels at frequencies above 100 kHz. Figure 1 makes it evident that a clear overall picture of a vessel's noise signature cannot be gained from narrow-band spectrum graphs. Instead, the complete noise signature from 10 Hz to 100 kHz is shown as a third-octave band analysis (i.e. the energy is averaged over 1/3 of each doubling of frequency).

Simplified noise curves from 1/3 octave band analyses of several vessels are shown in Figure 3. It is possible to convert to and from 1/3 octave to 1 Hz levels by using Figure 4 (e.g. to convert to 1 Hz level from 1/3 octave subtract the number of dB's at the given frequency); even though this procedure is not strictly correct it serves most practical purposes.

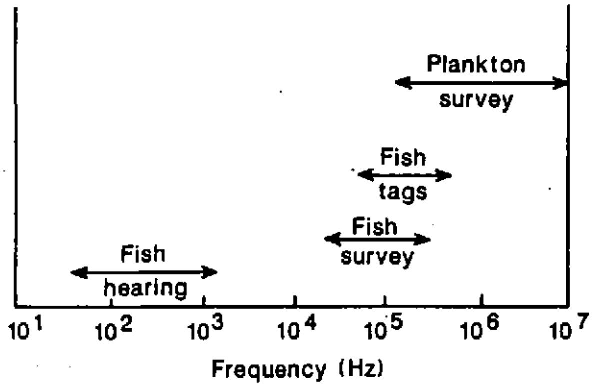

Figure 2 The full fisheries frequency spectrum.

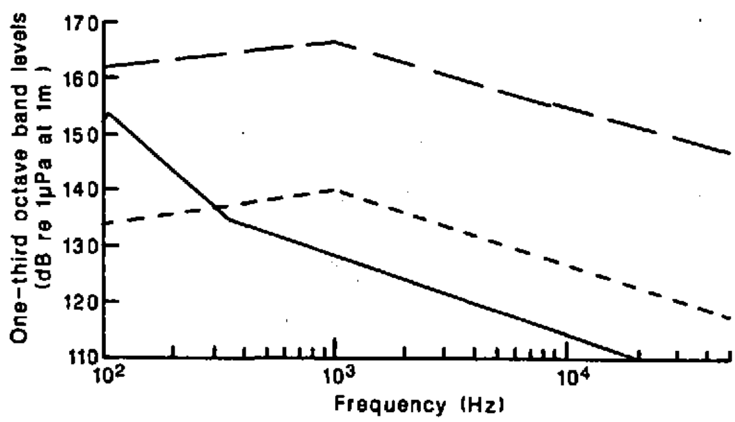

Figure 3 Noise levels at 11 knots.

At low frequencies, the engines and machinery tend to be the main sources of noise but between 1 kHz and 100 kHz the noise levels at higher speeds are usually dominated by propeller cavitation, although fluid flow and turbulence from the hull also contribute.

DEFINING ACCEPTABLE NOISE LIMITS

Acoustic systems

The fact that vessels must conform to an internal noise level standard means that vibration and noise reduction measures are part of the design brief but present legislative levels tend to be lax. There is no standard method for specifying acceptable levels of underwater noise in fishery research vessels.

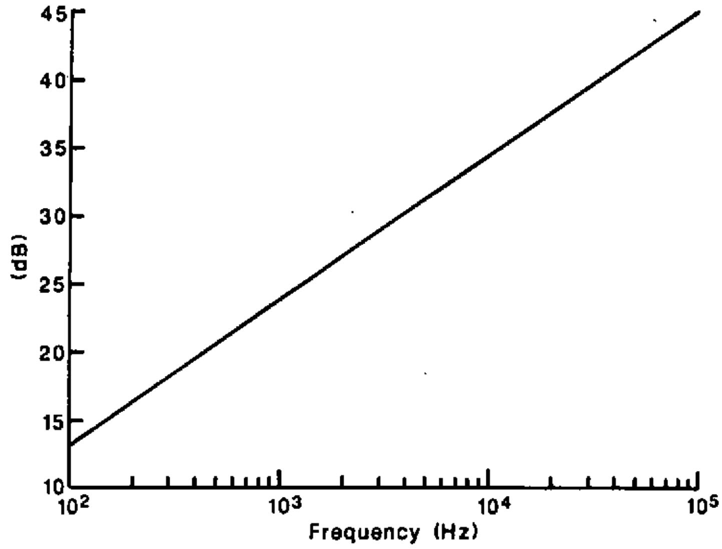

Figure 4 The conversion between 1/3 octave band and 1 Hz level.

An obvious criterion is that the most sensitive acoustic system should be able to perform its function efficiently when the vessel is running at the required speed. This is usually the fastest speed possible for the prevailing weather conditions to ensure maximum area coverage if an echo survey is underway.

Signals from the survey echo-sounder are amplified and the derived data are used to make quantitative estimates of fish stocks. It is, therefore, important to minimise the possibility of signals being contaminated by noise, so the signal-to-noise ratio (SNR) should be at least 20 dB above the dominant noise level. The ultimate lower limit is sea-state noise levels at just tolerable working conditions for the ship. This is likely to be at a maximum sea-state due to Beaufort wind force 6-7 where the system must be able to function with an acceptable SNR. Figure 5 shows the frequency/noise level curves extrapolated from Wenz[2] for sea-states 5 and 8 in coastal waters. From this information it is possible to draw the minimum level at which to aim and the maximum acceptable limits for the high-frequency (1-100 kHz) noise from the vessel. An example of such limits is drawn on Figure 5, using the above criteria.

The ship's high-frequency noise level must be assessed relative to the widest bandwidth of the most sensitive acoustic system. Echo-sounders usually have bandwidths pre-set to the survey requirement of maximum depth resolution (short pulse, wide bandwidth) or minimum noise level (long pulse, narrow bandwidth). The noise present in an echo-sounder will be the sum of the energy in all of the 1 Hz bands across the operating bandwidth. When the noise figures at the echo-sounder frequency relate to the 1 Hz (SPL) level, they must be converted to the band-level for the bandwidth in use. The conversion from spectrum level to band-level (BL) is:

$$BL = SPL + 10 \log BW \text{ in dB/1 } \mu Pa,$$

where BW = bandwidth.

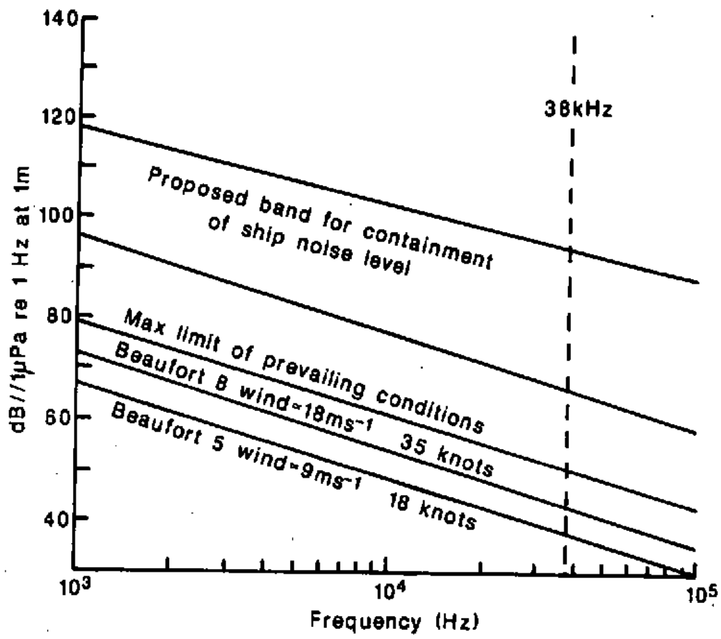

Figure 5 Proposed band for containment of ship noise level in relation to sea-state noise.

Example: from the 1/3 octave noise signature graph of the ship pick off the noise level at the echo-sounder frequency. Assuming that it is 128 dB//1 μPa/1 m at 38 kHz, convert this to SPL by subtracting 41 dB (128-41 = 87 dB). For an echo-sounder bandwidth of 2 kHz, 10 log BW = 33 dB, which must be added to give the band-level of noise (87 + 33 = 120 dB/1 μPa).

The voltage output from the transducer (VRT) would then be VRT = BL + SRT where SRT is the receiving sensitivity of the transducer, usually in the range -175 to -215 dB//1 V/1 μPa/1 m. Taking -187 dB//1 V/1 μPa/1 m as a typical figure:

$$VRT = 120 + (-187) = -67 \text{ dB//1 V} = 450\ \mu V$$

(about 100 times, or 20 dB, greater than would normally be acceptable).

However, this has assumed that the noise source and the reference distance on the <u>axis</u> of the transducer coincide, whereas in practice this would not be so. It could be argued that the noise at 38 kHz is predominantly due to the propeller, so, if a hull-mounted transducer were being used, it might be at a range of, say, 30 m. Unless spherical spreading is assumed, the noise level reduction due to the distance between the propeller and the transducer cannot easily be calculated. Despite the proximity of the hull, such an assumption often gives a good approximation in practical situations. Distance correction = 20 log 30 = 29.5 dB. But the transducer response at approximately 90° to the beam axis would be significantly lower (for the purpose of this example assume -30 dB re -187 dB), then -29.5 +(-30) = 59.5 dB. VRT = -67-59.5 = -126.5 dB, or 0.47 μV (a very significant decrease).

The simple example above has not taken into account any effect due to the proximity of the sea bed.

Fish scaring
Many observations have been made on the effects of ships approaching fish schools but it is difficult to quantify the relative significance of frequency and magnitude of the noise field. Olsen *et al.*[3] produced a preliminary model relating fish behaviour to approaching vessels but specific noise features were not included.

Bercy and Bordeau[1] have produced some convincing evidence of the effects of underwater noise, radiated by tuna fishing vessels, on fish behaviour. They make a plea for more consideration to be given to the reduction of noise levels in such vessels. Their work shows that where major peaks exist in the low-frequency noise spectrum of fishing vessels, catches are much lower than from vessels where the spectrum is relatively smooth. It is not clear how relevant these findings would be to other fish species but some can detect the direction and distance to a sound source[4]. The cod, for example, has high sensitivity to pure tones in the frequency range 30 Hz to 470 Hz. A new source of low-frequency tones has recently come to light during the respective noise rangings of the NATO vessel ALLIANCE and MAFF's RV CORYSTES. This is due to modern ship propulsion systems taking advantage of solid-state control devices which now rectify high-power alternating currents (AC) to allow good speed control of direct current (DC) propulsion motors. But the rectification is not complete and there is a current ripple at a frequency determined by the device configuration (e.g. for a 60 Hz AC supply with a 6-pulse rectifier the ripple will occur at 360 Hz). This results in vibration and structure-borne noise at the ripple frequency, which is in turn radiated as underwater noise due to the motors being solidly mounted. In the case of RV CORYSTES, with a 50 Hz system, the 300 Hz tone was 30 dB above the average low-frequency noise and there were prominent harmonics at 600, 900 and 1200 Hz before a full remedy was applied.

DISCUSSION

The underwater noise characteristics of ships varies greatly, partly because of the different power and configuration of the machinery but particularly at the higher frequencies because of propeller cavitation. The effect of the latter is probably most easily defined in relation to the speed at which acoustic surveys can be accomplished. Propeller design does not appear to be a complete science because of scale effects in tank testing and various conflicting criteria such as speed, bollard pull and power absorption so there is an element of chance in what is achieved by way of noise performance, especially the type of cavitation which may result and the speed of its inception.

It is possible to model the low-frequency generation, transmission and subsequent radiation of noise into the sea. If instruments are to be used at these frequencies it is possible to determine how the radiated noise levels will affect their operation.

An attempt has been made in this paper to suggest a basis for a high-frequency noise specification to be applied to fisheries research vessels. At low-frequencies, attention is drawn to a potential problem due to new propulsion systems. This is relevant to the findings of Bercy and Bordeau but in most situations there is, as yet, no means of telling how fish may react to pure tones emanating from continuous or intermittent noise transmission, nor to levels of wideband noise.

ACKNOWLEDGEMENTS

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