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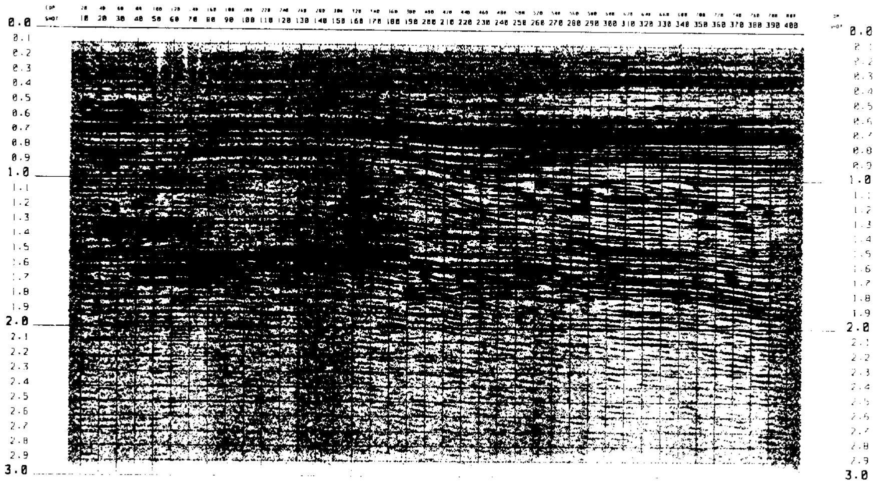

FIG. 3. Stack section of data acquired with 400-channel sign-bit recording system.

sweeps techniques (Varisweep and higher-swept bandwidth). The sign-bit section has superior shallower data due to no gapping in the receiver line and closer channel spacing.

In conclusion, we compared conventional and sign-bit recording systems by acquiring data with identical recording parameters and with parameters optimized for each system, then compared the resulting identically processed stack sections. The sections acquired using identical parameters indicates for Vibroseis data the results achieved are equivalent. Optimizing parameters for each system shows the 400-channel sign-bit instrument gives better temporal and spatial resolution.

Reference

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Acoustic and Mechanical Design Considerations for Digital Streamers POS 2.16

L. Peardon, Britoil PLC, Scotland; and N. Cameron, STC Ltd., England

In the quest for enhanced seismic resolution it is important that acquisition keeps abreast of processing. If the bandwidth is not present in the recorded field data then no amount of conventional processing can retrieve the missing information. It is true that certain data inversion techniques can achieve resolution beyond the bandwidth of the recorded data but these rely on additional information such as well log data. Even these techniques can benefit from improvements in the quality of recorded data. To this end, both source and receiver technology must be improved. In this paper we address the latter problem.

Three basic criteria for enhanced resolution at the recording stage are short group length, small group interval, and low noise thresholds. Short group lengths are required to preserve the all-important high frequencies. A small group interval is necessary to avoid spatial aliasing of low-velocity coherent noise and refractions which would otherwise contaminate the signal high-frequency components. High-velocity and incoherent noise must be kept to a minimum in order to maintain a reasonable signal-to-noise ratio at the higher frequencies. The requirement for a small group interval leads to increased channel density, i.e., more channels per unit length. For example, to maintain a group interval of 6.25 m in a 3 km streamer requires 500 channels. The inherent limitations of analog streamers led to the advent of digital streamers employing telemetry communications with the shipboard recorder. The ultimate objective of these systems is to record alias-free data with good high-frequency content. This would prove fruitless if the benefits were destroyed because of high noise levels due to poor design.

In this paper we consider the various noise mechanisms that affect a digital streamer and discuss ways in which noise suppression may be incorporated either in the design of the streamer or in processing data acquired. This is illustrated with data acquired from a digital streamer during sea trials.

Introduction

The trend for seismic streamers is toward increased channel capacity. This led to the advent of digital streamers because of the inability of analog systems to handle very many channels. It is important that the benefits of increased sampling are not offset by a degradation in performance due to high noise levels. Moreover, streamer noise sets the ultimate limit for resolution and, therefore, good streamer design is essential. The purpose of this paper is two-fold: It presents a detailed analysis of the types of noise we expect to see and, in particular, the mechanisms by which these noise trains are originated and transmitted in the streamer. Secondly, using this analysis we propose guidelines for good streamer design. We take cognizance of the fact that some excellent papers have been written on streamer noise (see references) but they are with respect to analog systems while this paper is biased to digital streamers. Although many features are common to both, a major factor is the fine spatial sampling afforded by digital streamers which allows more detailed analysis of certain noise trains that are not evident otherwise. Acoustic data acquired during recent sea trials of a digital system are used to corroborate the theoretical principles.

Noise sources

Following Bedenbender et al. (1970), the major noise components that occur in a marine seismic streamer may be categorized as follows.

Ambient. This consists of all natural sources of noise such as wind, wave action, biological interaction, and noise caused by

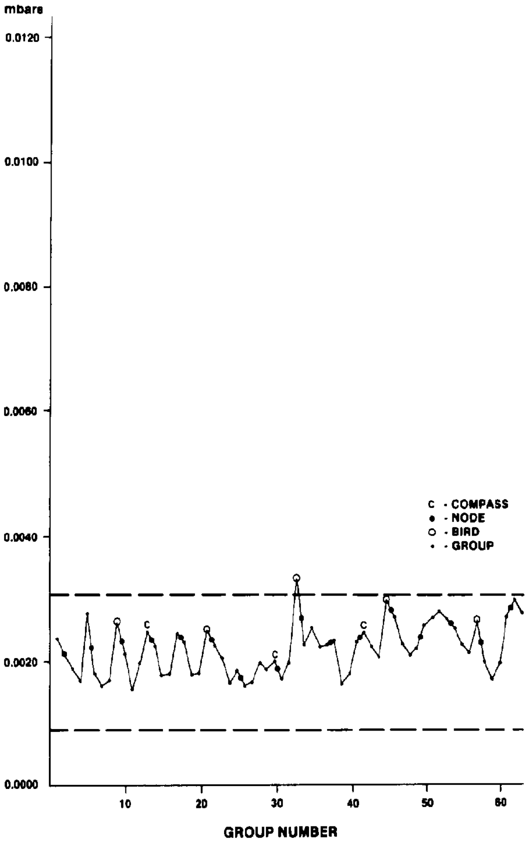


FIG. 1. Rms flow noise.

proximity to shore lines. This noise is extremely variable and dependent upon conditions prevailing at the time. It was investigated thoroughly by Wenz (1962), who gives upper and lower bounds which are heavily dependent on sea state. Swell noise can be particularly troublesome, causing bursts of high-amplitude noise on shot data.

Radiated. This is due to propellers and engines of the survey vessel and nearby rigs, platforms, and other sea-going traffic. It can be a major problem in determining true flow noise characteristics. Propagation of this noise can be via direct arrival through the sea; reflection from the sea floor and sea surface and seabed anomalies; refraction from the subsurface.

Mechanical. Tugging from the ship and tail buoy causes vibrations which are transmitted down the streamer through various paths (e.g., strain members, skin, etc.). This is a major component in the acoustic noise levels of a streamer.

Flow. This is caused by the stream of water over the skin which produces a turbulent boundary layer as the streamer passes through the sea. Pressure fluctuations in this layer cause noise to be induced in the streamer. Excitation caused by protuberances such as nodes and birds (Schoenberger and Mifsud, 1974) gives rise to particularly high noise levels. This is evident in Figure 1 which shows rms values of recorded noise along a streamer. The correlation between the peaks and the locations of birds and nodes is obvious.

Electronic. This includes all the electrical system noise in the streamer, e.g., A to D convertors, analog filters, and the telemetry system. This noise is relatively easily controlled by careful design of electronic components and on modern systems should not provide a major contribution to the overall noise level.

Figure 2 is a diagram of an F-K plot containing some of these noise trains as measured on a digital streamer. Of special interest is the ship noise at 1 650 m/s due to refractions through the sea bottom. A possible explanation for the ship backscattered noise is that this refracted wave was reflected from a fault (Larner et al., 1981). Also of importance is the bulge wave energy which is associated with blocking mechanisms within the streamer. It is of very high amplitude but is low frequency and low velocity and, consequently, readily removed in processing. We may further classify these noise components into external noise sources consisting of the radiated and ambient noise fields and "self" noise consisting of electronic, mechanical, and flow noise.

Radiated noise and coherent ambient noise may be attacked by data processing either in real time or subsequent to acquisition. If the data rate exceeds the recording bandwidth it makes sense to decimate in an "intelligent" manner by employing on-line beam forming techniques. Otherwise such techniques may be used off-line. Furthermore, we found that the superior spatial sampling afforded by digital streamers allows for very effective F-K filtering. Streamer self-noise, on the other hand, can only be effectively combatted by proper streamer design. This entails a thorough understanding of the mechanisms by which these noise components originate and are transmitted throughout the streamer.

Streamer self-noise

Streamer self-noise is initiated by two main exciting forces, namely axial vibrations and pressure fluctuations in the turbulent boundary layer. The axial vibrations are transmitted within the streamer by the strain members and are set up by (a) Input vibrations consisting of vibrations transmitted from the towing vessel along the tow cable, vibrations caused by tow cable strumming, and vibrations along the tail rope caused by tail buoy tugging. (b) Residual vibrations consisting of vibrations caused by out of balance forces on the streamer itself. The noise caused by axial vibration is difficult to quantify because it is dependent upon so many variables but in general it is biased to low frequencies

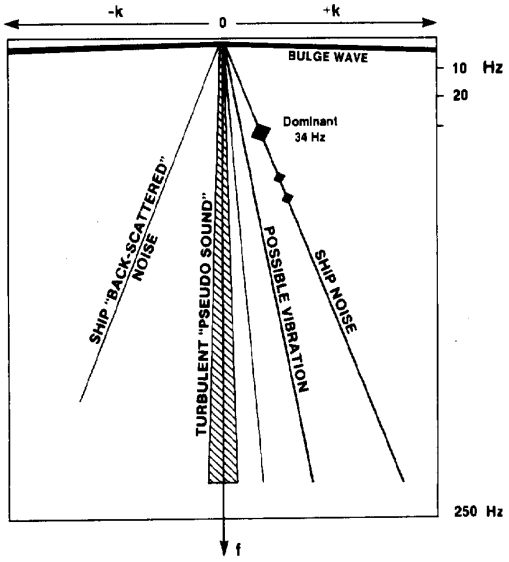
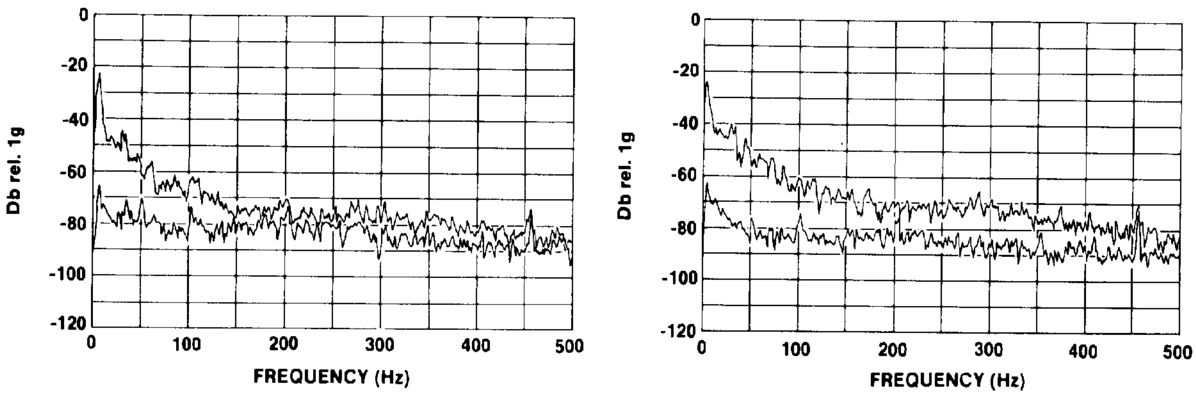


FIG. 2. Schematic F-K spectrum of streamer noise.



3 Knots

4.5 Knots

FIG. 3. Isolator tests. Spectra show input vibration to Isolator (upper curve) and residual vibration (lower curve).

where it dominates the turbulent boundary noise at normal towing speeds. The turbulent boundary layer is set up at the streamer wall as kinematic forces transcend the viscous forces of the sea. This causes noise that is spectrally white and is nonpropagating. For this reason it is often referred to as ''pseudosound''.

The exciting forces create noise in the streamer through various transfer modes, the main ones being scattering of axial vibrations by connectors and spacers, signal induction by vibration of hydrophones, collimated scattering of the turbulent boundary layer at connectors and internal components, convective transfer of the turbulent boundary layer pressure, and acoustic transmissions from the turbulent boundary layer. The scattering modes create internal pressure fields which set up waves upon which the tube acts as a restoring force. These are hose extensional waves and breathing waves.

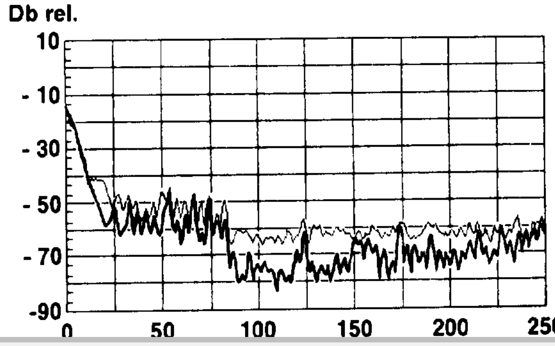
Streamer design

The basic philosophy for the design of an acoustically quiet streamer must be to minimize the exciting forces and reduce the transfer modes as far as possible. Furthermore, noise fields must be attenuated as quickly as possible once they have been initiated. Input vibrations can be reduced by tuning and isolating shipboard machinery and by the use of ''soft tows'' and fairings. However, it is essential also to reduce the input vibration by properly designed vibration isolator sections (Bedenbender et al., 1970). These can be designed to dissipate vibrational energy over a particular frequency range in order to match the input frequency. Figure 3 demonstrates the effectiveness of well designed isolators. The input vibration measured at the head of the isolator (upper curve) was reduced at output (lower curve) by some 20 dB out to 75 Hz at 3 knots towing speed (Figure 3a); this effect is enhanced at higher speeds as shown in Figure 3b for a speed of 4.5 knots.

Residual vibration can be reduced via tight manufacturing tolerances on weight and volume in order to lighten ballasting requirements on the streamer. The outer profile of the streamer should be smooth with no radial obtrusions which could cause fluctuations in the fluid flow. This is a problem in digital streamers where the electronic nodes are of larger diameter than the results of an experiment carried out in sea trials where the flow noise caused by two different diameter nodes was measured. The lower curve is obtained using a node 100 mm in diameter while the higher curve is from a node 115 mm in diameter. At frequencies below 80 Hz, ship-radiated noise dominates both experiments. However, at higher frequencies the streamer flow noise is in evidence. The restriction to 100 mm is obviously desirable giving an improvement of some 50 dB.

Once excitation vibrations have been reduced as far as possible, it is necessary to suppress the noise transfer modes. For example, to reduce direct transmissions from the turbulent boundary layer it is important to distance the hydrophones from the skin as far as possible, i.e., maximize the streamer diameter within winching constraints. Stiff skins also reduce these transmissions but this has direct implications on the noise fields within the streamer. Collimated scattering can be reduced by optimal design and matching of materials within the streamer. Scattering will occur where there is any physical discontinuity within the streamer and is most pronounced near the skin where internal pressure is strongest. Therefore, it is important to centralize internal components and make them low profile and leave as much of the inner volume open to fluid movement as possible. This entails the use of specially designed spacers and hydrophone mounts.

Once a noise field has been set up within the streamer it must be attenuated or rejected as quickly as possible. Breathing and



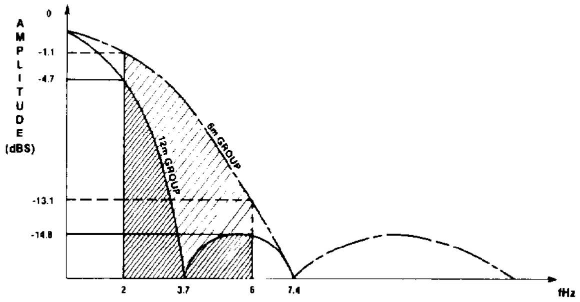


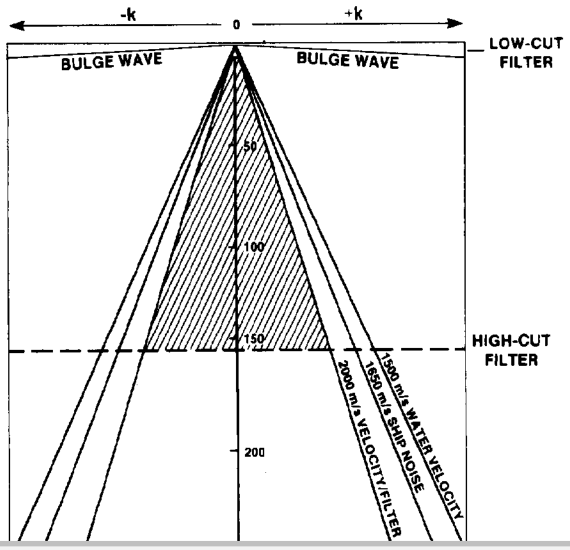
FIG. 5. Group responses for bulge wave noise (45 m/s).

hose extensional waves use the tube as a propagating medium, so by choosing a tube with a thin wall and low dynamic Young's modulus these waves will be attenuated quickly. However, this has direct implications on the amount of noise transfer to the system and so a trade-off must be sought.

Hydrophone group design can be employed to attenuate coherent noise with specific frequency and velocity characteristics. In Figure 5 we see group responses to a bulge wave traveling down the streamer at 45 m/s. It can be seen that the 12 m group offers greater attenuation than the 6 m group throughout the band 2-6 Hz which is the frequency band dominated by bulge wave noise. In fact, the 12 m group achieves infinite attenuation near the center of the band at 3.7 Hz. However, short groups enhance the high-frequency response and allow greater flexibility for array design. It is also worth noting that low-velocity coherent noise may be easily removed in processing without undue effect on the seismic data. Therefore, short groups are recommended bearing in mind dynamic range considerations and recording constraints.

F-K analysis

The fine spatial sampling afforded by digital streamers (typically 6.25 m) renders it possible to analyze noise trains more effectively. This allows greater exactitude in removing noise by F-K filtering. Futhermore, since spatial aliasing is dramatically reduced there will be less corruption of signal. Referring to the example illustrated in Figure 2, refracted ship-radiated noise and bulge-wave noise plus all water-borne noise are easily removed using the simple velocity filter shown in Figure 6. The application of such F-K filters allows rms noise estimates to be made within the useful seismic bandwidth. This has strong implications for seismic survey specifications since even very high-amplitude noise may not be detrimental to the final processed seismic data. Finally, the shot-generated side-scattered noise described by Larner et al. (1981) can also be effectively removed with such filters.



Conclusions

In conclusion, with the advent of high fidelity recording systems it becomes increasingly important to gain a thorough understanding of noise mechanisms and transmission modes. This understanding not only leads to good design principles but also enables the efficient use of processing for noise suppression. The latter should lead to a relaxation in acquisition constraints thereby reducing survey downtime.

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Processing of Wide-Angle Vibroseis Data

F. Wenzel, Geophysical Institute, University of Karlsruhe, West Germany

In 1984 seismic wide-angle Vibroseis® experiments across the Rhinegraben, eastern France/southwest Germany were carried out as a joint French/German venture. At the eastern flank of the graben in the Black Forest, signals generated by French vibrators were recorded with a 200-channel array spread along 16 km. Offsets ranged between 66 and 82 km. Data are characterized by low signal-to-noise ratio and distortions of seismic phases caused by strong topography. For wide-angle records conventional static corrections based on the assumption of vertical travel paths are no longer appropriate. Ray parameter-dependent time delays have to be used in order to eliminate topographic and near-surface influences on the data correctly. In addition the poor S/N ratio has to be improved in order to delineate reflecting elements.

A two-dimensional filter based on forward and inverse slant stacking was designed to handle both problems simultaneously. Stacking along a suite of ray parameters allows the incorporation of static corrections which depend on the angle of emergence of the seismic arrivals. The application of semblance as coherency measure emphasizes spatially correlatable phases. Both measures result in a significant improvement of the S/N ratio.

Data acquisition and characteristics

In fall 1984 two wide-angle Vibroseis experiments across the Rhinegraben were carried out by the French ECORS and the German DEKORP group (Damotte et al., 1985). The measurements