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NOISE GENERATED BY MOVING SEDIMENTS

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Introduction

For some time it has been noticed by users of various high frequency sonar systems[1] that bands of noise have occurred on their records and that these have coincided with the peaks of sand waves. This is where sand particles are most active and so seemed likely to be the source of the observed noise. With this observation and the need for a convenient instrument to help in the study of the process of sediment transport it was thought worthwhile to carry out an investigation into the possibility of using this noise as a basis for such an instrument. It was thought that the frequency band of the noise might vary with particle size, with frequencies ranging up to a few hundreds of KHz and so the instrument takes the form of a spectrum analyser to resolve the signals from an electrostrictive hydrophone sensor.

Description of instrument

The hydrophone used has a resonant frequency of 1.3MHz thus giving a flat response up to about 500KHz with a sensitivity of -130db re 1 volt per μb. This sensitivity is lower than would have been liked but that is the penalty paid for a high frequency response. The signal from the hydrophone is fed into a pre-amplifier with a balanced output, capable of driving a long cable, and then transformer coupled into the analyser. The first stage in the analyser is an amplifier/attenuator, the output from which passes into a high pass filter with a switchable low cut off of 100Hz, 1KHz, 10KHz and 50KHz to prevent the modulator from being overloaded by low frequency noise. The basis of the modulator was a μA796 double-balanced modulator integrated circuit and a voltage controlled oscillator whose frequency was swept, in various ranges, from 1KHz to 400KHz. Signals from the modulator then pass through a low pass filter with a switchable high pass cut off of 500Hz, 1.5KHz, 3KHz and 10KHz thus giving effective swept bandwidths of twice these frequencies. Following this are amplifier, detector and smoothing circuits, enabling the final output to be interfaced with any suitable recording instrument. Normally an XY recorder is used, with the X synchronised to the V.C.O. control voltage thus producing a frequency scale along the X axis and amplitude along the Y axis.

Experiments

Initial experiments carried out by laying a sediment bed in a flume were not very successful mainly due to excessive bubble noise. As a result a a 1m diameter wooden drum open at one end was constructed and mounted by its closed end on to an axle held in a frame so that the assembly could be lowered into a large tank of water. The drum could then be rotated with an electric motor via a variable gear box and rubber belt drive at any speed from 0 to 60rpm. In this way sediment could be placed in the drum and excited by rotation while the open end of the drum allowed the hydrophone to be inserted near to the moving sediment. Rotation of the drum with no sediment in showed the system to be acoustically quiet although constant problems were encountered with electrical pick-up. However, although it was difficult to eliminate it was easily identifiable.

The first experiments were carried out using graded solid glass spheres as a convenient and more uniform substitute for sand. The sizes used were nominally 1mm, 2mm, 3mm, 5mm and 6mm diameters ±20%. Later experiments were carried out using coarse sand and shingle which were graded to within the limits 1mm to 1.7mm, 2.8mm to 3.5mm, 4mm to 4.75mm, 5.6mm to 6.7mm and 8mm to 9.5mm. Each sample used weighed 2kgms and the drum, for the large part, was rotated at 1 revolution every 3 seconds.

Figure 1 shows some typical results from the experiments. In this example the analyser frequency was swept from 1KHz to 300KHz in 15 seconds (only 1KHz to 150KHz is shown) with a filter bandwidth of 3KHz. The high output at low frequency is partly due to leakage of the modulation frequency. The shapes of these curves were somewhat variable from sweep to sweep, sometimes the peak was less obvious than others but it was always in the same place. Also, there was a slight shift to a higher frequency if the drum speed was increased and an opposite effect on slowing down. Table 1 shows a summary of the results obtained.

Diameter mm	Glass (G) Shingle (S)	Frequency KHz
1	G	110
1.35	S	110
2	G	80
3	G	60
3.15	S	58
4.35	S	50
5	G	40
6	G	25
6.15	S	25
8.75	S	12

TABLE 1.

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<u>Explanation of results</u>

It was first guessed that there would be a frequency dependence on the size of the excited particles assuming individual spherical harmonic vibrations. However, taking the formula

(2)
$$\frac{ha}{\pi} = 0.82 \qquad \ldots (1)$$

for the poisson condition $\frac{k^2}{h^2} = 3$ and $h = \frac{k}{\sqrt{3}}$

Hence $\frac{2a}{\lambda\sqrt{3}} = .82$ if radius $a = 10^{-3}$m and $C_{glass} = 4000\text{m s}^{-1}$

this gives a frequency $f = 2.8 \times 10^6$ Hz.

If this were the case then it would have presented very great practical problems but it seemed unlikely to be the main source of the noise and the previous experiments showed there to be frequencies a lot lower than this.

The most likely explanation for these lower frequency peaks seems to be the interaction between two spheres, forming a double mass effectively held together by a spring at the point of contact. It can be shown that

(3)
$$y = 1.04 \sqrt[3]{\frac{P^2(D_1 + D_2)}{D_1 \cdot D_2}\left(\frac{1 - V_1^2}{E_1} + \frac{1 - V_2^2}{E_2}\right)^2} \qquad \ldots (2)$$

where y is the displacement of the centres of two spheres in contact towards each other, P is the force between them, D_1 and D_2 their diameters, V_1 and V_2 poisson's ratio and E_1 and E_2 Young's modulus.

If $D_1 = D_2$ $E_1 = E_2$ and $V_1 = V_2$

then
$$y = 1.04 \sqrt[3]{P^2 \frac{2}{D}\left(2 \cdot \frac{1 - V^2}{E}\right)^2} \qquad \ldots (3)$$

y is therefore proportional to $\sqrt[3]{\frac{P^2}{D}}$

and $\frac{dy}{dP} \propto \frac{2}{3}\frac{P^{-\frac{1}{3}}}{D^{\frac{1}{3}}}$, $\frac{dP}{dy} \propto D^{\frac{1}{3}}\ P^{\frac{1}{3}}$

Now $\omega \propto \sqrt{\frac{\frac{dP}{dy}}{m}}$ $\therefore \omega \propto \frac{D^{\frac{1}{6}}\ P^{\frac{1}{6}}}{D^{\frac{3}{2}}}$ $\therefore \omega \propto D^{-\frac{4}{3}}\ P^{\frac{1}{6}}$

where m is the mass of each sphere.

Hence $$\omega \propto \frac{P^{\frac{1}{6}}}{D^{\frac{4}{3}}} \qquad \ldots (4)$$

To see if in practice this held to be true, two steel spheres were suspended in a magnetic field generated by a D.C. current passing through a coil as shown in Figure 2. With no current flowing the suspension wires were adjusted so that the spheres were touching but experiencing no force between them. A calibration of force against D.C. current was carried out so that a known force could then be applied to them. A much smaller A.C. current (typically 0.5 Amps D.C. and 10mA A.C.) was added to excite the spheres. Vibrations were detected by a small accelerometer glued to one of the spheres and plots of excitation frequency against accelerometer output were made for various forces. The family of curves from a pair of 2.7cm spheres is shown in Figure 3a. It demonstrates the $P^{1/6}$ dependence of the resonant frequency as can be seen from Figure 3b which shows both the theoretical line and the experimental values. Also, putting P = 1 Newton, $D = 27 \times 10^{-3}$m, E = 20.3 Newtons m^{-2} and V = 0.3 into Equation (3) and subsequent equations yields a frequency of 2.2KHz which is very close to the experimental value.

It was also found that these steel spheres could be excited to vibrate in these modes by applying a much lower frequency, which may be similar to conditions experienced by moving sediments. This is demonstrated in the oscillogram depicted in Figure 4a where 2.7cm spheres show signs of oscillation when excited by a 150Hz oscillation.

A crude acoustic measurement showed that the spheres radiated as a dipole, with maximum radiation in line with them and minimum at right angles to them. Unfortunately, for these frequencies, the tank was not big enough to obtain any quantitative results. It may be worth while doing further experiments in the future.

Another mechanism which must be happening in the drum is the collision of particles. Figure 4b shows the accelerometer output when two 2.7cm spheres collide. If this waveform could be described mathematically by $Ae^{-\delta t} \sin(\omega t - \phi)$, as can the waveform generated by a capacitor discharging through an inductor, shown for comparison in Figure 4c, then one would expect the Fourier transform to take the form of that shown in Figure 4d with a peak at the LC resonance. However it was shown experimentally to be like that shown in Figure 4e. Although there is a peak at the resonance a large amount of the energy is contained in frequencies up to 25KHz which is a phenomenon not observed with the drum experiments.

The indeterminant part of the process happening in the drum is the magnitude of the forces acting on the sediment. In Figure 5 theoretical lines have been drawn, using Equation (3), for forces of .01N, 1N and 100N. The experimental results form a line within these limits. The trend of increasing force with increasing particle size reverses at about 6mm but it is difficult to say whether this is peculiar to this experiment or not. Nevertheless a frequency dependence on the size is clearly demonstrated. Also it shows that glass spheres and shingle behave similarly.

One other factor of importance is the level of the sound generated and perhaps, whether this can be related to the quantity of material in motion. Certainly the level varies with the size of material. In the drum experiments, with 2Kg of material in the drum rotating at 1 revolution in 3 seconds the largest size (8.75mm) was measured to have a level of -3db re 1μb $Hz^{-\frac{1}{2}}$. This level decreased with size and with 1.3mm diameter the level was -23db re 1μb $Hz^{-\frac{1}{2}}$. This is unfortunate because hydrophones become less sensitive as their frequency range increases. The noise level also increased with the speed of the drum. Further experiments will have to be carried out to establish what relationships hold between drum speed and noise level and also volume of sediment and noise level.

Conclusions

If the experimental curve in Figure 5 is representative of what happens in practice in the sea then, assuming the noise levels are not very different, it should be possible not only to say when sediment is moving but also obtain some information about the size. The lower limit on particle size from which signals can be processed is difficult to estimate from these experiments. One mm was the smallest from which results were used in these experiments as the 0.5mm sample was difficult to interpret. There are several reasons for this which, hopefully, can be improved if the monitoring of smaller sediments is required. The problems encountered with electrical interference from external sources became more significant at these lower levels as did the high level of ambient noise inevitable in a tank in a laboratory. Also the hydrophone was not optimum as a certain amount of sensitivity was sacrificed by having a flat response up to a frequency which was higher than necessary.

Trials in the sea with the instrument and also an underwater television camera to monitor the sediment, are being planned at present and it is hoped that these will contribute towards both some of the unanswered questions in this present work and to the design of a practical instrument.

REFERENCES

1. STUBBS, A.R., McCARTNEY, B.S., LEGG, J.G. (1974) 'Telesounding, a method of wide swathe depth measurement.' International Hydrographic Review. L1 (1).

   VOGLIS, G.M., COOK, J.C. (1970) 'A new source of acoustic noise observed in the North Sea'. Ultrasonic, 8(2) pp. 100-101.

2. LOVE, A.E.H. 'A treatise on the mathematical theory of elasticity'. Dover.

3. ROARK. Formulae for stress and strain. McGraw Hill.

4. JOHNSON, P., MUIR, T.C. (1969) 'Acoustic detection of sediment movement'. Journal of hydraulic research, 7, (4) pp.519-540.

5. HOPKINS, I.L. (1965) 'Comments on Fitzgerald Resonances' Journal of the Acoustical Society of America, 38, (1) pp.145-146.

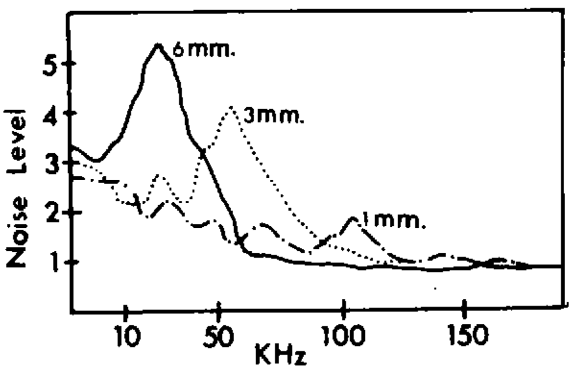


Figure 1. Typical experimental curves.

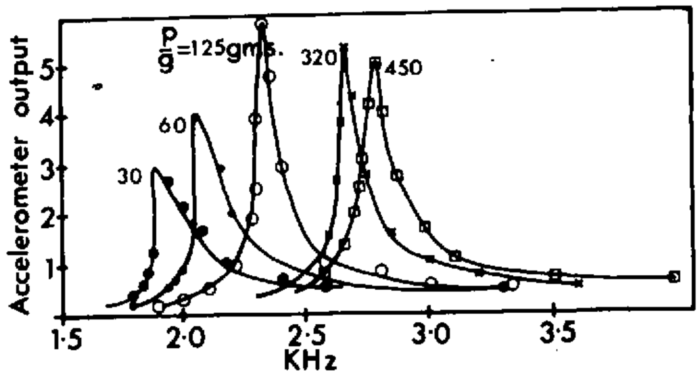


Figure 3a. Oscillation of 2·7 cm. steel spheres under various forces.

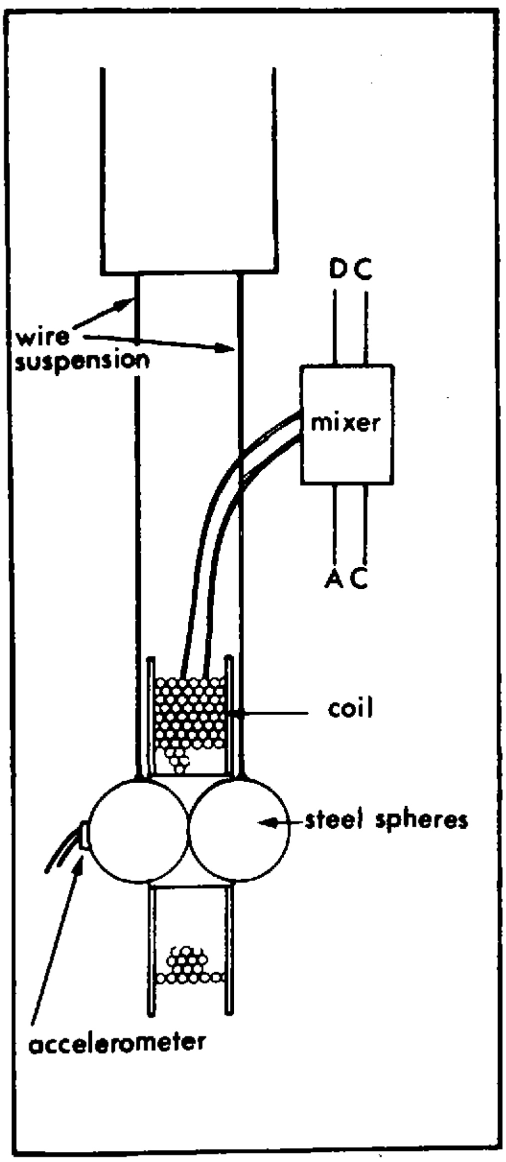


Figure 2. Schematic of apperatus used for steel sphere experiments

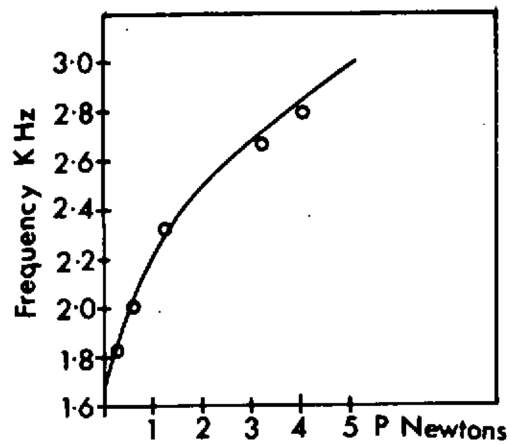


Figure 3b. Theoretical line for 2·7 cm spheres with experimental results shown o. Demonstrating the $P^{1/6}$ dependence of frequency.

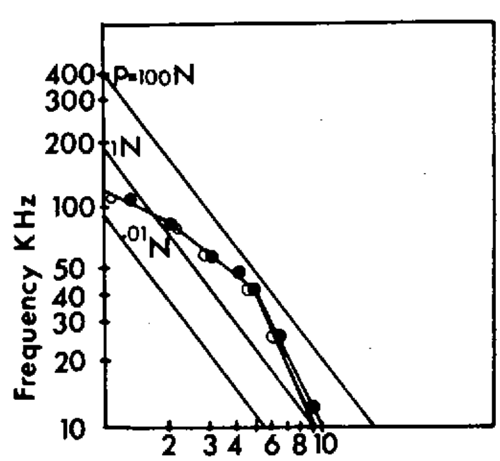
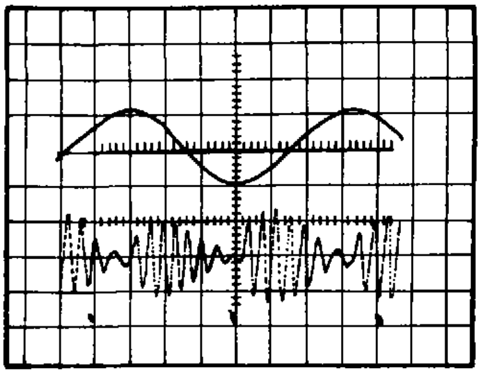


Figure 5. Diam. mm

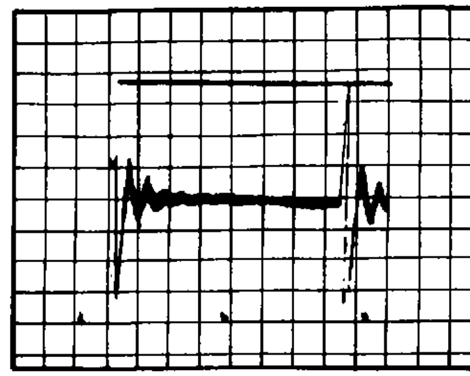
o Glass spheres

• Course sand or shingle

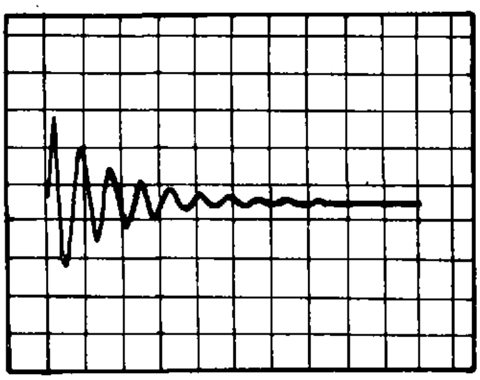
Figure. 4.



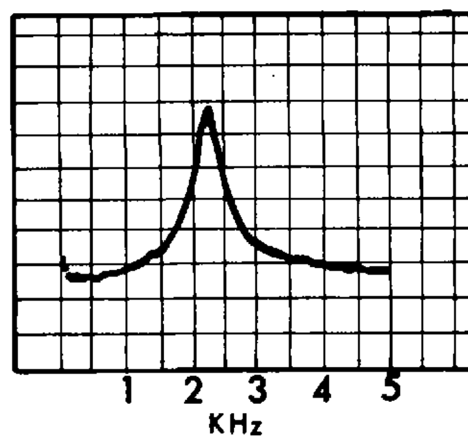
Upper Trace -- Excitation Current
Lower Trace -- Accelerometer Output
a. 2·7 cm. dia. 1 ms.cm.$^{-1}$



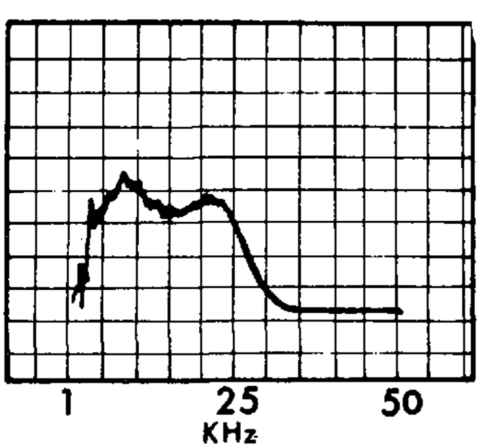
b. 2·7cm. dia. 0·5ms.cm.$^{-1}$



c. L. = mH. C = 2·24 μF.
0·5ms cm^{-1}



d. 0·5 KHz cm^{-1}



e. 5·0 KHz cm^{-1}

a. Excitation by a low frequency

b. Accelerometer output on collision between two spheres

c. L.C. Discharge

d. Spectrum from L.C. discharge shown in c.

e. Spectrum from waveform generated by colliding spheres shown in b.