PARTICLE VELOCITY MEASUREMENTS

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1 INTRODUCTION

The environmental impact of new off shore structures such as Ocean Power Generation systems is of increasing concern. The desire for knowledge of potential environmental impacts has brought attention to inherent problems with collecting the desired data. Particle velocity generated from anthropogenic sources is one of the environmental impacts of growing interest.

This paper discusses the practical issues associated with using directional hydrophones to make particle velocity measurements. Because of the nature of particle velocity sensors, they are more susceptible to mechanical self-noise compared with normal pressure-sensing hydrophones. Further, with particle velocity sensors, the ratio of signal to mechanical self-noise decreases as the frequency decreases. Because of the susceptibility to mechanical self-noise, extra care (compared to pressure-sensing hydrophones) must be taken in the suspension of a particle velocity sensor, particularly when the water current or sea state is high. The authors draw on their experience with directional sonobuoys to explain why this is so and what is required of the sensor and its suspension system to minimize the noise generated by vibration.

2 WHAT IS A PARTICLE VELOCITY SENSOR

One method of making a particle velocity sensor is to mount orthogonally-arranged accelerometers within a pressure vessel. The acoustic wave accelerates the pressure vessel, just like it would a water molecule. If the pressure vessel is neutrally buoyant and small compared to a wavelength, the velocities of the pressure vessel and water molecules are identical in amplitude and phase. The pressure vessel must also contain a pressure hydrophone to resolve left-right ambiguity and an orientation sensor.

In practice, it is usually not a good idea to make the pressure vessel neutrally buoyant because of mechanical noise. The price paid for negatively-buoyant pressure vessels is a slight loss in sensitivity. The velocity of the pressure vessel relative to a water molecule is $\frac{3\rho_w}{\rho_w+2\rho_b}$, where ρ_w is the density of water, and ρ_b is the density of the vessel[1]. For a vessel with density 1.8, the loss in acoustic sensitivity is 20 log (3/(1+3.6)) = -3.7 dB. So long as the electrical noise is well below the pressures that are to be detected, this loss in sensitivity is well worth the price.

The accelerometers used must be matched to one another in phase and amplitude over the frequency band of interest. This is easy to do when the accelerometers are used below their mechanical resonance, but more difficult when the acoustic band is wide and the accelerometers must be used near and above their resonance. A “wobbler” accelerometer[2] was developed to optimise the tracking between channels and maximise bearing performance of the transducers. The sensors currently in use by GeoSpectrum Technologies Inc. are made from separate sense elements that can be individually tuned to achieve this same excellent performance.

Particle velocity sensors are designed to measure vibration amplitudes associated with acoustic waves and these acoustically-induced amplitudes are far smaller than other mechanical inputs. The velocity of a water molecule in a plane wave is related to the pressure by $P = \rho c U$, where P is the pressure amplitude, ρ is the density, c is the speed of sound and U is the particle velocity[1]. As an example, if P = 1 Pa (120 dB re 1 µPa) in sea water, U = 6.5 10^{-7} m/s. At 100 Hz, this corresponds to a vibratory displacement of 10^{-9} m.

3 MECHANICALLY-INDUCED NOISE

It is now possible to appreciate that the small amplitudes of acoustic vibrations make it crucial to minimize vibratory inputs from sources other than the acoustic wave. A Sea State 3 (SS3) based on the Pierson-Moskowitz[3] scale has a wave height of a little over a metre and a mean period of 4s. If the particle velocity sensor is suspended without mechanical isolation from a surface float, the mechanical input from the wave would be nine orders of magnitude greater than the 120 dB acoustic signal. Even though the dominant frequency input from the wave may be far below typical bands of acoustic interest, components of the wave will be in the acoustic band and thus must not be transferred to the particle velocity sensor. Furthermore, the low frequency vibration could saturate the analogue front end of the preamplifier.

Flow noise is another source of mechanically-induced noise. In a tidal area, a peak flow of 1 m/s is not unusual, and as the period is very long – roughly 12 hours, the worst case for noise will be at the high peak flow. The flow itself is not an issue. The problem that arises is the noise that is caused by the water moving around the sensor, unless the sensor is allowed to drift, in which case then it will be relatively easy to minimise mechanically-induced noise. However, if the objective is to make measurements in a particular area, a drifting buoy is not a good option. The moored sensor therefore needs to be mounted in a manner that minimises the introduction of noise from water flowing around the sensor and around the mooring lines and hardware. Ideally, the flow should be kept way from the sensor altogether, and the flow around the shielding structure be made to be as quiet as possible. This typically means maintaining laminar flow. Mounting hardware directly on the sea floor is the best option, as the flow rate tends to be lower and an effective shield can be raised more easily as one side of the sensor will see no flow. If a particle velocity sensor is assumed to be 125mm in diameter and 200mm long, the drag force can be calculated from:[4] $F_D = \frac{1}{2}\rho v^2 C_D A$. For C_D = 0.47, ρ = 1026 kg/m^3, v = 1 m/s, and A = 0.025m^2 the resulting F_D = 12.1 N. The energy that must be dissipated is equal to the force times the distance or force times velocity times time. For 1s at 1m/s E = F_D(v)(t) or about 12 Joules/sec or 12 Watts. The acoustic intensity in our 120 dB sound wave is 6.6 10^{-7} W/m^2. Multiplying this by the area of the sensor, 0.025 m^2, the energy intercepted by the sensor is 1.6 10^{-8} Watts, or about 9 orders of magnitude less than the energy dissipated in drag. Again, the energy in the (mechanical) flow is far greater than the acoustic energy and thus the sensor must be isolated from the flow.

Mechanically-induced noise is worse for a particle velocity sensor compared to a pressure-sensing hydrophone, particularly at low frequencies. A sound pressure of 120 dB re 1 µPa produces the same signal amplitude in a pressure hydrophone regardless of whether the frequency is 100 or 10 Hz. For the same sound pressure level, though, the output from a particle velocity sensor decreases linearly with decreasing frequency. Thus, the output of a particle velocity sensor is 20 dB less at 10 Hz than it is at 100 Hz so if signals at 100 Hz are just detectable, the signal will probably be buried in noise at 10 Hz, particularly if there is more mechanically-induced motion at lower frequencies.

4 PARTICLE VELOCITY SENSOR AND SUSPENSION DESIGN

Both authors have backgrounds in designing sensors and suspensions for anti-submarine warfare applications. For many years the sensor of choice for tracking submarines was the AN/SSQ-53 DIFAR sonobuoy[5] and its derivatives, and these are still in use today. The lessons learned in this industry are applicable to other uses of particle velocity sensors.

Sonobuoys are “drifters”. There is a surface float with a 30m long soft suspension to isolate the sensor from the surface float. Sea anchors in the suspension, both horizontal and vertical, assist in mechanical isolation from float motion. All suspension components near the sensor are surrounded by netting to minimize strum. There is an optimum amount of netting; too little and the suspension strums, too much and the suspension vibrates excessively.

Regarding sensor design, a sensor with greater moment of inertia will be quieter than one with a smaller moment of inertia (bigger is better!). Another more sophisticated method of making a sensor quiet is to place the accelerometers at the proper location within the pressure vessel, as indicated in the Figure 1. Although the dominant motion caused by forces in the suspension will be vertical, there will always be a small horizontal component of force, which will cause the sensor to both translate and rotate. At one location, the forward motion caused by translation will be precisely countered by the backward motion from rotation about the centre of rotation.

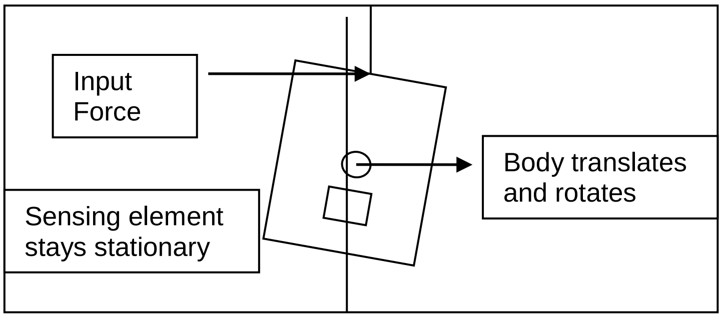

Figure 1 Acceleration Balancing

5 CONCLUSIONS

Making acoustic measurements in high flow areas is difficult, and making particle velocity measurements poses even more challenges. Nevertheless, the sonobuoy industry has shown the way ahead. With the right equipment and an understanding of the issues, good measurements can be made. It is important, though, to set the expectations for results at a reasonable level and avoid attempting measurements that are impossible to do.

6 REFERENCES

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