Considerations on current and future multicomponent streamer design

Nicolas Goujon, Susanne Rentsch, Leendert Combee and Fabien Guizelin, Shearwater GeoServices

Summary

The towed-streamer market is moving towards multi-component streamers, which contain hydrophones and particle motion sensors. The main source of noise on particle motion sensors is the streamer vibration, and it can be challenging to obtain a high enough signal to noise ratio. In this paper, we study how the characteristics of transverse vibration noise are affected by the choice of the streamer mechanical platform. To compare the implications of design options side by side we have built different streamer sections with dense point receiver sampling, identical electronic backbone and MEMS sensors, but different mechanical properties. We towed them together under different tensions in a fjord experiment. We observed that, as expected, the transverse vibration noise was the dominant noise mode, with dispersion characteristics depending on the streamer bending stiffness. We also found that the noise amplitude and maximum frequency depends on the mechanical properties of the cable, and that they could be reduced by using a new type of gel optimized to dampen vibration. Based on these findings, we see an opportunity to design a cost-efficient streamer combining an optimized mechanical platform with a new single sensor configuration.

Introduction

When acquiring data using towed marine seismic streamer the near perfect reflection of seismic waves at the sea surface results in both constructive and destructive interference of the up-going and down-going wavefield. This is commonly called the “ghost” problem and can limit the interpretability of the acquired data significantly. Typically, marine seismic streamers were towed at relatively shallow depth to push the ghost frequency band upwards and outside desired seismic bandwidth. However, this comes at the cost of also limiting the low frequency part of the seismic bandwidth and the weather window of an acquisition. As operational efficiency and low frequencies in seismic data grew in importance, streamers measuring pressure and particle motion jointly were introduced just over a decade ago. Today three such multi-measurement seismic acquisition systems are commercially available in the market, see Tenghamn et al. 2007, Ozdemir et al. 2012 and Mellier et al. 2014. Interestingly, the three systems have significantly different mechanical and electronical platforms. Any seismic streamer measuring particle motion is exposed to various noise modes of a streamer under a broad range of tensions. In this paper, we will study streamer design implications for the most dominant noise mode in more details.

Theoretical considerations

Teigen et al. 2012 describes the noise modes in a towed streamer under tension. In this paper we focus on the noise propagation characteristics of the transverse vibration noise, which is the dominant noise mode affecting the data quality of the particle motion measurements. While Teigen et al. 2012 suggest that in a gel streamer, the Young’s modulus and consequently its bending stiffness can be taken as zero, our field data indicate that it does not completely reduce to zero but to a small value. The exact value depends on the gel rheology, streamer skin properties and mechanical layout. In Figure 1 we present examples of theoretical transverse vibration noise characteristics for four different solid streamer platforms using low and high extremes of the possible tension range along a streamer. Two of the four platforms are plastic, one with a very high bending stiffness of 360 Nm^2 (solid 1) and a second one with a moderate stiffness of about 170 Nm^2 (solid 2). The other two cables are gel filled platforms, one representing a standard gel with a bending stiffness of about 50 Nm^2 (gel 1) and the second gel being designed for high vibration attenuation having a bending stiffness of about 20 Nm^2 (gel 2).

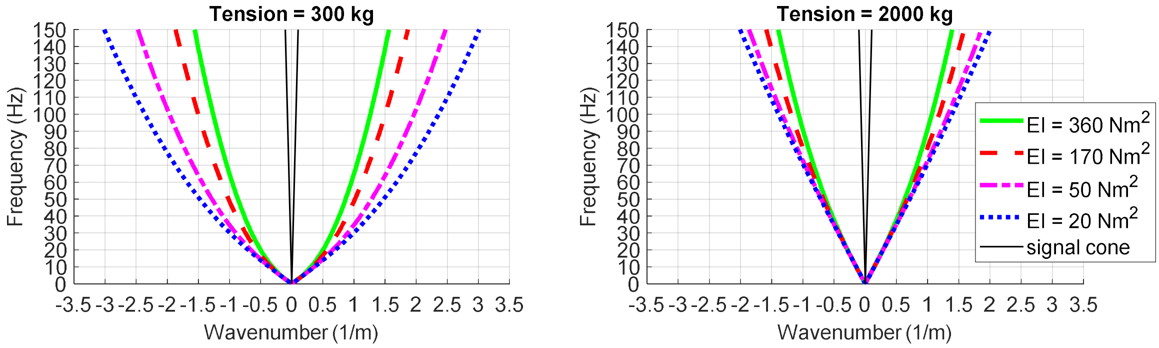

Figure 1 *The frequency-wavenumber (f-k) dispersion curves for two plastic streamers (green and red) and two gel filled streamers (magenta and blue). The left-hand side is for a low-tension case and the right-hand side for high tension.*

As shown in Figure 1 the low-tension case has more severe implications in terms of the noise sampling required to avoid aliasing. The platform with the highest bending stiffness requires the least number of sensors to adequately sample the noise while the gel platform with the lowest bending stiffness appears to require twice as many sensors to achieve that. If one was to use sensor arrays / group forming for noise removal, the frequency-wavenumber dispersion curves also have implications on the group length, number of sensors in a group and the minimum spacing in a group required to adequately attenuate the noise in all observed tension scenarios. However, those dispersion curves give us the propagation characteristics, but not the amplitude and the frequency content. Naturally, the question arises if the visco-elastic properties of a gel attenuate the vibration noise faster than in more rigid plastic platforms and what implications this would have on design options.

Examples

To compare the implications of design options side by side in the same experiment we built different streamer sections with dense point receiver sampling and identical electronic backbone and MEMS sensors (Paulson et al. 2015). Some sections were Isometrix sections with mechanical properties equivalent to solid 1 (highest bending stiffness in Figure 1). The accelerometer spacing was uniform at 62.5 cm with mounting locations alternating either side of the cable core allowing angular vibration noise to be mapped away from the signal cone. We did not build a second plastic platform with the lower bending stiffness from Figure 1 as plastic was not expected to achieve fast attenuation of the vibration noise. Another section was filled with a standard gel (gel 1) and equipped with accelerometers every 37 cm. The last streamer section shown in this paper was identical to the one from gel 1 but filled with a gel whose rheology was optimized for vibration damping (gel 2). We conducted several experiments in a fjord in Norway where the three sections were towed in the middle of a 1.2 km long streamer to measure noise records. The experiment was repeated several times and in the second part of the experiment sea-anchors were attached at the tail of the streamer to increase the sampled tension range. Thanks to the dense single sensor sampling, we could study the details of the raw noise in the cables. The frequency-wavenumber spectra of the three different sections are shown in Figure 2 a) – c) for approximately 300 kg tension and e) – f) for approximately 1500 kg tension both of which were acquired at 5 knots tow speed.

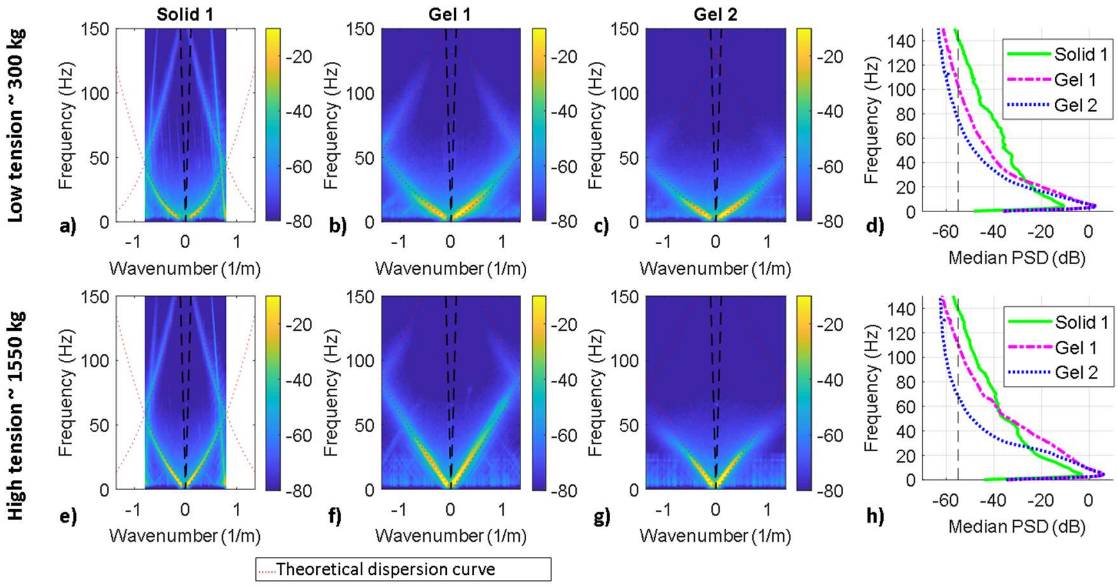

Figure 2 *Frequency wave number spectra of three different sections a) – c) under low tension of approximately 300 kg and their respective median power spectral densities (PSDs) in d). Corresponding f-k spectra under high tension (1500kg) in e) – g) and the median PSDs in h).*

We observe that, as expected, the transverse vibration noise is the dominant noise mode. It generally fits well the theoretical dispersion curve, except for the gel 2 under tension (Figure 2g), where we observe that the noise propagation velocity decreases with frequency. The beam model used for the theoretical curve does not capture the interactions between gel, skin and stress-member under tension, and a more complex model would be needed. The solid 1 section has additional angular vibration noise starting from +/- Nyquist wavenumber as expected from the cable design. Its transverse vibration noise mode changes only very little in the two tension regimes which are realistic for the front and tail of a typical acquisition. Furthermore, the width of the vibration noise at each frequency stays relatively small and sharp. In contrast, both gels visibly change the propagation speed of the transverse vibration noise with tension. The sharpness of the vibration noise wavenumber width is also reduced, making the noise curves appear fuzzier than in solid 1. This has implications on noise attenuation capabilities using either group forming or digital single sensor filtering as the desired solution needs to deliver fit for purpose data from front (high tension) to tail (low tension) of a streamer. We also find that the noise amplitude and maximum frequency (under equal towing conditions) is different depending on the cable's mechanical properties, see Figure 2 d) and h). The solid 1 design exhibits noise throughout the desired seismic bandwidth. Both gels are dampening the vibration noise faster than the solid 1 with gel 2 having notably higher attenuation.

Discussion

Having a better understanding of the noise characteristics of the different cables, we can now examine their implication on the sensor layout. A first step is to define the range of noise wavelengths that need to be attenuated. We determined a maximum noise frequency for the different streamer types at low and high tension. From this and our knowledge of the noise propagation characteristics in each type of cable, we can derive an envelope of the noise wavelengths vs. frequency from the front to the tail of the streamer.

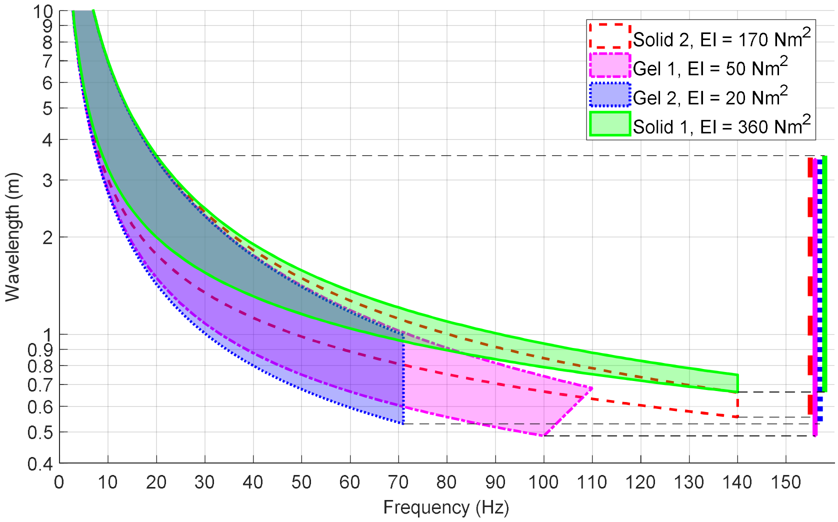

Figure 3 *Wavelength versus frequency areas of transverse vibration noise. The upper boundary relating to high tension (here 2000 kg) and the lower boundary to the low tension (300 kg) observed at a streamer tail. The right-hand boundary of each area represents the frequency at which the raw noise was below -57 dB in Figure 2 d) and h), except for solid 2 for which we do not have field data.*

We observe that the noise covers a large range of wavelengths. Although the solid 1 cable has the largest noise frequency bandwidth, it keeps the narrowest wavelength range as shown in Figure 3.

Two main types of sensor layouts have been used in the industry to attenuate towed streamer noise: analogue arrays and single sensor recording with uniform sensor spacing, first introduced for hydrophones only (Martin et al. 2000), and later for multicomponent streamers (Paulson et al. 2015).

For hydrophone channels, the traditional approach of using analogue arrays is widely accepted in the industry and provides an adequate level of noise attenuation. The noise characteristics are, however, significantly different for hydrophones compared to particle motion sensors. Firstly, the signal to noise ratio of the raw data is significantly higher for hydrophone data. Secondly, the behavior is more stable as there is less variability due to tension along the streamer and lastly, the frequency bandwidth is narrower with waterborne shipping noise being usually dominant above 30 Hz (Muyzert et al. 2007, Dao and Landrø 2017). Part of the higher frequency waterborne noise is also attenuated because of the array response, this however comes together with some signal filtering (Martin et al. 2000).

Designing an analog array or fixed *k*-filter to attenuate particle motion noise in a streamer presents significant challenges. The *k*-response of the filter has to provide a high level of attenuation over a wide *k* range. An approach can be to specifically target the frequencies where the hydrophone receiver ghost notch is expected. Even then, we can see from Figure 3 that the corresponding *k* value will vary with a factor of 2.5 between the front and the tail of the streamer due to tension. Unless different section designs are used at the front and the tail of the streamer, it is very difficult to find a good compromise giving sufficient noise attenuation.

The second layout approach, single sensor recording, has demonstrated very high level of noise attenuation, more than 30 dB, when used on solid 1 data (Ozdemir et al 2012). Applying this approach on gel 1 or 2 would require an even higher number of sensors, as the minimum wavelength on these cables is shorter than on solid 1 (Figure 3) and would therefore not be practical. To take advantage of the noise amplitude reduction we have observed on gel 2, one could use a third type of sensor layout: non-uniform single sensor recording. Having a variable spacing between sensors gives the possibility to cover the whole range of noise wavelengths without requiring a very high number of sensors. Compared to full sampling one might lose some noise attenuation power, this could however at least in part be compensated by the lower noise amplitude in raw data provided by gel 2. Such a layout would allow for a number of noise filtering options. A first simple solution could be to use digital *k*-filters, building on what is used in analogue arrays. The single sensor approach would bring a high level of flexibility in the design of such filters. The data could be decomposed into frequency bands, and filters optimized for each band. Array length, selection of sensors and weight applied to each of them could be optimized for each frequency. In addition, by knowing the position in the streamer and the tension, one could predict the wavelength of the noise for a given frequency, making it possible to design a notch filter with high attenuation for where it is required.

In addition to this flexible *k*-filtering, such a non-uniform sampling would also open a whole avenue of new possibilities, such as the use of compressed sensing algorithms.

Conclusion

We have studied the vibration noise characteristics for different streamer platforms. We have built three streamer sections, using the same sensors in different mechanical platforms, and towed them in the same streamer for direct comparison. We have shown that by using a new type of gel, optimized to dampen the vibration, we could reduce the amplitude and frequency bandwidth of the noise, but not its spatial bandwidth. Based on these findings, we see an opportunity to design a cost-efficient multicomponent streamer by combining an optimized mechanical platform and a new single sensor configuration, which could have the potential to approach the noise attenuation performance of a fully sampled solid streamer.

Acknowledgments

We thank Bent Kjellesvig and Kemal Ozdemir as well as our manufacturing, technical support teams and the crew from our test station for all their contributions.

References

Dao T. and Landrø M. [2017] Streamer depth versus vessel and seismic interference noise, *Geophysics*, 82 (4), P41–P51

Martin J. E., Özbek A., Combee L., Lunde N., Bittleston S., and Kragh E. [2000] Acquisition of marine point receiver seismic data with a towed streamer. *SEG Technical Program Expanded Abstracts 2000*: pp. 37-40.

Mellier G., Maples M., Hepp J., LeBoeuf S., and Lansley M. [2014] A new multisensor solid streamer. *SEG Technical Program Expanded Abstracts*: pp. 228-232

Muyzert E. [2007] Do We Reduce Noise by Towing Deeper? *69th EAGE Conference and Exhibition,* Extended Abstracts B007

Ozdemir K., Kjellesvig B. A., Ozbeck A. and Martin J. E. [2012] Digital Noise Attenuation of Particle Motion Data in a Multicomponent 4C towed streamer, *74th EAGE Conference and Exhibition*, Extended abstracts, I017

Paulson H., Husom V.A. and Goujon N. [2015] A MEMS accelerometer for multicomponent streamers. *77th EAGE Conference and Exhibition*, Extended Abstracts, P6 06

Teigen O., Ozdemir K., Kjellesvig B. A., Goujon N. and Pabon J. [2012] Characterization of Noise Modes in Multicomponent (4C) Towed-streamer, *74th EAGE Conference and Exhibition,* Extended abstracts, Z013

Tenghamn R., Vaage S., and Borresen C. [2007] A dual-sensor towed marine streamer: Its viable implementation and initial results. *SEG Technical Program Expanded Abstracts 2007*: pp. 989-993.