Current and future multicomponent towed streamer design

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SUMMARY

The towed streamer market is moving towards the widespread use of multicomponent streamers. This type of streamer contains hydrophones and particle motion sensors which are used to carry out receiver-side de-ghosting of the data. The main source of noise on the particle motion sensors is streamer transverse vibration, and it can be challenging to obtain a high enough signal to noise ratio to use this data in the de-ghosting process.

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 we built different streamer sections with dense single sensor sampling, identical electronic backbones and MEMS sensors. We towed them together under different tensions in a field experiment and 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 (under the same towing conditions) 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.

As a result of theoretical modelling and these field observations we propose a new approach to streamer noise attenuation which involves optimising the mechanical characteristics and using non-uniform single sensor sampling in the design of the cable. This avoids some of the compromises we incur using analog arrays and the high cost of single sensor, uniform Nyquist sampling.

Key words: Broadband, multicomponent, accelerometer, streamer design, noise mode.

INTRODUCTION

The term ‘broadband’ has become ubiquitous in the seismic industry and encompasses acquisition and/or processing techniques used to de-ghost and broaden the bandwidth of seismic data. Acquisition related methods have included over/under streamers, variable depth streamers, multilevel sources and more recently multicomponent streamers. Multicomponent streamers (which measure pressure and particle motion jointly) were introduced just over a decade ago and are becoming the preferred acquisition solution for removing the receiver-side ghost.
Today three such multicomponent towed streamer acquisition systems are commercially available on 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 electronic platforms and use the data in different ways to produce a de-ghosted seismic product. Any seismic streamer measuring particle motion is exposed to various, strong noise modes under a broad range of tensions and the three platforms differ significantly in how they approach noise removal.

In this paper, we study streamer design implications for the most dominant noise mode and show how a combination of theoretical modelling, the building and field testing of various cable designs and new paradigms in sensing are being used to design a new generation of multicomponent streamer.

STREAMER NOISE MODELLING

Teigen et al. 2012 describes the various noise modes in a towed streamer under tension. Here we focus on the noise propagation characteristics of the transverse vibration noise, which is the dominant noise mode affecting the data quality of 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 show 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 and a second one with a moderate stiffness of about 170 Nm^2. The other two cables are gel filled platforms, one representing a standard gel with a bending stiffness of about 50 Nm^2 and the second gel being designed for high vibration attenuation having a bending stiffness of about 20 Nm^2.

As shown in Figure 1 the low-tension case has more severe implications for the required sampling if one wants to avoid the noise aliasing back into the signal cone. 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. While the dispersion curves give us the propagation characteristics of the noise they do not give amplitude and the frequency content. The question that arises is how the visco-elastic properties of a gel can be used for noise attenuation and what implications that would have on streamer architecture.

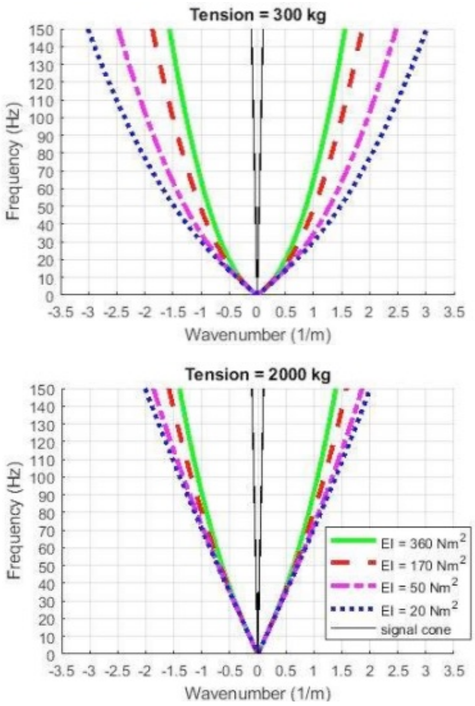

Figure 1. Frequency-wavenumber (*f-k*) dispersion curves for two plastic streamers (green and red) and two gel filled streamers (magenta and blue). The upper picture is for a low-tension case and the lower for high-tension.

TEST CABLE AND FIELD EXPERIMENTS

To empirically evaluate the effects of different streamer fill materials on noise characteristics we built streamer sections with single sensor sampling, identical electronic backbones and MEMS sensors (Figure 2). The high-bandwidth optical backbone allows for a very dense sensor spacing which is a key requirement for conducting field experiments. The test sections were built at a streamer manufacturing facility in Malaysia which also has the ability to develop the bespoke streamer gels through combining various copolymers. The sections were tested through different stages of the production process and eventually verified in a scaled spread as part of a final factory acceptance test.

We built a solid plastic section with the highest bending stiffness with noise characteristics shown in Figure 1. The accelerometer spacing was uniform at 62.5cm with mounting locations alternating either side of the cable core allowing angular (torsional) 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 high attenuation of the vibration noise. Another section was filled with a standard gel (gel 1) and equipped with accelerometers every 37cm and 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).

Several experiments were conducted in a Norwegian fjord where the three sections were connected and towed in the middle of a 1.2km long streamer. 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 tension range. Due to dense single sensor sampling, we were able to record and analyse the details of the raw noise characteristics in the cable. The frequency-wavenumber (*f-k*) spectra of the three different sections are shown in Figure 3 a) – c) for approximately 300 kg tension and e) – g) for approximately 1500 kg tension both of which were acquired at 5 knots towing speed.

We observed 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 3g), 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 section 1 has additional angular vibration noise starting from +/- Nyquist wavenumbers as expected by the cable design. Its transverse vibration noise mode changes only very little in the two typical tension regimes at the front and tail of a streamer. Furthermore, the width of the vibration noise at each frequency stays relatively small and sharp. In contrast, both gels change the propagation speed of the transverse vibration noise visibly 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 found that the noise amplitude and maximum frequency (under equal towing conditions) is different depending on the cable's mechanical properties (see Figure 3d and h). The solid 1 design exhibits noise throughout the desired seismic bandwidth. Both gels show better attenuation of vibration noise compared to the solid 1 with gel 2 having the best attenuation characteristics.

Figure 2. Construction of test cable sections in manufacturing facility

DISCUSSION

Having a better understanding of the noise characteristics of different cable designs, allows us to examine the implications on the required sensor layout. To attenuate towed streamer noise there are currently two main types of sensor layouts used in the industry which are analog arrays and single sensor recording with uniform sensor spacing. The latter was first introduced for hydrophones only (Martin et al. 2000), and later for multi-measurement streamers (Paulson et al. 2015).

For hydrophone channels, the traditional approach of using analog 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, hydrophone noise velocity shows less variability due to tension along the streamer and lastly, its frequency bandwidth is narrower with waterborne shipping noise being usually dominant above 20 to 30 Hz (Muyzert et al. 2007, Dao and Landrø 2017). Part of the higher frequency waterborne noise is also filtered because of the array response, that however comes together with some high incidence signal filtering (Martin et al. 2000).

Conversely, designing an analog array or fixed wavenumber *k*-filter to attenuate particle motion noise in a streamer presents significant challenges. The *k* response of the filter must provide a high level of attenuation over a wide range of wavenumbers. To reduce the width of the wavenumber range one may target the frequencies where the hydrophone notch is expected. However, as the frequencies of the hydrophone notch increase with increasing wavefield incidence angle one could only safely eliminate frequencies below the first zero incidence angle hydrophone notch. Even then, we can see from Figure 3 that the corresponding wavenumber 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 will be very difficult to find a good compromise giving sufficient noise attenuation.

In the ideal case we would adequately sample the noise with single sensor recording which would allow us to remove it without affecting the seismic signal. The single sensor approach has demonstrated a very high level of noise attenuation, (more than 30 dB), when used on solid 1 data (Ozdemir et al 2012). However, Nyquist sampling of the slow transverse noise mode requires dense sensor spacing and applying this approach on gel 1 or 2 would require an even higher number of sensors than on solid 1 as the minimum wavelength on these cables is shorter. The high number of sensors increases data transmission and power requirements which increases the cost of the cable therefore we desire alternative methods of sampling and/or noise attenuation using fewer sensors.

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 allows the possibility of covering the whole range of noise wavelengths without requiring a very high number of sensors. Compared to full sampling one might lose some noise attenuation, but this could in part be compensated for by the lower noise amplitude in the raw data provided by a high dampening gel like 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 those used in analog 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 the weighting 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. The filters could be predefined or determined adaptively. 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.

CONCLUSIONS

We have improved understanding of the noise behaviour in towed multicomponent streamers using a combination of theoretical modelling and by field testing various cable designs and fillings. The field tests have shown that the selection of steamer filling material has a significant impact not just on the noise propagation but also on the dampening of the vibration noise. We show that we can reduce the amplitude and frequency bandwidth of the noise, but that the spatial bandwidth remains fairly large.

As well as streamer mechanical properties we must consider sensor layouts of which there are two main types currently being used in the industry; analog arrays and uniformly spaced single sensors. However, analog arrays introduce compromises in noise attenuation performance and single sensor, uniform Nyquist sampling is costly therefore a new sensor layout type is desired. The new proposed layout involves non-uniform, single sensor sampling which brings a high level of flexibility into the design of spatial filters. This solution decreases the number of compromises that analog arrays present while being lower cost than single sensor, uniform Nyquist sampling.

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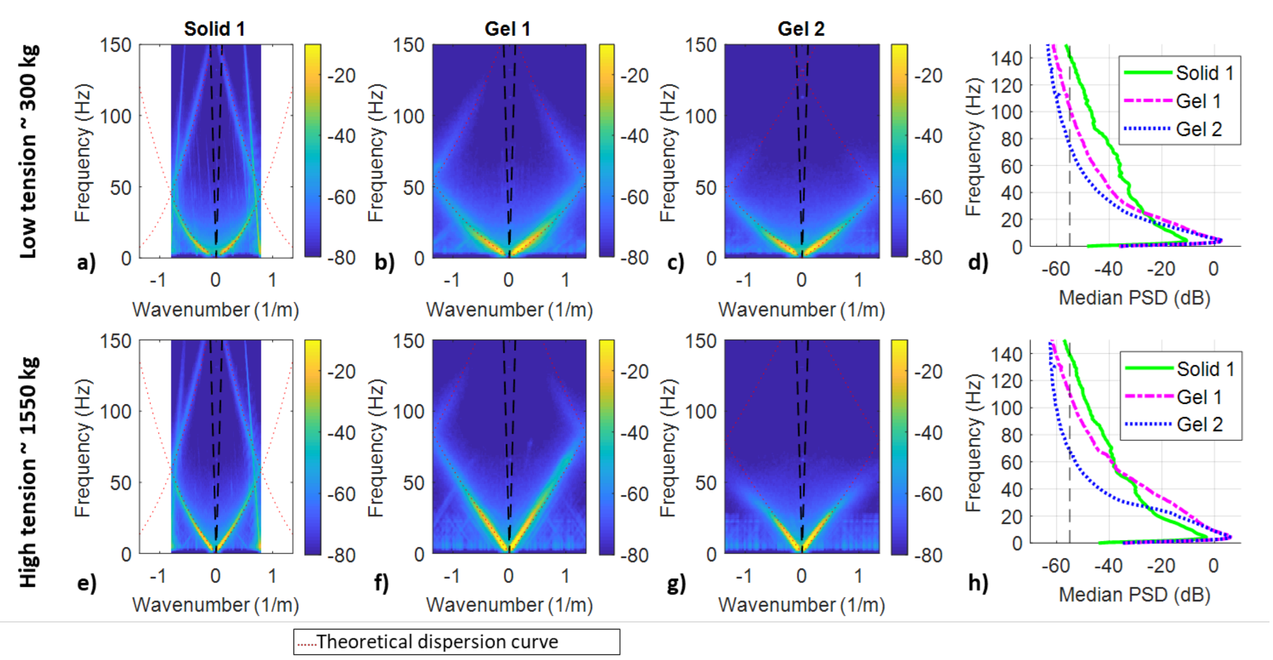

Figure 3. Frequency-wavenumber *(f-k)* spectra of three different sections. Under low tension of approximately 300kg, a) – c) and their respective median power spectral densities (PSD's), d). Corresponding *f-k* spectra under high tension (1500kg), e) – g) and their median PSD's, h).