Increased resolution of seismic data from a dual sensor streamer cable
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Summary

Presented are processed seismic data acquired from a dual sensor marine cable that records with both hydrophones and motion sensors. An overview of the theory for this acquisition concept is presented with an outline of the steps used that utilize the benefit of acquiring two separate wave-field components (Fokkema and van den Berg, 1993).

2D field test data was acquired concurrently with a survey that used standard (hydrophone only) cables. The data acquired using the dual sensor cable is shown to be correctly deghosted and has improved frequency bandwidth compared with the data acquired using standard cables.

Introduction

Traditionally, marine cables measure the seismic wavefield pressure using hydrophones. A new solid core dual sensor cable has been introduced (Tenghamn et.al., SEG submitted abstract, 2007). This cable measures the pressure wavefield using hydrophones and simultaneously measures the vertical component of the particle velocity using motion sensors. The advantages of measuring the complete wave field in this manner are numerous. These advantages include reduced acquisition noise and improved ability to acquire data during rough weather. The advantages arise from the fact that the cable can be towed deeper and that both wave-field measures are at exactly the same location. The simultaneous recording at the same location avoids cable positioning difficulties.

One particular advantage is that the two independent measures can be combined to separate the wave-field into up-going and down-going components. This separation has many applications. This paper shows an application for increased bandwidth for both low and high frequencies. Another application is multiple elimination (Söllner et.al., SEG submitted abstract, 2007).

Complementary amplitude spectra

The responses of a hydrophone and a motion sensor are fundamentally different. The hydrophone records a scalar measure of a wave-field; the measurement does not depend on the direction of the wave pulses. The motion sensor records a directional measure of a wave-field. This difference is most prevalent when the sea surface ghosts are recorded. For each type of measurement, the water surface reflections (ghosts) imposes a filter on the data. The 3D filter can be illustrated by restricting the effect to angle zero, i.e. vertically propagating signal.

For zero angle reflections, the hydrophone recording has a notch at 0 Hz and \( \frac{c}{2d} \) where \( c \) is the velocity of water and \( d \) is the cable depth of the hydrophones. There also is a notch at all integer multiples of \( \frac{c}{2d} \). Figure 1 shows the notches for \( d \) equal to 6, 7.5, and 15 meters with \( c \) assuming the value of 1500 m/sec. The frequency of the second notch become smaller as the depth becomes larger. Also, note that the lower frequencies are better preserved as the depth becomes larger. Because these notches should not be within the frequencies needed for data interpretation, hydrophone acquisition cable are not generally towed deeper than 8 meters. The second hydrophone notch is at 50 Hz. when the depth is 15 meters.

Figure 2 shows the notches for \( d \) equal to 15 meters for both the hydrophones (blue) and motion sensors (orange). The notches also have a spacing of \( \frac{c}{2d} \) but the first notch is not at zero but at \( \frac{c}{4d} \). That is, for the same depth the period of the motion sensor notches are the same as for the hydrophone but the notches are shifted by half the period or \( \frac{c}{4d} \). Because the hydrophones and motion sensors compliment each other in frequencies, they can be combined to yield a signal that does not have the effect of the surface ghost.
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The figures below are all derived from two shot records, hydrophone and motion sensor acquired at 15 meters.

Preprocessing dual sensor data

The preprocessing steps for dual sensor streamer data are similar to traditional processing of streamer data with a few exceptions:

1) The impulse response of the motion sensor (which has a non-flat spectrum) is matched to the flat zero phase hydrophone spectrum. The sensitivity functions for both are taken into account.

2) The hydrophone measurements are more stable because the motion sensor is recording a derivative or a rate of change of the wave-field. A low frequency compensation procedure is used to stabilize the motion sensor recordings.

3) The data is separated into up-going and down-going components using angle dependent methods similar to those for ocean bottom seismic processing (Ikelle and Amundsen, 2005).

4) After being separated into up-going and down-going components, both the hydrophone data and the motion sensor data can be extrapolated to different receiver depths.

Figures 3 through 5 illustrate some results of the above processing steps for one shot. Figure 6 shows the added value of this method by comparing the amplitude spectrum for the up-going wave-field with that of total wave-fields at the same depth. The up-going pressure field data does not have a ghost (i.e. does not have reflections from the surface to the cable). Multiples, including sea surface multiples, still remain in the up-going wave-field. However, the amplitude spectrum is broader; the broader bandwidth giving better resolution which is seen in the migrated field data.

Figure 2: Zero angle ghost notches for the motion sensor (orange) and hydrophone (blue) at a depth of 15 meters.

Figure 3: Amplitude spectrum of a near trace window for the recorded hydrophone shot record. Note the outline of the notch as illustrated in figures 1 and 2.

Figure 4: Example of an up-going pressure field. The hydrophone and motion sensor shots were decomposed into up-going and down-going pressure and vertical velocity field.

Figure 5: Amplitude spectrum of a near trace (green) window in the up-going hydrophone record in figure 4. Note the wide frequency bandwidth.
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Field data examples

As mentioned above, the data from a dual sensor cable has been recorded in the same survey using traditional (hydrophone only) streamers. The traditional streamer was at a depth of 8 meters and the dual sensor streamer was at a depth of 15 meters. The data were parallel processed except that the dual sensor data was preprocessed as discussed earlier and extrapolated to 8 meter cable depth.

Figure 7 is the migrated total wave-field from the dual sensor data extrapolated to a cable depth of 8 meters. As expected, this is very similar to the traditional streamer migrated data shown in figure 8. A dramatic difference is illustrated when the migrated traditional data is compared to the migrated up-going wave-field data in figure 9. The zoomed in windows show that thin beds are better defined as a result of the expanded frequency bandwidth.

Figure 6: Amplitude spectra for the up-going wave compared with total wave-field spectra. The extrapolated total wave-field is the sum of extrapolated up-going and down-going wave-fields.

Figure 7: The data was acquired using a dual sensor streamer at 15 meters, decomposed into up-going and down-going wavefields, extrapolated to 8 meter cable depth, reconstructed to form a total wavefield and processed up to time migration (Kirchhoff).
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Figure 8: The comparison section acquired using a hydrophone cable at depth 8 meters and processed up to time migration (Kirchhoff).

Conclusions

The concept and implementation of processing acquired marine dual sensor data is verified. The separation of the wave-field into up-going and down-going wave-fields gives more opportunities to extract information from the data. The up-going wave-field has a broader amplitude spectrum than the total wave-field data and gives better seismic resolution.

Figure 9: The up-going wave-field acquired using a dual sensor cable at 15 meters, extrapolated to 8 meter cable depth, and processed up to time migration (Kirchhoff). Note the improved resolution in the magnified window compared to figure 8.

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