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Towed Marine Vibrator Acquisition

Mike Jenkerson, Paul Allen, Heidi Scott, Tony Noss[2]

Mobil E & P Technical Center, Dallas, Tx, USA, [2]Schlumberger Geco-Prakla

Abstract

Previous studies have demonstrated that marine vibrators are a viable source for stationary acquisition in the transition zone. In this study we evaluate the performance of towed marine vibrators, and their advantages and disadvantages as an alternative to airguns. The test programs show that marine vibrators are a practical source for towed marine acquisition, that the phase distortion effect due to the vibrator motion can be corrected, and their environmental impact is low.

INTRODUCTION

Concerns about the environmental effects of impulsive marine and transition zone seismic sources, claims of damage to fish and crustacean stocks by fishermen and fishing authorities, and the expansion of seismic programs into more environmentally sensitive areas has led Mobil to investigate sources that will fulfil the geophysical requirements of seismic surveys while having acceptable environmental impact.

Marine vibrators have features that help to achieve these goals. The sweep spectrum is easily shaped allowing greater control of the signature, and in the homogeneous coupling environment of sea water the signature is expected to be more stable than the signature of an airgun array. Because the energy is delivered over time, typically 5-10 seconds, marine vibrators have low output power and hence acceptable environmental impact.

Mobil conducted a series of experiments in conjunction with Geco-Prakla to clarify the theory of marine vibroseis, to test the optimum amplitude and phase control methodology and to evaluate the acoustic behaviour (Walker et al, 1996). Following this work, the vibrator was re-engineered to improve the low frequency response of the transducer and a test program was subsequently shot in Schooner Bayou, Louisiana. This test indicated that stationary marine vibrators were a viable seismic source for acquisition in the transition zone and the data quality was comparable to both airgun and dynamite data. Further work also indicated that in conjunction with High Fidelity Vibratory Seismic (HFVS) processing the wavelet stability and repeatability could be improved (Smith and Jenkerson, 1998).

The qualities that made the marine vibrator attractive in the transition zone environment are also attractive in the deeper water seismic environment. A series of test programs was conducted to evaluate the effectiveness of marine vibrators in towed acquisition, and to evaluate the advantages and disadvantages of marine vibrators as an alternative to airguns.

EXPERIMENTAL EQUIPMENT CONFIGURATION

For the production testing six marine vibrators were deployed in a chevron pattern with 8 m crossline and 5 m inline separation. Each vibrator was enclosed within a rigid frame which was towed by a 200 m umbilical containing all stress members, and electrical and hydraulic lines. Mounted on each frame were four hydraulic accumulators to improve the low frequency performance, and a vane which allowed the vibrators to be diverted laterally. Each vibrator was powered by an electrically driven hydraulic pump with a separate hydraulic reservoir. This, plus fail safe umbilicals and a low pressure cut off system ensured that no significant amount of hydraulic fluid would be lost in the unlikely event that an umbilical was ruptured. As a final safeguard, Mobil used biodegradeable hydraulic oil (Mobil EAL224H) to ensure that even in the unlikely event of a hydraulic failure there would be no environmental damage. The vibrators were controlled using Pelton Advance II electronics with modified firmware for differential acceleration phase control. The measured motions from each vibrator were also recorded to allow inversion of the data (HFVS).

TEST PROGRAMS

Previous studies investigated the operational and geophysical characteristics of the marine vibrator in stationary acquisition. However, a number of performance issues remained unanswered since no recent data had been acquired to evaluate the performance of the modified vibrators when towed at standard acquisition speeds (4-5 knots):

- Had the modifications to the stroke and hydraulic sytems improved the low frequency performance of the vibrators?
- Could sufficient energy be imparted in a standard 25 m (12 sec) shot interval to acquire acceptable seismic data?
- Would the dip and frequency dependent 'Doppler' phase distortion inherent with a moving non-impulsive source significantly affect the phase of the data (Dragoset 1988, Hampson and Jakubowicz 1995, Noss et al, 1999)?

In order to address these issues two test programs were acquired. These programs were designed to compare airguns and marine vibrators, to evaluate the relative bandwidth and penetration of each source and to test the operational reliability of towed marine vibrators.

The first program was acquired in 1996 in the Norwegian North Sea, using a single 4000 m towed streamer. A 20 km long test line was acquired using both a 4258 cu.in. airgun array and the array of six marine vibrators. This was followed by a four line, 265 km proprietary marine vibrator program in another area. The six vibrators were deployed from a second vessel and a 70 m nominal crossline separation was maintained during the two boat recording. On site testing indicated that with a 25 m shotpoint interval it should be possible to record a 9.5 second record. A 5 second 5-90 hz linear upsweep was used for all the acquisition. The vibrator and airgun data from the test line, displayed in Figure 1, were very comparable.

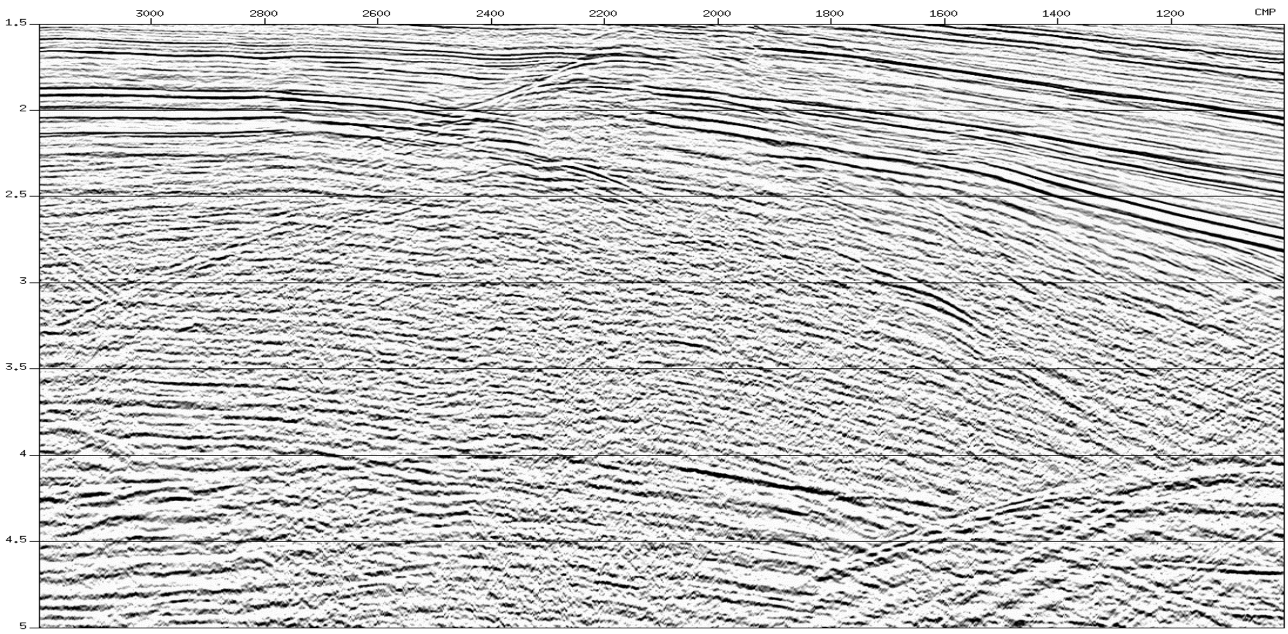

Figure 1 - Marine Vibrator (top) and Airgun (bottom)

One of the problems with making comparisons on streamer data is that the cable suffers from feather and therefore multiple passes along the same line can illuminate a slightly different piece of earth. This plus the two boat vibrator operation complicated the comparison of the airgun and streamer data. It was therefore decided to acquire a further test into a fixed, dual sensor OBC cable to eliminate the effects cable movement may have on the evaluation of the sources.

The second program was carried out early in 1998 in the Gulf of Mexico, where data was acquired into a 10 km long dual sensor OBC cable with a 50 m group interval. A 16 km long source line with a 16.7 m shotpoint interval was shot five times, once with a 3959 cu.in. airgun array, and then subsequently with 3, 4, 5 and 6 marine vibrators.

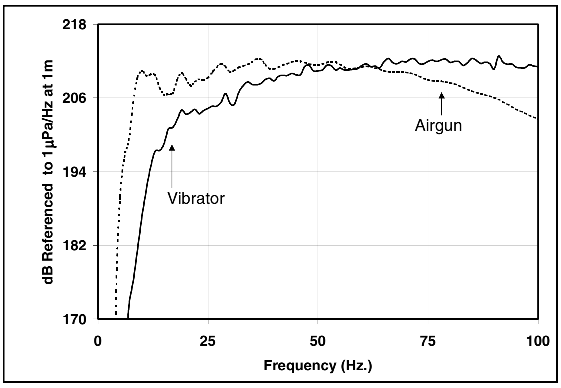

Figure 2 - Amplitude spectra of airgun and vibrator arrays.

ACOUSTIC OUTPUT OF THE MARINE VIBRATOR

In order to evaluate the effect of the increased stroke and improved hydraulic supply on the output of the vibrator, a calibrated far field signature was recorded in a fjord. Figure 2 compares the amplitude spectra of an 8 second, 8-120 Hz. linear sweep from an array of 6 modified vibrators and a 3000 cu.in airgun array, both at 6 m depth.

Although the airgun array still has more energy in the 0 to 30 Hz range, the two sources are virtually identical from 30 to 60 Hz. and above 70 Hz the vibrator has more energy than the airgun array. This is supported by an analysis of the experimental data recorded with both airguns and vibrators. Inspection of the stacked data indicates that airgun has better penetration of frequencies below 30 Hz. and marine vibroseis has better penetration of frequencies above 30 Hz.

HFVS PROCESSING OF THE MARINE VIBRATOR DATA

Previous analysis at Schooner Bayou (Smith and Jenkerson, 1998) showed that if the data is inverted with HFVS wavelet stability and repeatability is improved. In this analysis however, phase encoding was used to to allow separation of individual vibrator contributions, and each separated record was inverted with its appropriate measured motion. However, when operating the marine vibrators in towed mode, we cannot acquire multiple sweeps at a given location, thus separation is not possible. When only one record can be acquired, we currently have no option but to correlate with the reference, which we know is a sub-optimal process, or to invert the recorded data with the sum of the vibrator differential accelerations.

Analytically it can be shown that inverting with the sum of the differential accelerations is exactly equivalent to summing individually inverted records when: the Earth's transfer function is exactly equal at each vibrator location, or the vibrator motions are exactly equal. We know that the first condition is not exactly true since the vibrators don't occupy the same physical location when they are swept. We also know that the vibrator motions are not exactly equal, primarily due to differences in their harmonics. However, both individual vibrator repeatability and similarity between vibrators is very high when the vibrators are operated using fundamental phase lock and force control. Figure 3 shows a plot of cross-correlation matrices for a good (left), bad (center) vibrator and a sum of all six differential acceleration signals. Each one is a plot of the semblance between every pair of signals from 1052 records. While there are minor variations in the measured motion from shot to shot, the summed differential acceleration signal is very stable. This indicates that it should be possible to improve data quality by inverting the data using the sum of the differential accelerations.

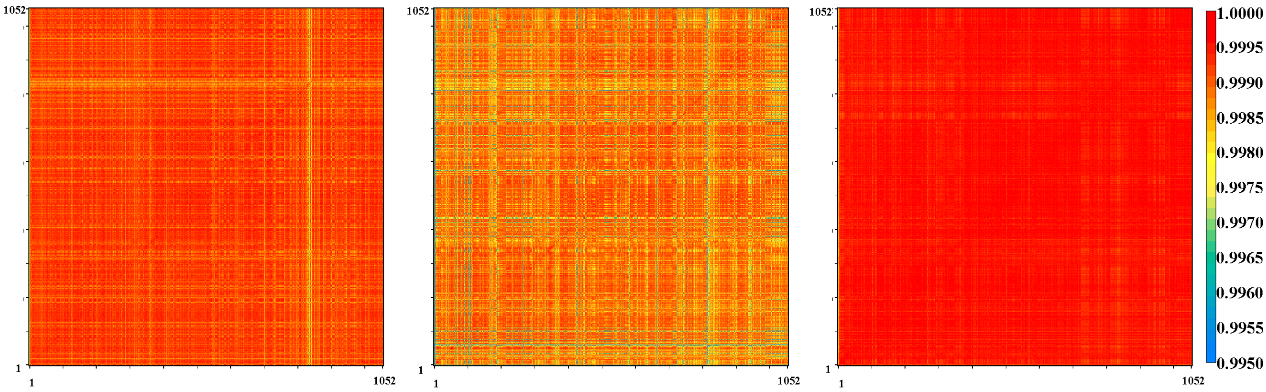

Figure 3 - Cross-Correlation matrices for a good (left) and bad (center) vibrator and summed differential accelerations for all six vibrators. As can be seen both the good and bad vibrators have very high similarity between the measured motions and the summed differential acceleration has a very high correlation coefficient.

SOLUTIONS TO THE PHASE DISTORTION PROBLEM

Over time a number of authors have discussed the dip and frequency dependent phase distortion caused by the motion of the source during the sweep (Dragoset, 1988, Schultz et al, 1989, and Hampson and Jakubowicz, 1990). Although some have presented solutions, the most practical have suffered from the lack of sufficient sampling along the shot axis, and have been quite expensive to run.

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Geco-Prakla has adaptated the Schultz method to allow the correction to be applied in the frequency-space domain, and has reduced some of the spatial sampling requirements (shot intervals as large as 25 m can now be corrected with full fidelity). Further work is ongoing on methods that use the much finer spatial sampling along the receiver axis. Model work has shown these techniques to be very effective. It is likely that a combination of these two methods will cover all normal scenarios for towed vibrator acquisition.

As part of both the streamer and OBC programs, one line was recorded using 23 second sweeps for subsequent testing of the phase distortion correction algorithms. In both cases the line was acquired over an area of steep dip to test the limits of the correction algorithms. Tests on this data as well as model data indicate that the two methods perform effectively.

ADVANTAGES OF THE MARINE VIBRATOR

Although its total energy is approximately equivalent, the marine vibrator has a maximum peak to peak pressure output level of 0.14 MPa-m compared to 4.0 MPa-m for a 750 cu.in. air gun subarray (0-800 Hz). Marine vibrators have also been shown to cause no damage to fish and crustaceans, and it is possible that they will prove less disturbing to marine mammals. This is because the only energy outside of the sweep band is harmonics, while the airguns have energy in the kHz range. The amplitude and frequency content of this harmonic energy will be measured later this year.

The flexibility of the marine vibrator holds out the possibility that different methods can be found for improving their efficiency, such as simultaneous dual source acquisition and slip sweep acquisition. For slip sweep acquisition, recording systems will have to be modified to allow continuous recording. Slip sweep was tested during the OBC acquisition and found to be operationally feasible apart from continuous recording.

One additional advantage of the marine vibrator is that it can be used with a much shorter near trace offset without overdriving the traces. This, plus the measurable signature could have processing advantages (eg.multiple removal).

CONCLUSIONS

Data acquired in Norway and the Gulf of Mexico has shown that marine vibrators are a viable towed seismic source with comparable data quality to airguns. A number of questions relating to the operational feasability of marine vibrators were answered:

- The low end deficiency has been partially addressed by the use of hydraulic accumulators and can be further improved by the use of a low frequency dwell. The vibrator has better output than the airgun at high frequencies.
- For normal record lengths marine vibrators can impart sufficient energy in a 25 m shotpoint interval to acquire good data.
- Processing methods exist to correct for the phase distortion caused by the source and receiver motion. These methods can be applied to standard streamer and OBC geometries.
- The lower peak pressure of the marine vibrators will have a negligible impact on marine life.

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