Slip Sweep Harmonic Noise Rejection on Correlated Shot Data

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Summary

A new method has been developed for rejection of harmonic noise in vibroseis data recorded with slip sweep. The filter for harmonic noise estimation is derived using only the recorded Ground Force and the start times for the sweeps. The recorded Ground Force is separated into the fundamental and the harmonic noise components and the two separated signals are used to design the filter. The harmonic noise is computed by convolution of this filter with the correlated traces of the shot for which it was recorded. The traces are correlated with either the pilot sweep or the Ground Force. The estimated noise is then subtracted from the traces of the previous shot. This approach is very efficient and robust because the traces can be correlated in the field using the Ground Force signal and the harmonic noise can be removed either in the field or in the processing center. Examples using synthetics show that harmonic noise becomes significant when there is a very large first break that is more than 100 times the amplitude of the subsurface reflection amplitudes. Results from a field data show excellent reduction of the harmonic noise without degradation of the desired signal

Introduction

To improve the efficiency of acquisition, a second vibroseis sweep is started before the end of the recording time for the previous sweep. Harmonic noise is generated in the base plate and is sent into the earth as signal. Engineers have been unsuccessful in eliminating it from vibroseis systems. When the vibroseis sweeps are overlapped in time, using the method known as slip sweep, the harmonic noise of the second sweep is correlated into the traces of the first sweep. Several methods have been published and patented for rejection of this harmonic noise in the recorded traces. Fleure, 2002, proposes a method of overlapping sweeps in time but the frequencies of the 2 sweeps are controlled such that there is separation in the frequency domain. Munier, 2003, proposes a method of predicting each harmonic and recursively removing the noise due to each harmonic. Moerig, 2007, proposes a method of estimating the harmonic noise by correlating the records for negative and positive times and using the negative time portion as a noise estimate for the previous shot.

A new method for rejecting this noise is presented. We observe that the recorded Ground Force signal contains the primary signal and the harmonic noise. We first separate the Ground Force into the fundamental and harmonic noise. A filter is computed using the signal and the noise from the Ground Force. The filter is used to estimate the harmonic noise generated by the current shot and contributed to the previous shot. Synthetic and real data examples show that the approach works very well. Every reflector in the subsurface generates harmonic noise. Synthetics show that the amplitude of the harmonic noise is approximately a factor of 100 lower than the amplitude of the reflection that produces the noise. Harmonic noise becomes very large in the presence of a very large first break. The high amplitude harmonic noise overlaps the subsurface reflections in the previous shot. This filtering technique has been used successfully on field data and is much more efficient and robust than previous techniques.

Background

Harmonic noise is generated by the base plate and reaction mass system. Figure 1 shows an example of harmonic noise on field data traces. Because of this noise, most seismic vibroseis data is recorded such that the two sweeps are not overlapping in time. However, the desire to save acquisition time has led to an increase in the popularity of slip sweep recording. The recorded Ground Force contains the entire signal sent into the ground, including the harmonic noise. The offending noise can be separated from the Ground Force recording and used with the separated fundamental to compute a filter for predicting the noise on the traces of the previous shot. Figure 2 shows the Ground Force and the separated signals. Figure 3a shows an example of the Frequency-Time plot for a field recorded Ground Force signal. The fundamental is the high amplitude diagonal line in Frequency-Time. The harmonic noise is all of the other energy. Figure 3b shows the Frequency-Time plot of the derived filter using the fundamental and noise separated from the Ground Force.

Filter Design

Separating the GF into fundamental and harmonics yields a fundamental trace and a noise trace as shown in Figure 2. A filter is computed by spectral division of the cross correlation of the signal with the noise and the autocorrelation of the signal.

$$F(f) = CC(f)/A(f)$$

The minimum length of the filter is the slip time between overlapping shots. In general, the length of the filter is computed for the length of the sweep. In the example shown the length is 12 seconds. The filter is convolved with the traces of the current shot to predict the noise on the traces for the previous shot. Adaptive subtraction is used to subtract the predicted noise from the traces of the previous shot. One filter is computed for each shot and applied to all of the traces in the shot.

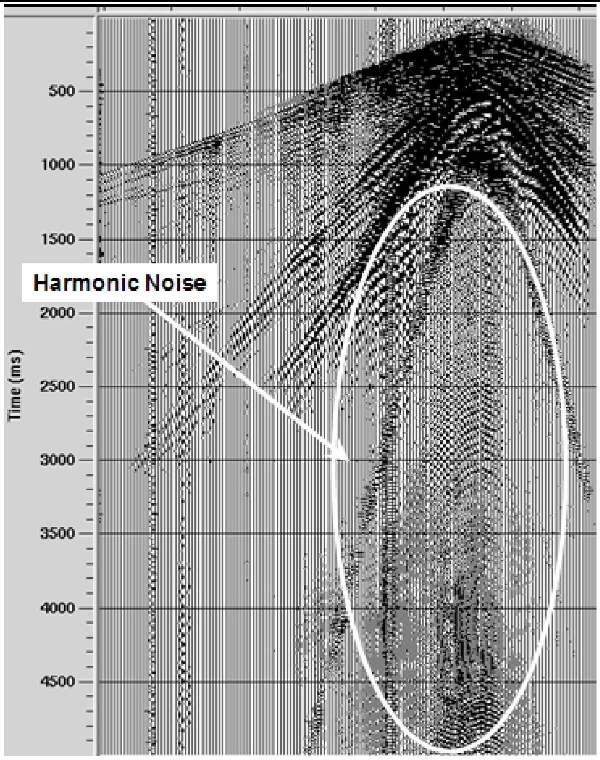

Figure 1: Example of harmonic noise on the correlated traces of a field record.

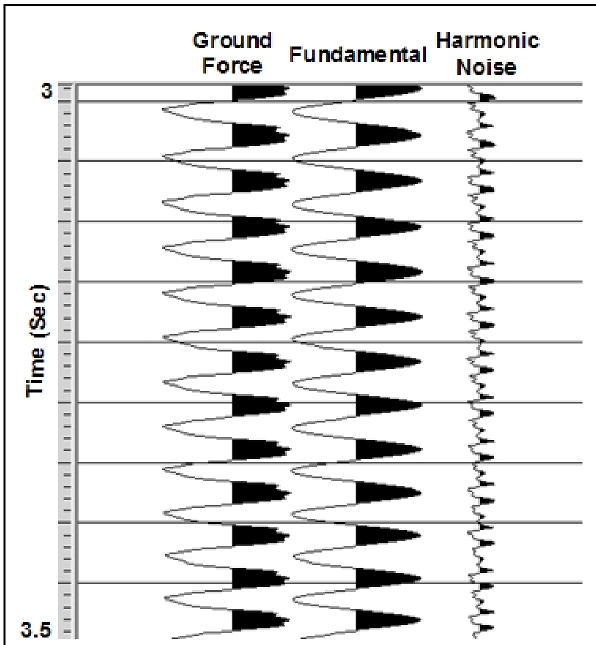

Figure 2: Example of a Ground Force recording, the separated fundamental, and the separated harmonic noise for the time window 3.0 to 3.5 seconds.

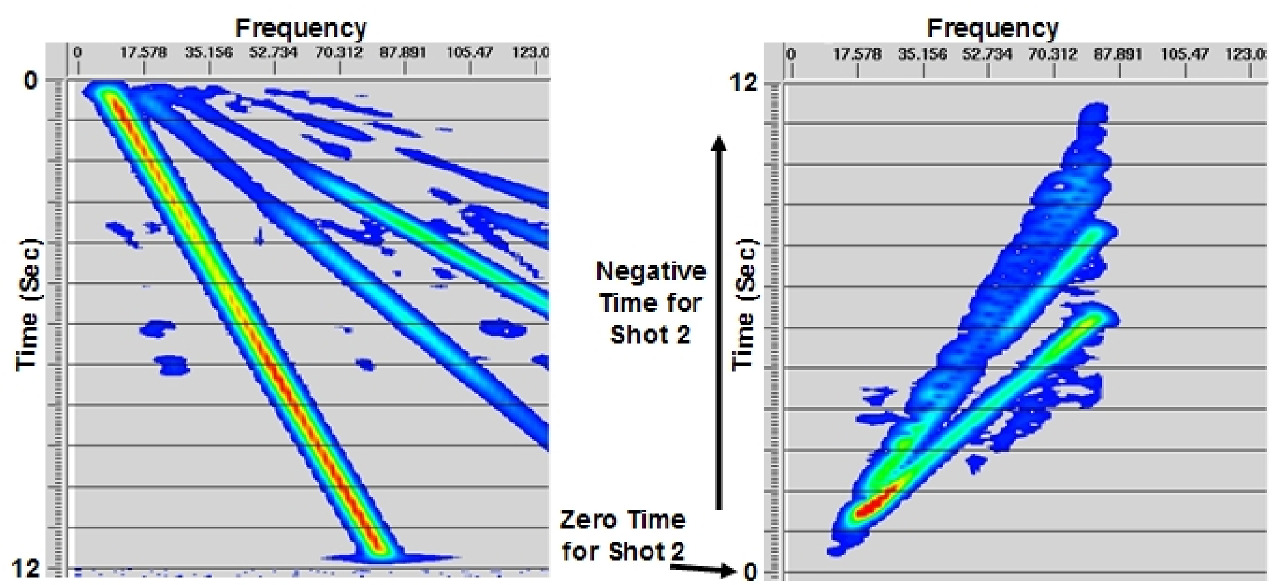

Figure 3: a) Frequency-Time transform of the Ground Force signal from Figure 2. b) FT transform of derived filter. This is the harmonic noise filter used to estimate harmonic noise in prior shot.

Synthetic Examples

A synthetic with 3 reflection events and 1 shallow first break event was created and used for investigation of the amplitude of harmonic noise created by the amplitude of the first break. The field data and the synthetic had a sweep length of 12 seconds and a correlated record length of 5 seconds. The field data has a very large first break. The ratio of the first break amplitude to the reflection amplitudes was varied until the harmonic noise in the synthetic matched that observed in the field data. For this data example the first break amplitude was raised to 300 times the amplitude of the reflectors. Figure 4 shows a field trace and the synthetic trace with the first break. The Frequency-Time transforms in Figure 4 show that the harmonic noise is equivalent in the two traces. The first break amplitude was then varied from a factor of 1 times the reflection amplitudes to a factor of 300 times the reflection amplitudes. The harmonic noise produced for a factor of 1 times the reflection amplitudes was negligible. The first break factor had to reach a factor of 50 times the reflection amplitude before the reflection amplitudes were compromised by the harmonic noise.

Field Data

The filter technique presented in this study was applied to a full 3D survey with very good results. Figure 5 shows the correlated traces from a single cable from a field record. The left panel shows the traces with the harmonic noise and the right panel shows the traces after noise rejection. An automated workflow was used on all of the correlated shots for the entire survey. The requirements for this technique are the correlated data traces, the Ground Force recordings, and the start times for each sweep. The compute time is not large which makes the process is very robust. It can be implemented in the field or applied at the processing center.

Conclusions

The new method for rejection of harmonic noise in slip sweep recordings is very robust and efficient and can be applied in the field or in the processing center. Uncorrelated traces are not required for this method. The data required is the Ground Force recording for each shot, the start time for each shot, and the correlated traces. Examples using synthetics show that harmonic noise becomes significant when there is a very large first break event that is more than 100 times the amplitude of the subsurface reflection amplitudes. Results from a field data show excellent rejection of the harmonic noise without degradation of the desired signal

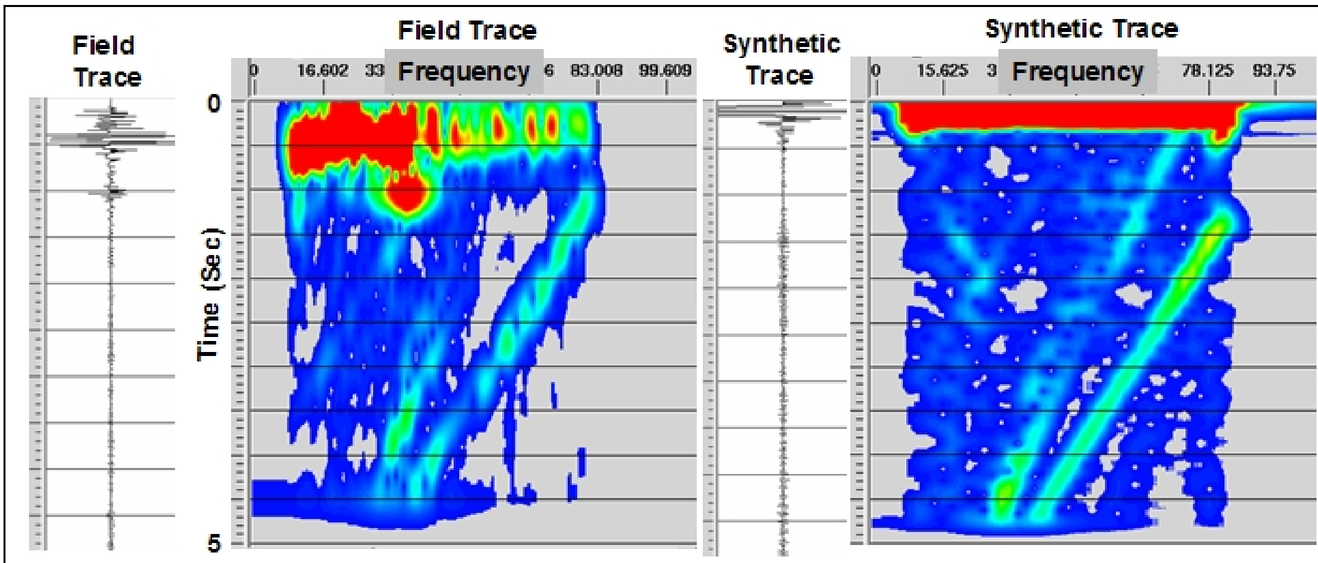

Figure 4: *a*) Field trace with high amplitude first break. *b*) Synthetic trace with slip sweep noise created with first break amplitude and reflection amplitudes that match the field trace. The first break amplitude is 300 times the amplitude of the reflections. *c*) Frequency-Time transform of the field trace in *a*. *d*) Frequency-Time transform of the synthetic trace in b.

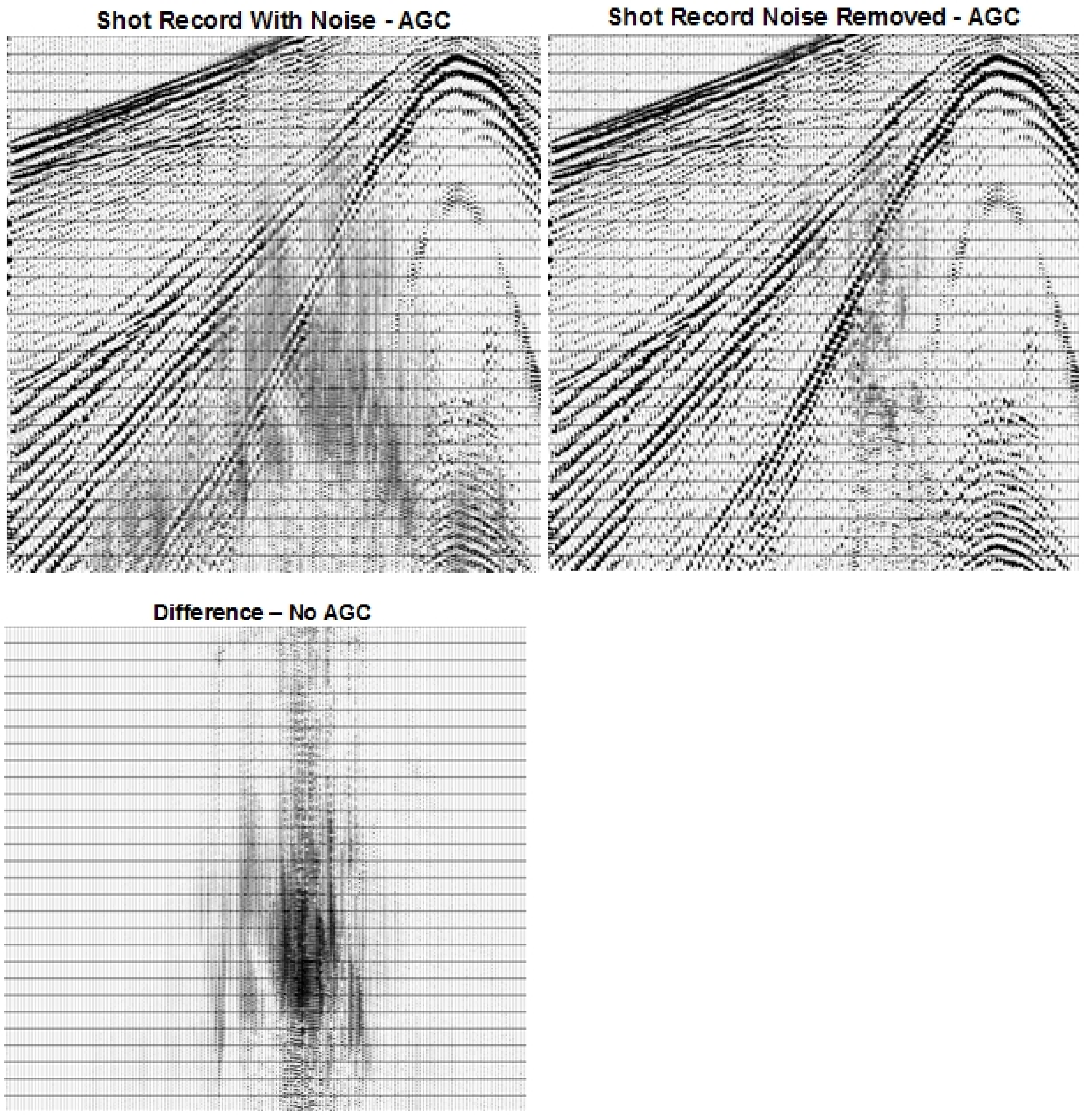

Figure 5: Field record *a*) with harmonic noise, *b*) after noise rejection and *c*) difference.