# Correlating Versus Inverting Vibroseis Records: Recovering What You Put into the Ground*

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## Abstract

Inverting uncorrelated seismic records avoids problems associated with the correlation method of removing the sweep energy by an approach, which deconvolves, or inverts, with a recorded measured motion trace. North American Oil Sands Corporation has successfully used the method to image the McMurray target (depths of 500m) with high resolution (5m) and broad bandwidth (8-175Hz). The method is considered to address three main areas of vibroseis specific noise: harmonic energy, side-lobe spurious reflectivity generated by correlation and, thirdly, potential recovery of a record from a sweep, which deviates from the theoretical.

## Problems

The first of vibroseis specific noise, harmonics, is illustrated in Figure 1 and Figure 2. Figure 1: *Spectrum of non-linear sweep (theoretical)* indicates the energy, which we are attempting to generate at the vibrator. This we call the theoretical, fundamental, or radio sweep, among other names. Figure 2: *Spectrum of uncorrelated trace* is the resultant energy recorded at a receiver station. The repeating energy recorded is termed harmonic energy.

The mathematical process of correlating vibroseis records with the theoretical sweep to collapse the sweep effectively ignores the harmonic energy. It has generally been an aspect of vibratory data, which is considered to be within acceptable limits of noise, the fundamental energy being of much higher amplitude over the sweep spectrum. One tantalizing feature of the harmonic energy is that the frequencies generated are greater than the input signal (a 100 Hz fundamental has a first harmonic of 200 Hz). This aspect of harmonic energy has led many in the field of vibratory data acquisition and processing in attempts to harness this “noise”. Interestingly, as much work has been conducted to suppress the noise (generally at the acquisition stage) as there have been to harness the noise (at the processing stage).

The second problem associated with vibratory records is side-lobe energy and the related issue of mixed phase wavelets, which result when the recorded trace is cross-correlated with the theoretical sweep. Cross correlating the records to collapse the sweep results in a zero-phase Klauder wavelet convolved with the minimum phase earth response (Yilmaz 1996), a mixed phase wavelet would be the result. Converting the zero-phase Klauder to a minimum phase wavelet introduces “processing” noise, which is dependent on how the match filter was, designed (Gibson and Larner, 1984). The last problem is the simple notion that if the actual sweep deviates from the theoretical by a large degree the resultant correlated record would be unusable.

## Solutions (Methodology)

An accurate recording of the energy being generated by the vibrator is the key component of inverting the sweep energy from the raw records through designature deconvolution. North American Oil Sands Corporation commissioned the outfitting of minivibes to record 24-bit digital records of the baseplate and reaction mass motions during the acquisition of seismic data in the northeastern plains of Alberta. Single vibrator/single sweep shaking was adopted ensuring that the sweep energy being recorded at the receiver station would be free of multi-vibrator interference. Figure 2 and Figure 3 indicate that harmonic energy is captured at the receiver station and at the baseplate.

Figure 3 shows that harmonic energy is captured at the point of sweep generation. Spiking deconvolution is then applied to the measured motion trace resulting in an estimate of source signature (see Figure 4) which will be removed from the uncorrelated records. The reason for spiking the trace has been explained by Krohn and Johnson (2006) based on work of Allen et al. (1998). In effect, spiking the trace reduces it to a phase only operator.

The usual vibroseis convolutional model is:

$$x(t) = s(t) * w(t) * e(t) \qquad \text{Equation 1}$$

where x(t) is the recorded trace, s(t) is the sweep, w(t) is the seismic wavelet, and e(t) is the earth’s impulse response.  After correlation, this becomes:

$$x'(t)= k(t) * w(t) *e(t) \qquad \text{Equation 2}$$

where k(t) is the zero phase Klauder wavelet. We now have the situation where an inverse filter can be determistically designed (see Figure 4) then applied to the recorded trace thus removing s(t) from equation 1. The approach is analogous to the marine case of removing the recorded far field source signature from the recorded trace, however in the vibroseis case being discussed here; there is a source signature for every sweep.

Therefore, after applying a deterministically designed inverse filter, the vibroseis convolutional model looks like

$$x'(t) = w(t) * e(t) \qquad \text{Equation 3}$$

## Results

Comparing final migrated sections from vibroseis data, which was recovered by the source designature technique (Figure 5, left) versus that which was recovered by correlation (Figure 5, right), we find little difference in the recovered frequency spectrum, however sharper event delineation was noted on the designature section.

## Conclusions

Using the measured motion trace to recover vibroseis records is proving to provide excellent results on shallow, high-resolution targets. The approach continues to be used and improved.

## Selected References

Allen, K.P., M.L. Johnson, and J.S. Ma, 1998, High fidelity seismic (HFVS) method for acquiring seismic data: 68th Annual International Meeting, SEG, Expanded Abstracts, p. 140-146.

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Krohn, C., and M. Johnson, 2006, HFVSTM: Enhanced data quality through technology integration: Geophysics, v. 71, p. E13-E23.

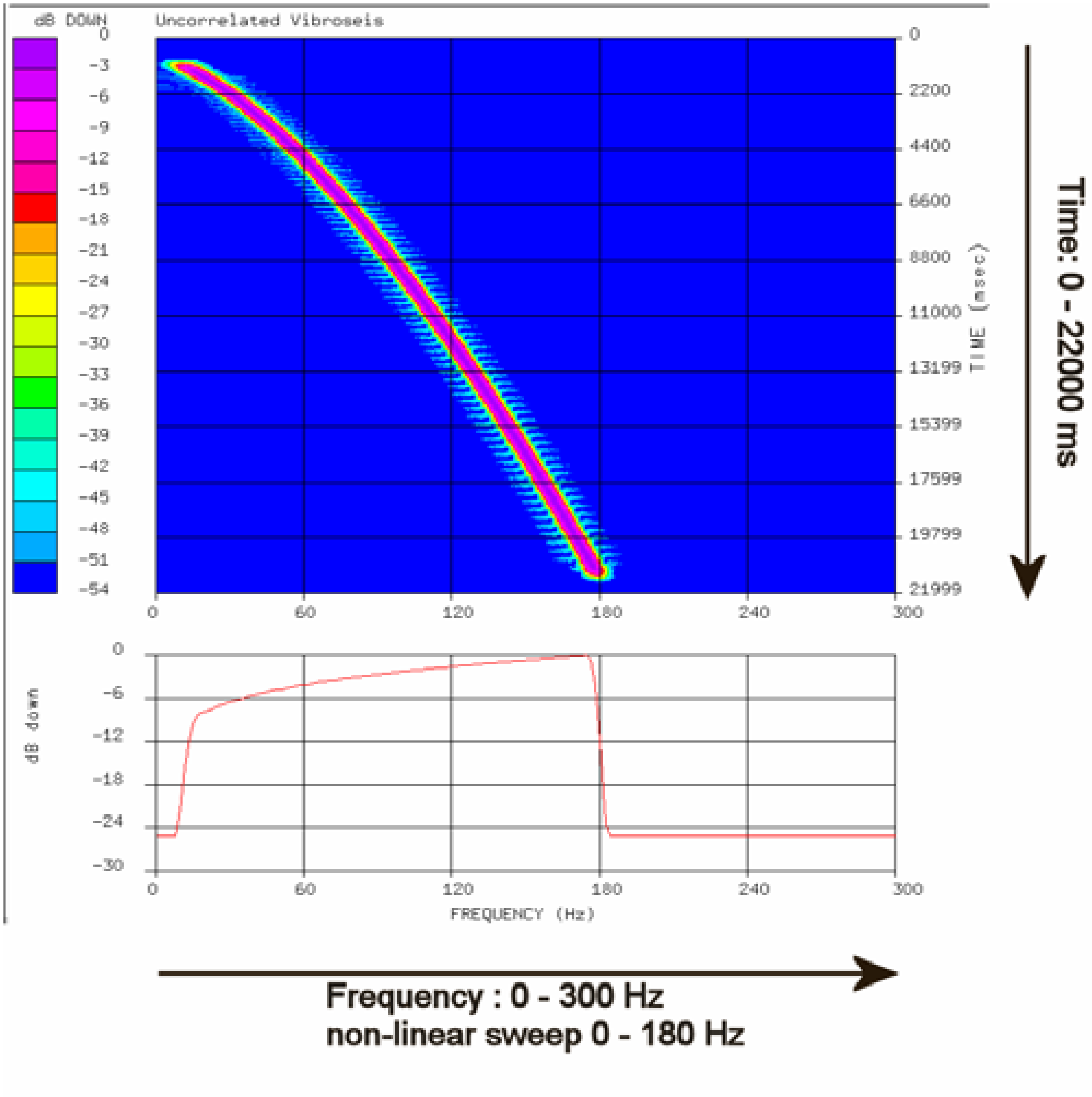

Figure 1. Spectrum of non-linear sweep (theoretical or fundamental sweep).

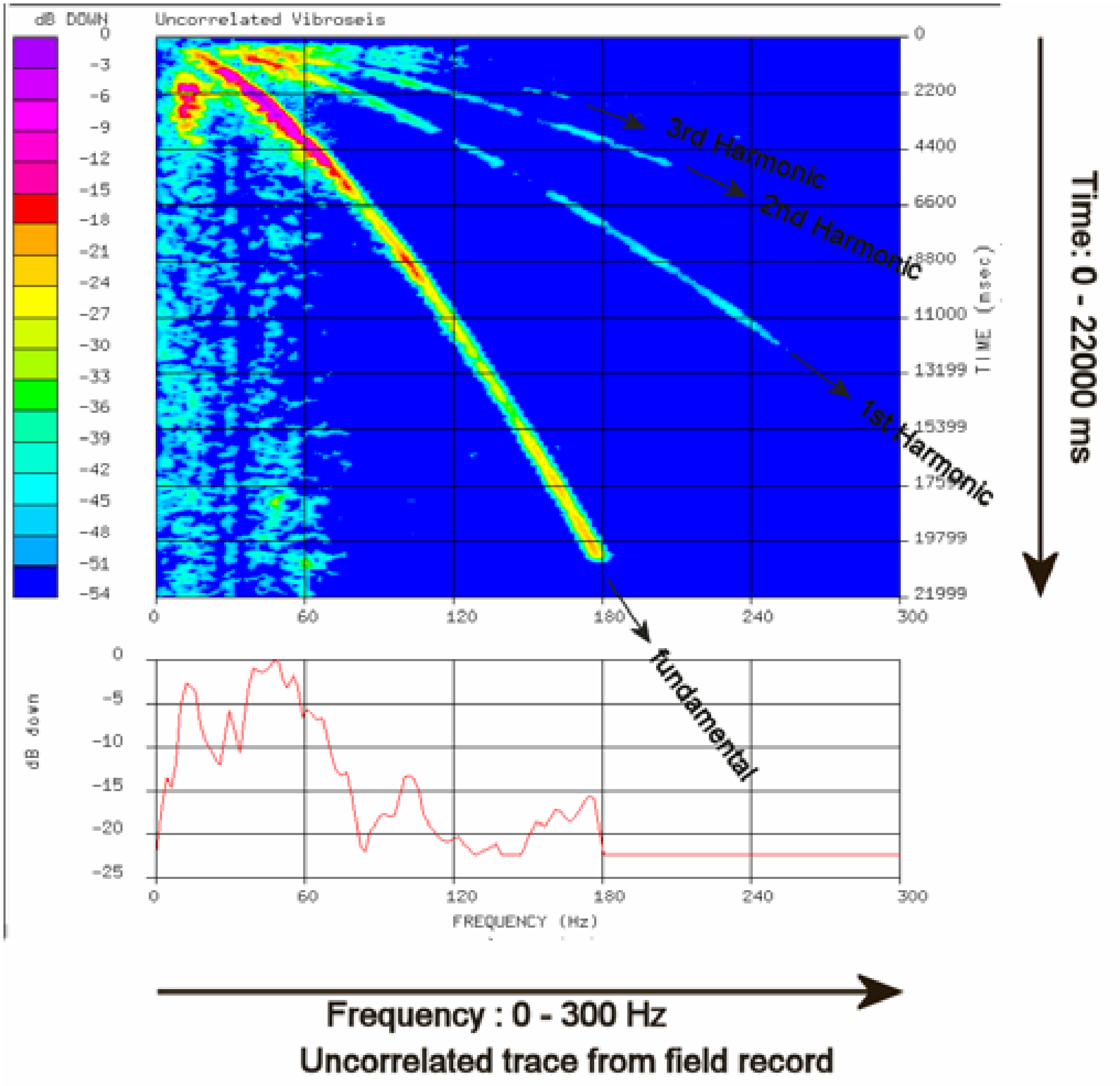

Figure 2. Spectrum of uncorrelated trace recorded at an offset of 700 m.

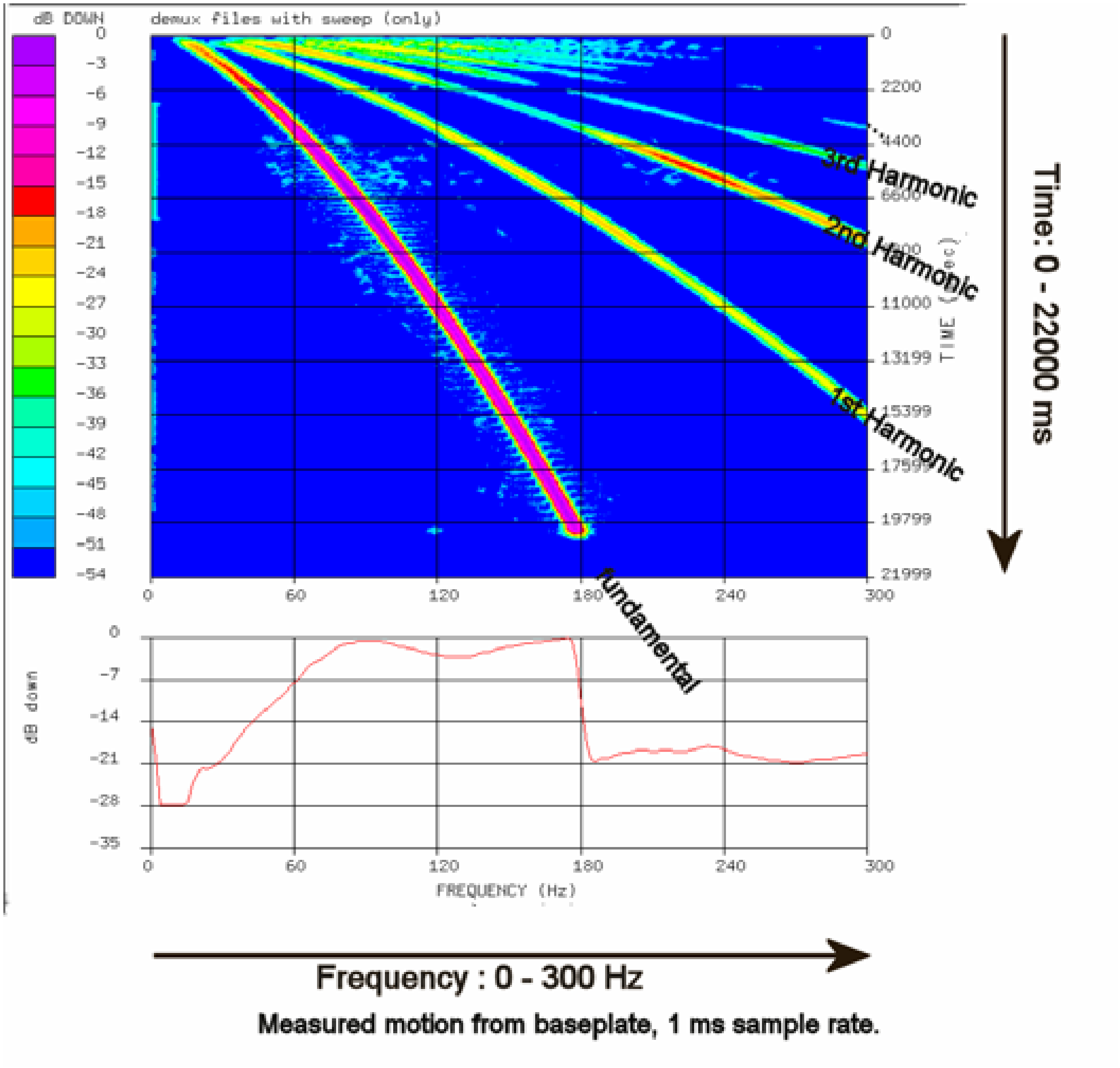

Figure 3. Spectrum of measured motion recorded on vibrator baseplate. Sample rate = 1ms. Sweep: 8 – 180 Hz.

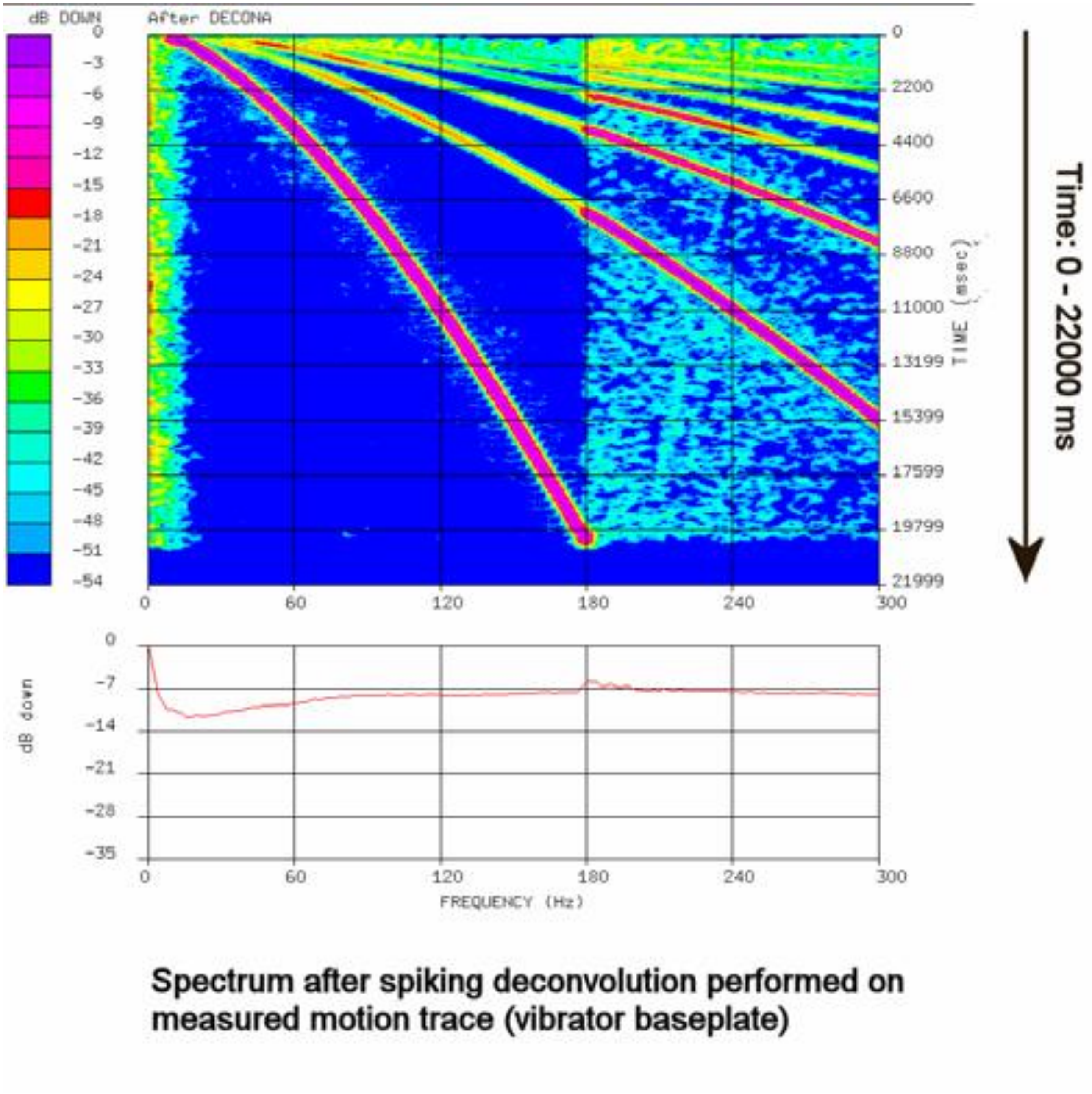

Figure 4. Spectrum of measured motion after spiking deconvolution.

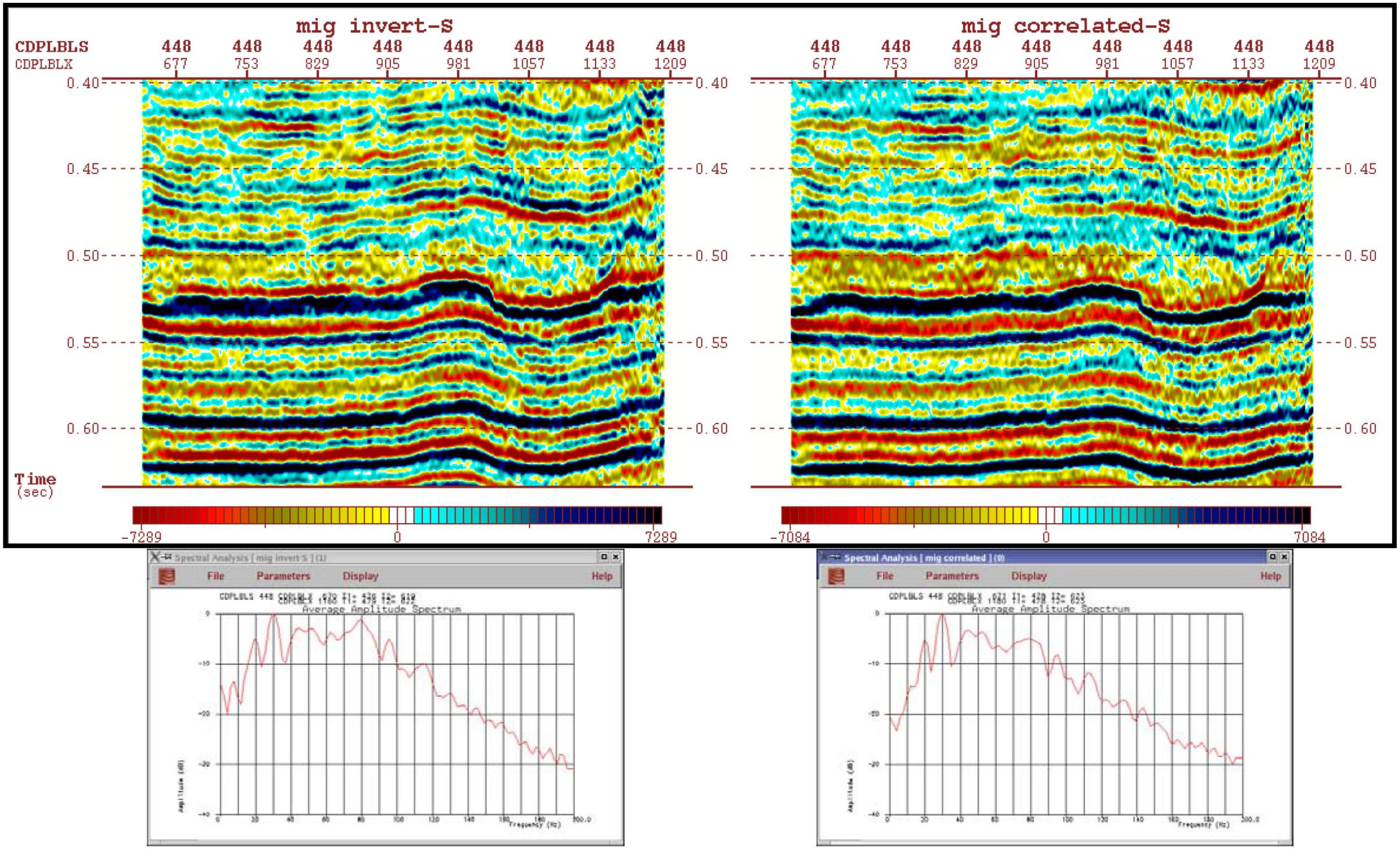

Figure 5. Comparing final migrated sections from vibroseis data.