Workshop paper: I01

Land Vibroseis Source Advances towards Low Frequencies

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SUMMARY

Extending the frequency bandwidth towards low frequencies using the Vibroseis method has gained a lot of attenation recently. The source (vibrators) becomes one of the obtacles in the success of recording low frequency seismic signals. How do we increase the vibrator ground force at low frequencies (< 10 Hz)? Can the vibrator control electronics effectively supress harmonic distortion at low frequencies? This paper attempts to provide a fresh look at these questions.

Introduction

Low frequency content in seismic data can bring many geophysical benefits, for example obtaining deeper structure information, improving waveform inversion for velocity model determination. Additionally, low frequencies can help minimize side lobes of cross correlation wavelets thereby improving the resolution of seismic data. However, it is a challenge for seismic vibrators to produce sufficient force with a good S/N ratio at low frequencies.

Improving the vibrator ground-force output

One approach for this challenge is to improve the vibrator mechanical and hydraulic system to make the vibrator more effeiciently produce the ground force. Figure 1 shows that with improved vibrator mechanical and hydraulic system, the radiated low frequency energy is increased. Figure 1 displays a ccomparison of time variant spectra plots using a geophone at 15 m depth with a conventional vibrator (Figure 1a) and a modified vibrator (Figure 1b). Two lines at 10 Hz and 6 Hz are added for better illustration of improvements. It can be seen that with the modified vibrator, the radiated energy between 6 Hz and 10 Hz is significantly enhanced. Moreover, the modified vibrator extends the radiated energy significantly down to at least 2Hz whilst using identical linear sweeps.

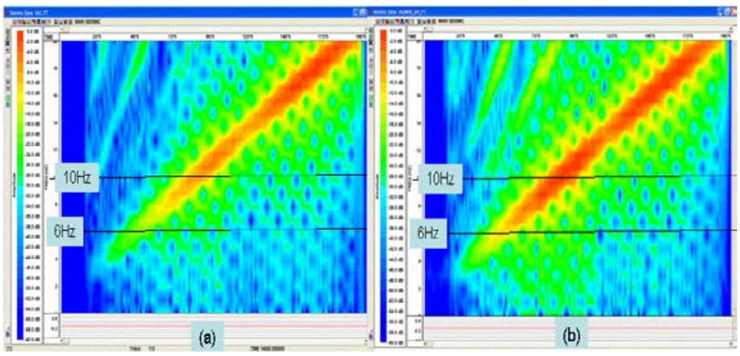

Figure 1 *Time variant spectra analyses of (a) a conventional vibrator and (b) a modified vibrator.*

Another approach for this challenge is to design a low frequency sweep so that the vibrator output follows a low frequency force profile without exceeding its physical limits, and then dwelling for a longer time (Bagaini 2008; Sallas 2010; Baeten 2011; Wei and Phillips 2012). Figure 2 shows as an example to demonstrate that a vibrator ground force at low frequencies can be improved with a low frequency sweep. The plot was generated with data recorded on the same vibrator using weighted-sum ground forces that were produced with a low frequency sweep and a linear sweep. Both sweeps are from 1 Hz to 100 Hz in 24s at a target force of 186,816 N. It can be seen that at low frequencies more ground force power can be generated with the low frequency sweep than using a conventional linear sweep.

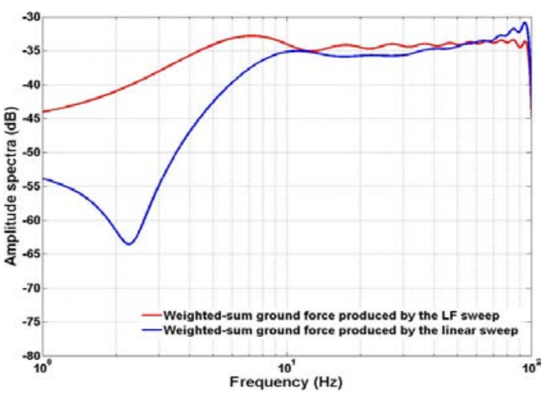

Figure 2 *The amplitude spectra of the weighted-sum ground force produced with two different sweeps, a low frequency sweep and a linear sweep.*

Suppressing harmonic distortion

Due to physical limitations in vibrator mechanical and hydraulic systems, the ground force output from a vibrator at low frequencies is limited. This limited ground force is severely distorted by harmonic distortion such that the ground force in fundamental frequencies is reduced. With deep understanding of the nonlinearities in the vibrator system, control algorithms can be developed to suppress harmonic distortion at low frequencies.

Figure 3 illustrates the improvement of the vibrator performance at low frequencies with the harmonic distortion reduction control. This plot was produced using a 10s linear sweep from 1 Hz to 11 Hz Figures 3a, 3b and 3c show the fundamental force, phase and harmonic distortion, respectively. It can be seen with harmonic distortion reduction control, both the fundamental force and phase are improved. The improvement of the fundamental force is very pronounced above 3 seconds which corresponds to 4 Hz. The phase, in general, is closer to the zero degree line, especially above 3 seconds. At very low frequencies (below 3 seconds) the phase is moderately enhanced. Figure 3b shows that the harmonic distortion is significantly suppressed between 2.5 seconds (3.5 Hz) and 7 seconds (8 Hz) with the harmonic distortion reduction control.

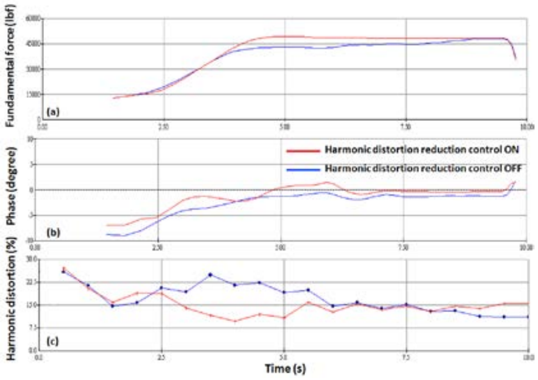

Figure 3 *Comparisons of the vibrator performance at low frequencies using a linear sweep from 1 to 11 Hz in 10 seconds at a drive level of 213,600 N (48,000 lbf) with harmonic distortion reduction control ON and OFF, (a) fundamental force, (b) phase, (c) harmonic distortion.*

Conclusions

Many efforts have been made in recent years to push the Vibroseis bandwidth towards low frequencies. This paper has discussed two fundamental aspects of the vibrator system and demonstrated that improving the mechanical and hydraulic system of the vibrator and its control electronics can significantly extend the frequency bandwidth towards lower frequencies. Additionally, with low frequency sweeps vibrators can generate more ground force at low frequencies.

References

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