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Broadband Pseudo-random Vibratory Sweeps for Productivity Enhancement

P. Scholtz* (TGS Geophysical Company (UK) Ltd)

SUMMARY

Increasing the vibratory seismic bandwidth especially on the low end brought new challenges. To reach deeper signal penetration, to improve reflection continuity and to enhance inversion solutions, broadband non-linear sweeps were introduced to overcome the mechanic and hydraulic limitations of a standard seismic vibrator. The main disadvantage is the substantially longer non-linear sweep length compared to the length of an equivalent energy linear sweep. Pseudo-random sweeps are also tested and applied with success, but have not gathered enough momentum for widespread use yet. We have developed a global optimisation method and defined constraints to produce broadband pseudo-random sweep sequences, which have the potential to replace broadband non-linear sweeps with satisfactory quality while reducing sweep length to increase productivity. The optimisation process could incorporate the need for higher sweep energy, lower spectral fluctuations and also keeping vibrator limitations, the control parameters which are unavailable in the standard software given by the vibrator manufacturers. Our numerical calculations show that optimised broadband pseudo-random sweeps have the potential for a few percentage productivity increase in normal applications, but several hundred percentage enhancement in urban seismic measurements, where resonance effect reductions are also on our side.

Introduction

During a seismic acquisition there is always a compromise between cost and quality. The seismic reflection methodology went through mayor changes in recent years to improve data quality while increasing productivity. Nowadays broadening of the seismic bandwidth brought an important step forward in case of seismic vibrator sources. Unfortunately the standard hydraulic vibrators have serious limitations especially on producing low frequencies hence special sweep signals were introduced to meet the challenges. A general solution for low starting frequency is a low-dwell non-linear sweep, as given by Bagaini (2008). The sweep designs have to take into account the displacement and hydraulic flow limitations of the actual vibrator. As a result the sweep length is much longer than the length of an equivalent energy linear sweep. For simultaneous source acquisition and broadband tests Sallas *et al*. (2008) and Maxwell *et al*. (2010) employ pseudo-random sequences. The main advantage with pseudo-random sweeps is that the entire sweep length is utilized to emit all the frequencies hence the peak demand is spread along it. There are beneficial side-effects, too, such as the substantial reduction in resonance levels which are highlighted by Scholtz (2013). In this study the pseudo-random sweep optimisation technique is further developed to include steps to optimise for broadband applications, where urban seismic measurements would see the most in productivity increases.

Broadband pseudo-random sweep optimisation

Only three critical points are mentioned here for broadband non-linear sweeps: due to the hydraulic and mechanical constraints the sweep has low energy; in simultaneous source techniques there is a chance for strong cross-talk; in built-up area there is a risk for damage due to high resonance effects. In general pseudo-random sweeps could provide solutions for all these problems, but not in the simple form as the vibrator manufacturers offer them in their software packages.

Here we apply a global optimisation technique to produce broadband pseudo-random sweep sequences, which reduces the unwanted features, while enhancing the beneficial ones. The optimisation is focussing on - among others - the total sweep energy, the smoothness of the frequency spectrum and the vibrator limitations. The mechanical and hydraulic behaviour of the vibrator and also its control system is taken into account as frequency dependent sweep amplitude limits and instantaneous frequency limits. Unfortunately, the more constraints we introduce into the optimisation process the less effective it gets.

As a result of our numerical calculations (Fig. 1) - through the optimisation technique - we were able to increase the energy of the broadband pseudo-random sweep by 50% above a typical non-linear broadband sweep, while the spectrum fluctuations were kept at low levels. This can be achieved when mass stroke and hydraulic pump flow limits are set according to real life parameters. Analysing the data of a few field tests available to us suggests that the low frequencies (below 6 Hz) were emitted with reasonable accuracy. We have also found a linear transfer function between the ground force signal and the theoretical sweep, which could be addressed, too. In urban applications these improvements together with the 3–5 times resonance reductions seen by Scholtz (2013) could result in a massive productivity increase which are crucial to shorten the time a crew spend in an inhabited area.

Conclusions

Pseudo-random sweep sequences are shown to be an alternative for non-linear sweeps in broadband vibratory seismic measurements. The optimisation technique applied in this study could take into account vibrator limitations and increase the total seismic energy, while maintaining a reasonably even frequency spectrum. These qualities could enhance productivity by the application of shorter sweep sequences compared to broadband non-linear sweeps. The most advantageous use is expected in built-up areas, where the resonance effect reduction of pseudo-random sweeps also acts in our favour.

References

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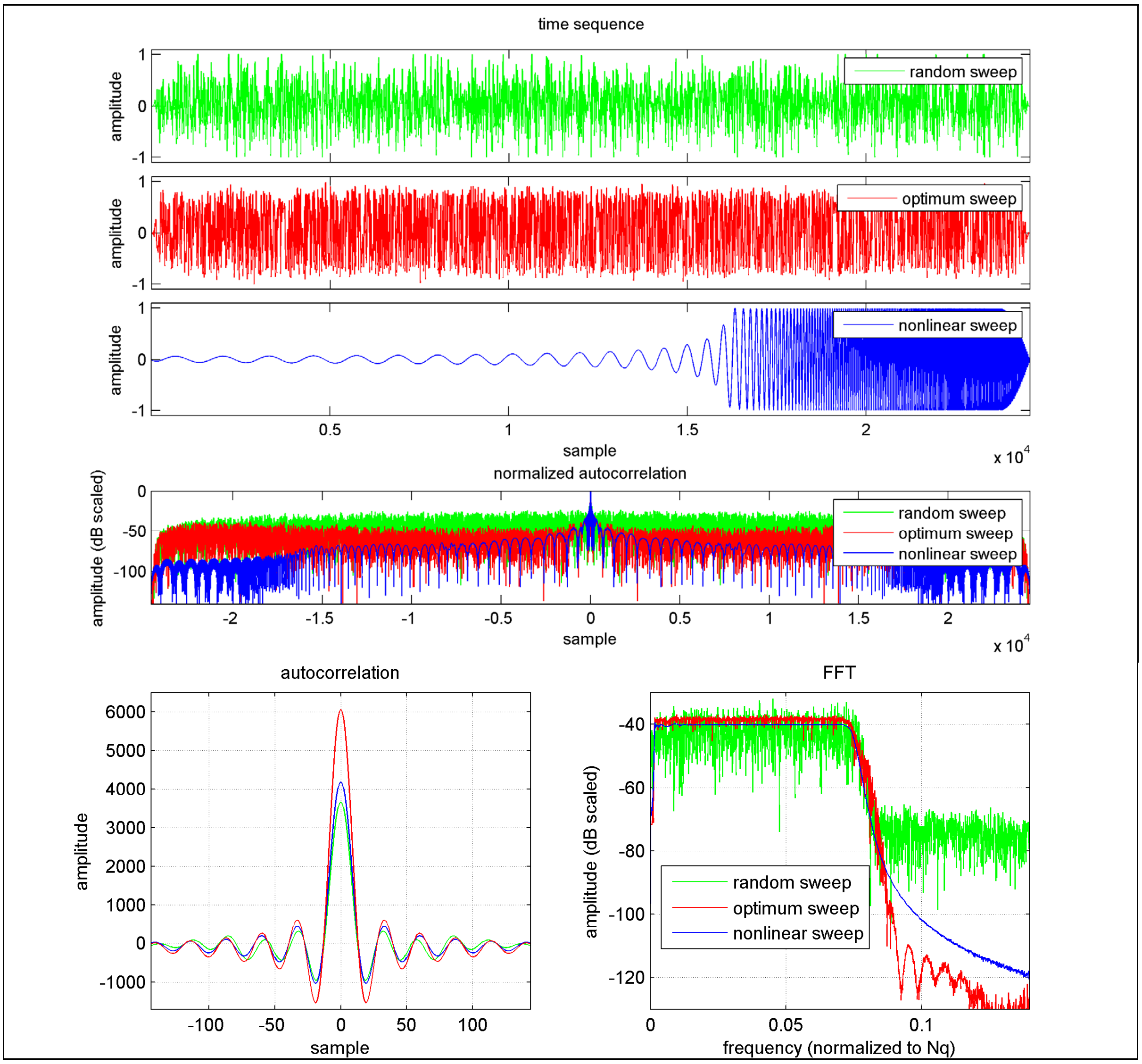

Figure 1 *A simple off the shelf random (green), an optimised pseudo-random (red) and a broadband non-linear sweep (blue). For comparison their dB scaled autocorrelation functions and also their relative autocorrelation peaks are given (representing the total energy; bottom, left). The frequency domain spectrum smoothness improvement of the optimised broadband pseudo-random sweep over the simple, off the shelf random sweep is also shown (bottom, right).*