The use of pseudorandom sweeps to reduce interference noise in simultaneous Vibroseis surveys

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SUMMARY

The cost of land seismic surveys is largely reliant on the total acquisition time. If the total acquisition time itself is limited then we may need to compromise the parameters used for the survey and thus the quality of the data acquired may be reduced. To overcome the productivity limitations associated with conventional Vibroseis acquisition, simultaneous shooting, where fleets of vibrators sweep at different locations at the same time, has been employed. Such methods typically require that the number of sweeps acquired at each source position is equal to the number of fleets, thus reducing any increase in productivity. Despite the use of such methods the data may still contain significant levels of noise contamination.

In this study we describe a new technique for generating sets of pseudorandom sweeps with cross-correlation attributes tailored to reduce interference noise. By using both synthetic and real data examples we show that such sweeps can significantly reduce the interference noise inherent in simultaneous shooting and thus have the potential to dramatically increase Vibroseis productivity without significantly affecting data quality.

Key words: Pseudorandom, sweep, Vibroseis, simultaneous.

INTRODUCTION

The cost of land seismic surveys is largely reliant on the total acquisition time. Limitations in time and/or funds may lead to compromises in the acquisition parameters and thus the quality of the data acquired. The two major factors that affect Vibroseis survey productivity are the time required to move the detectors and the time spent sweeping. To minimise the time required on each source point, multiple vibrators, typically between two and five, are deployed in fleets; the increase in the number of vibrators allowing the sweep length to be reduced significantly. Using groups of vibrators, however, introduces source array related affects (e.g. intra-array statics) which may degrade the data. Using single sources avoids these problems and also allows a larger number of fleets to be used for the survey and thus the acquisition of more source points within a denser source grid.

Of course the cycle-time limit for conventional techniques (sweep length + listen time), even with the most favourable parameters, typically restricts productivity to no more than three sweeps/minute, thus restricting possible increases in productivity from having a large number of fleets. What is required is a method for acquiring multiple fleets simultaneously, hopefully without seriously affecting quality.

Several acquisition techniques have been proposed that allow simultaneous acquisition, either based on separation of sources using time and/or distance or by decomposing the data after acquiring data with the initial phase varied between the sweeps. We begin by discussing these techniques briefly (for a more comprehensive discussion see Bagaini (2010)) before describing a method for simultaneous sweeping that utilises specially designed pseudorandom sweeps. We include both synthetic and real data examples.

SOURCE TECHNIQUES

Separation in Time/Frequency

Rozemond (1996) recognised that when a series of sweeps acquired using flip-flop acquisition is viewed in the time-frequency domain there are gaps between the sweeps that do not contain data. By decreasing the interval between sweeps (the slip-time) to less than the sum of the sweep length and listen time productivity could be improved without affecting quality. The presence of harmonic noise in Vibroseis data, however, results in noise contamination between records. If the slip-time cannot be increased sufficiently then some form of harmonic noise removal is typically required (e.g. Bagaini (2010)).

Spatial Separation

The Distance Separated Simultaneous Sweeping or DS^3 method (Bouska 2010) utilises significant distance separation between simultaneous sources groups to limit interference to below the horizons of interest. As long as the separation limits are observed then data quality is not compromised. DS^3 surveys, however, require a very large active spread which adds significantly to the complexity and cost of a survey.

Phase Encoded Separation

Phase encoded separation methods, such as High Fidelity Vibratory Seismic (HFVS) (Krohn & Johnson 2003), involve a fleet of single vibrators transmitting a sequence of sweeps (at least as many as there are vibrators sweeping simultaneously) with each set of sweeps having a different range of initial phases. The contribution of each sweep to each record is then separated mathematically. Although relatively effective the requirement that the number of sweeps is at least equal to the number of vibrators means that its ability to increase productivity is minimal if only a single sweep/VP is required.

No Separation

The final technique described here is one that utilises no separation scheme at all. The Independent Simultaneous Sweeping (ISS) technique (Howe et al., 2008) involves multiple sources acting independently and emitting sweeps at points within a pre-assigned area whenever they are ready. In initial implementations each source had a unique sweep but this has since been discarded. The interference noise resulting from the use of this technique is removed during processing.

Dean et al. (2010) compared various acquisition techniques and concluded that a combination of the DS^3 and slip-sweep methods results in the highest productivity while preserving data quality. The productivity of phase encoded techniques, even when the listen time was excluded, was limited by the requirement to acquire additional sweeps.

Pseudorandom Sweep Design

Pseudorandom sweeps, as originally described by Goupillaud (1976), were designed by grouping the sample values of a sweep into blocks with adjacent samples retaining a constant polarity. These blocks were then randomly concatenated keeping a sequence of positive and negative values (Goupillaud, 1976). The random nature of these sweeps resulted in the sweeps being substantially uncorrelated with each other enabling them to be acquired simultaneously without significant interference.

Cunningham (1979) used pseudorandom codes consisting of binary sequences multiplied by a constant frequency carrier signal to design sweeps whose Klauder wavelet had smaller side lobes than conventional sweep designs.

It is only with the introduction of modern source controllers that the ability to sweep truly pseudorandom sweeps (i.e. not just pseudorandom re-ordering of sweep segments) has been acquired (Burger & Baliguet 1992). Their lack of obvious advantages has limited their use until more recently when their use to reduce interference noise for simultaneous surveys was identified.

Sallas et al. (2008) used specially designed 64 s long pseudorandom sweeps, similar to those described in this paper, to acquire a small 2D line. They also acquired HFVS data with four 16 s sweeps/VP. The pseudorandom sweep data appears to be better quality that the HFVS data with interference noise being limited to the near offsets.

A full description of the technique used to generate the pseudorandom sweeps used in this study is contained in Iranpour et al. (2009). It utilises a simulated annealing algorithm with a cost function that includes the amplitude spectra of the sweeps and the cross-correlation amplitude at times greater than 4 s. This ensures that the interference between the sweeps is minimised. In the results presented here we generated a pair of sweeps (Figure 1), but there is no limit to the number of sweeps that can be generated (although the ability to constrain the spectra and cross-correlation of the sweeps decreases with an increased number of sweeps).

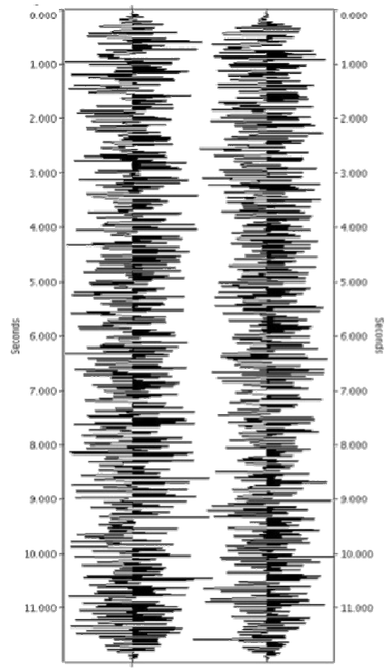

Figure 1. The two pseudorandom sweeps generated using the simulated annealing algorithm used in this study.

Figure 2 shows the autocorrelation of the two pseudorandom sweeps and an example Maximum Displacement (MD) low-frequency sweep (Bagaini, 2008). The side-lobes of the pseudorandom sweep decay significantly faster than the MD sweep.

The cross-correlation of the two sweeps (Figure 3) shows that the design process has been successful in forcing what is effectively interference noise to the areas beyond ±4 s. The crosscorrelation between ±4 s is more than 35 dB less than the peak autocorrelation value.

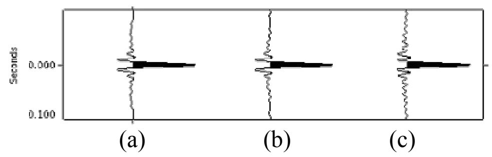

Figure 2. The auto-correlations of the two pseudorandom sweeps (a and b) and a Maximum Displacement sweep (c).

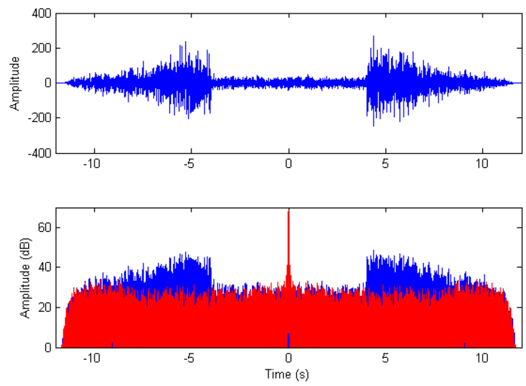

Figure 3: Cross correlation of the two pseudorandom sweeps. In the bottom plot the autocorrelation is shown in red.

Synthetic Results

Synthetic data was generated using reflections generated using a Tesseral model and noise generated using the Omega seismic processing system. The model included reflections, realistic ground-roll and airwave components.

The left record in Figure 4 is the sum of two uncorrelated records, each corresponding to one of the two sweeps shown in Figure 1 correlated with the first sweep. The centre record is the record corresponding to sweep 1 only correlated with sweep 1. The record on the right is the difference, i.e. the noise resulting from the acquisition of the two sources simultaneously. The length of the records has been extended to 8 s to show how the cross-correlation noise appears at time greater than 4 s as expected. The only significant noise at $t < 4$ s limited to the near offsets (< 800 m).

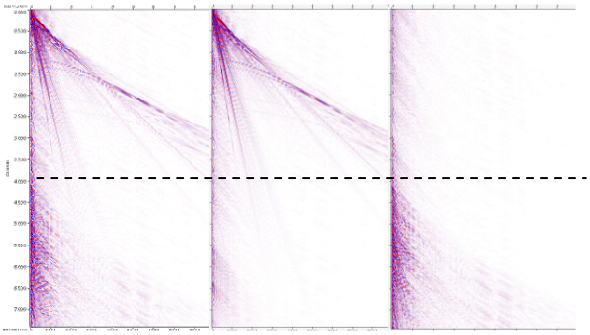

Figure 4. Synthetic simultaneous record (left), individual record (middle) and the difference (right). The dashed horizontal line is drawn at 4 s. The maximum offset is 8,000 m.

Figure 5 shows the synthetic data of Figure 4 after it has been stacked. Again the interference noise is concentrated at times greater than 4 s and there is little difference between the simultaneous and non-simultaneous stacks.

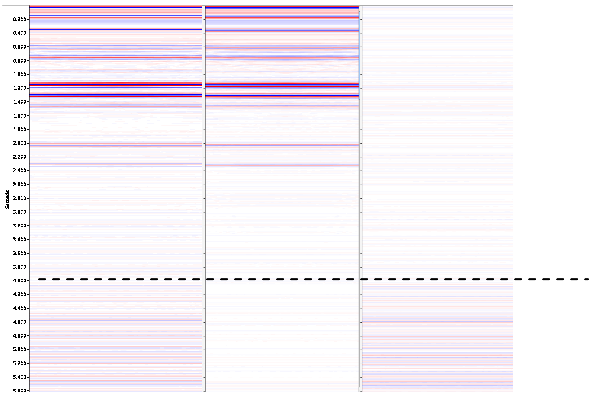

Figure 5: CMP stack of synthetic simultaneous records (left), individual records (middle) and the difference (right). The dashed horizontal line is drawn at 4 s.

Field Results

As a preliminary test these sweeps were acquired into a 2D line consisting of 200 geophone accelerometers placed at 6 m intervals. Our initial concern was the vibrator would struggle to transmit the sweep but this did not eventuate. The power spectral density (PSD) of the data acquired using the sweeps being consistent with that of the MD-sweep, after allowing for the differences in the PSD of the pilots (Figure 6). There is more high and low frequency content in the MD sweep data but this is due to the pilot itself having greater amplitudes at these frequencies (the pseudorandom sweeps were designed independently of the MD sweep design but there is nothing to prevent them being the same in future tests).

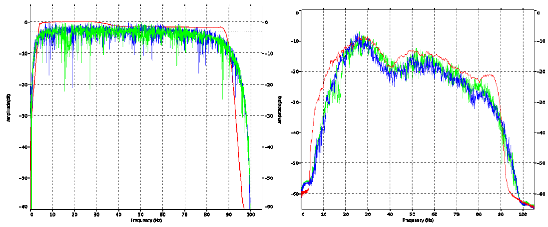

Figure 6: Spectra of the pseudorandom sweeps (Blue and green) and the MD sweep (Red). Pilots on the left and data on the right.

No data was acquired using both sweeps simultaneously as only a single vibrator was available for the test but we can simulate how the data may appear by summing two uncorrelated records acquired using each of the sweeps and then correlating with a single pilot. The resulting records are shown in Figure 7. Similar to Figure 4 the 'simultaneous' record is shown on the left, the individual record in the middle and the difference on the right. As for the synthetic data and the results of Sallas et al. (2008) the noise is confined to the near offsets and has the appearance of the vibrator 'noise chimney'.

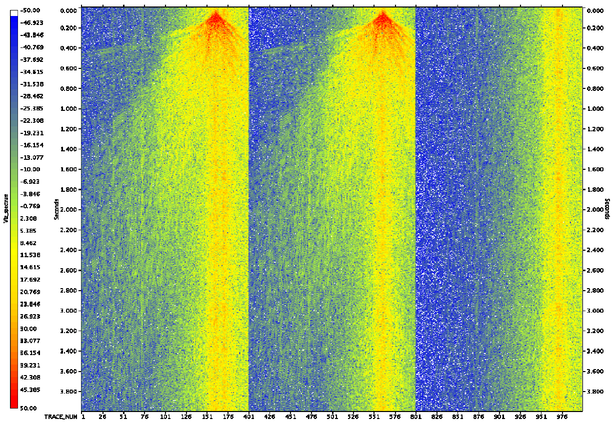

Figure 7. Simulated simultaneous record generated using field data (left), the individual record (middle) and the difference (right). The length of the receiver line was 1,200 m. Amplitudes are plotted in dB.

CONCLUSIONS

Although only preliminary results are shown there appears to be much promise in the use of pseudorandom sweeps to minimise interference noise in simultaneous surveys. The use of such sweeps overcomes the problems associated with other simultaneous methods which require multiple sweeps at each source point.

The use of these sweeps would result in productivities equivalent to, if not slightly higher, than that of DS^3 surveys. Instead of having to wait for a vibrator from each of the smaller distance-separated groups to be ready to sweep we can sweep as soon as any of the vibrators are ready. We could also place the vibrators close together making logistics simpler and removing the requirement for large receiver spreads.

Although productivity would by less than an ISS survey the improvement in quality would be well worthwhile.

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