Seismo-acoustic characterization of a seismic vibrator
Claudio Bagaini*, Martin Laycock and Colin Readman, WesternGeco; Emmanuel Coste, Schlumberger; Colin Anderson, Siemens PLM Software

Summary
A seismic vibrator generates seismic and acoustic noise as soon as it is pressured up and located in the proximity of a recording spread. The noise in the seismic bandwidth is more critical in vibroseis surveys where a large number of vibrators are used as in the case of simultaneous acquisitions. The noise in the acoustic bandwidth is particularly important when the survey takes place in populated areas.
We carried out a seismo-acoustic experiment to characterize these noises. We present the results obtained while the vibrator is pressured up but not sweeping, with the baseplate in contact or not with the ground. We demonstrate that several monochromatic noise components can be related to the cooling and exhaust systems. We also show the effects in the seismic and acoustic bandwidths of modifications to the cooling and exhaust systems.

Introduction
Over the last three decades, the increase in total productivity in land vibroseis seismic acquisition (here defined as the total number of traces acquired in a time interval) has been mainly due to increases in the recording system channel count. Only in the last few years has the source side substantially contributed to the total productivity, thanks to the widespread use of simultaneous source techniques. However, simultaneous shooting presents in general two types of challenges: one challenge for the acquisition system, and another for the data processing.

The challenge for the acquisition system is due to the fact that, to efficiently implement the simultaneous shooting techniques, a continuous recording system with a large channel count must be available. Moreover, the acquisition system must be capable of handling communication between numerous vibrators and the recording truck. The most advanced land acquisition systems fulfil both these requirements.

The data processing challenge is due to the fact that the speed-up in acquisition should ideally not affect the final data quality but it should actually be used to improve it by reducing the shot point interval and/or improving the economic acquisition template. It is therefore necessary to either develop algorithms to separate the data by removing the cross-talk noise or to develop new algorithms to process these data without separating them in the early processing stages. In addition to the cross-talk noise, simultaneous vibroseis acquisitions are affected by other noise components.

The field experiment described here aimed at acquiring seismic and acoustic data to improve our understanding of noises that affect simultaneous vibroseis surveys, but are different than cross-talk (Figure 1). The first type of noise, often referred to as “chimney noise”, contaminates the very near offsets, typically less than 200 m. The name comes from its aspect when the data are correlated with the survey sweep and visualized. It is also visible when other vibrator units or vehicles are standing or moving around the active spread (Figure 1 and Figure 2). It is often assumed that it is generated by the vibrator itself (engine, cooling and hydraulic systems, and others).

The chimney noise makes the very near offsets practically unusable for applications such as statics estimation and surface-related multiple elimination that benefit from the presence of the very near offsets. The information recorded by the near-offset traces, when they are recorded with point-receiver acquisition systems, can be instrumental for seismic characterization of the near-surface.

Figure 1. A typical vibroseis shot record. Ground-roll, chimney noise and airblast are highlighted.

The detrimental effect of the chimney noise is greater in simultaneous vibroseis surveys (Figure 2) because it affects not only the very near offsets of the vibrator that generated it but it also affects the weak signals at the medium-long offsets of other vibrators that emit their signals simultaneously or almost simultaneously. The chimney noise is also generated by vibrators standing along the
Vibrator seismo-acoustic noise

spread, but not sweeping. This noise is more critical in simultaneous vibroseis surveys because the number of vibrators in the field is significantly higher than in sequential acquisitions.

The second type of noise is the air blast (Sallas and Brook, 1989). Also, this type of noise is more critical in simultaneous vibroseis surveys because the air blast generated by one vibrator may affect several records (Figure 2).

Another type of noise often observed during vibroseis surveys using a large number of vibrators is composed of monochromatic components that are generated by seismic vibrators regardless of whether they are sweeping or not. Acoustic and vibrational noise at frequencies beyond the seismic bandwidth are also of interest for their effect on the vibrator personnel and, when operating in populated areas, on nearby inhabitants.

To obtain a better insight on these types of noise, we carried out a field test that comprised seismic and acoustic pressure measurements with vibrators in different configurations. We present the results obtained in configurations where the vibrator is pressured up but not sweeping.

Figure 2. A correlated record from a simultaneous vibroseis acquisition.

Field test

The acquisition geometry of the field test here described is sketched in Figure 3. The test setup consisted of two distinct but complementary parts. The surface seismic equipment consisted of one Stratavisor NZ recorder, 4 Geode nodes and several GS-32 10-Hz geophones. The acoustic equipment comprised two types of microphones: PCB 130D21 that were deployed (on a tripod) at 20 m offset and B&K 4189 for longer-offset measurements. The vibrator was equipped with PCB356A02 accelerometers and PCB 130D21 microphones were installed in the vicinity of the equipment where acoustic energy was expected to be generated. Two different 80,000-lbf vibrators were used. The first was a standard vibrator and the second was a modified vibrator. On the second vehicle, the skid unit was replaced by one with an alternative intake, exhaust and cooling system.

Figure 3. Acquisition geometry with highlighted geophone and microphone locations.

Figure 4 shows a geophone record (located at 50 m offset) during the following sequence: baseplate lowered and in contact with the ground with hold-down weight applied (pad-down configuration), baseplate raised (pad-up) and again in the pad-down configuration. It is clear that, when the baseplate is in contact with the ground, the geophone records a broadband noise in the 15-55 Hz frequency range. The baseplate is isolated from the vertical vibrations of the truck by air bags whose natural frequency is just above 2.0 Hz. However, when the vibrator is pressured up and the engine is running, horizontal vibrations are also generated. Horizontal vibrations can, therefore, be transmitted to the ground even if the vibrator is not sweeping.

Monochromatic noise components appear in both pad-up and pad-down configurations. The frequencies of 34 Hz and 102 Hz are dominant. The fact that these noise components have approximately the same intensity indicates that they are likely to be airborne. They are recorded by the geophones because of the ground-roll coupling to compressional waves phenomenon (Press and Ewing, 1951). We study these monochromatic noise components in more detail by considering both seismic and acoustic measurements.
Vibrator seismo-acoustic noise

Figure 5 shows several geophone and microphone measurements made while the vibrator was in pad-down configuration. They are representative of the geophone recordings at 50 m offset and microphone recording at 20 m offset. Several monochromatic noise components appear in both records, as highlighted in the figures. These monochromatic noise components can be explained by considering the features of the vibrators.

The vibrator used for this experiment was equipped with a Caterpillar C-15 engine. This is a 4-stroke diesel engine with 6-cylinders in-line that, during the test, was running at 2,050 rpm. The cooling system is composed of a large fan with 16 blades driven by the engine and running at 1600 rpm. The individual monochromatic noises are related to the engine and cooling system as described below.

- 17.1 Hz – ½ order engine (one cylinder fires every two crankshaft revolutions in a 4-stroke engine)
- 26.9 Hz – 1st order cooling fan
- 34.2 Hz – 1st order engine
- 51.3 Hz – 1.5 order engine
- 85.4 Hz – 2.5 order engine
- 102.5 Hz – 3rd order engine (firing frequency for the 6 cylinder 4-stroke engine running at 2050 rpm)
- 105.0 Hz – 3rd order engine for a vibrator running at 2100 rpm.

The engine 3rd order noise can come from a variety of sources. The 3rd order engine is the firing frequency, so there will always be significant excitation at this frequency. The fact that the 3rd order engine (102-102.5 Hz) is the strongest component denotes that the engine is well balanced and all the cylinders fire almost evenly. Any small imbalance of the fan generates the 1st order harmonic of the fan. The 1st order engine vibration could be caused by imbalance of the parts of the engine which rotate or reciprocate once per revolution. To determine the transmission paths of the noise generated by vibrations and acoustic sources, we followed two methods:

1) Comparison of geophone data with microphone and baseplate data.
2) Comparison of pad-down data with pad-up and ambient noise data.

The 3rd order engine noise is visible in the geophone measurements, but more pronounced in the microphone measurements. Some additional insights on this noise component can be obtained by analyzing some geophone traces acquired while the vibrator was pressured up but not sweeping in pad-up or pad-down configurations (Figure 6). The 3rd order engine is unchanged when the baseplate is lowered. The analysis of accelerometers mounted on the vibrator highlighted that the effect of the radiation of vibrations at the 3rd order engine frequency is negligible. We conclude that the 3rd order engine noise is mainly airborne.

Analysis of Figure 5 highlights that the ½ order engine (17.1 Hz) is mainly structure borne (i.e. skid frame, bushes, vibrator frame, base plate), and transmitted to the ground by means of the baseplate or possibly even from the frame through the tires. The 1st order cooling fan noise (26.9 Hz) is also likely to be mainly structure-borne but there is no conclusive evidence of this.

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Vibrator modifications and noise affecting nearby people

A vibrator with a modified cooling system was also tested. The single large engine-driven fan was replaced by several smaller hydraulically driven fan units (operating at a constant speed of around 700 rpm) and a drum-based system. The 1st order cooling fan (26.9 Hz) visible in Figure 5 has been completely eliminated in Figure 6. Vibrator noise beyond the seismic bandwidth affects the vibrator personnel and, when operating in populated areas, nearby people. The first and second stages of the exhaust system were modified with a silencer. The effects of these modifications can be seen in Figure 7. The 6th and 10th engine order are significantly reduced, along with a general reduction in the frequency range between 100 and 400 Hz. A microphone located at the exhaust orifice (Figure 8) confirms the origin of this noise and the effects of the modified exhaust. A reduction of the acoustic noise between 100 and 400 Hz is obtained when only the first stage is modified. Further attenuation up to 2 kHz is obtained when both first and second stages are modified.
Vibrator seismo-acoustic noise

Figure 5. Seismic and acoustic measurements for a vibrator in pad-down configuration (five measurements). (a) Spectral analysis of a geophone (50 m offset) record. (b) Spectral analysis of a microphone (20 m offset) measurement.

Figure 6. Spectral analysis of two geophone traces acquired with a modified vibrator in pad-up and pad-down configurations. This vibrator included a modified cooling system that completely removed the 1st order fan component seen in Figure 5. Spectra of data acquired with pad-up (red), pad-down (green) and ambient noise (blue) are superimposed.

Figure 7. Vibrator noise beyond the seismic bandwidth. Average of four microphone measurements. Original vibrator (red), vibrator with modified cooling system and first-stage exhaust (green), vibrator with also the second-stage exhaust modified (blue).

Figure 8. Spectrum of a microphone located at the exhaust orifice. Same color convention as in Figure 7.

Conclusions

A vibrator pressured up and located in the proximity of the receiver spread generates seismic noise that can detrimentally affects the seismic data plus acoustic noise that disturbs nearby people when operating in populated areas.

A number of monochromatic noises were measured during a field experiment when a vibrator was pressured-up but not sweeping. A quantitative analysis of these noises measured by geophones and microphones enabled us to relate these noises to the frequency of rotations of both engine and fan. The transmission paths for these noises were identified with a good degree of confidence. It was also observed that a vibrator in pad-down configuration generally emits more structure/ground-borne noise than when it is in pad-up configuration.

Modifications in the cooling system eliminated the 1st order (26.9 Hz) fan noise and reduced the acoustic noise significantly. Modifications in the exhaust system showed some improvements in the seismic and acoustic bandwidth owing to reductions in the 6th and 10th order engine harmonics and in the frequency range up to 2 kHz.

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EDITED REFERENCES
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REFERENCES