# Impact of the use of low-frequency heavy vibrators on crew productivity

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## Summary

During the last years, the challenge of extending the vibroseis bandwidth towards low frequencies has been largely addressed and fulfilled by the seismic industry, thanks to numerous evolutions and improvements, particularly on vibrator and sweep design. Heavy vibrators were primarily designed for high productivity single-point acquisition. The new ones, optimized for low frequencies, are generally considered only as broadband tools, while their strong impact on crew productivity is often neglected or ignored in the case of very low-frequency acquisition. After a presentation of the latest vibrator improvements in this matter, this abstract presents both simulations and field results that allow quantifying the productivity gain permitted by these new low-frequency vibrators. An extension of these results to super-heavy vibrators opens the way to a reconsideration of their field application for very low-frequency acquisition, from powerful single-point to high-productivity sources.

## Introduction

Extending the recorded seismic data bandwidth is an ever growing trend in the industry. The low-frequency challenge has already been largely dealt with by using new vibrators, custom sweeps and processing methodologies able to preserve the low-frequency content. However, the impact of an extra low-frequency bandwidth recording in terms of productivity needs being closely examined. New vibrators optimized for low-frequencies are now available on the seismic market. Compared to conventional vibrators that are also able to generate low frequencies but at a slower sweep rate, they appear to be not only broadband tools, but preeminently excellent for increasing crew productivity in case of very low-frequency acquisition, while super-heavy vibrators may turn out to be even more powerful productivity instruments.

## Vibroseis low-frequency generation issues

The recent development of low-frequency seismic acquisition has been accompanied by numerous evolutions and progress in equipment design and sweep parameters, in order to control the generation of this extra bandwidth.

Regarding vibrators, the mechanical and hydraulic factors limiting the low-frequency emission have been identified (Sallas, 2010) as:

- Mass stroke, i.e., the mass maximum displacement.
- Pump flow, i.e., the pump ability to answer the strong flow oscillations imposed by low frequencies.
- Valve flow, equivalent of the above for the valve.

Nonetheless, using a relevant design and size of hydraulic accumulators, pump and valve limits are pushed back; mass stroke becomes the key limitation factor.

In practice this challenge is addressed using a heavier mass and a larger mass stroke (the sweep full-drive start frequency being inversely proportional to the square root of the actuator mass and to the square root of the mass stroke), higher hydraulic pressure, and hydraulic accumulators as close as possible to the servovalve. The low-frequency vibrators designed accordingly allow reducing the sweep start full-drive frequency in a 1 to 2 Hz range (6-7 Hz for conventional heavy vibrators, against 5-5.5 Hz for low-frequency vibrators). While this gain may not look so impactful at first glance, its consequences on low-frequency acquisition productivity are far from negligible and rarely taken into account in the industry.

## Low-frequency sweeps and productivity

Most of the vibrators can now start sweeping from 1 Hz, but not at full drive. Therefore, from 1 Hz to the full-drive start frequency, a custom sweep with a low-dwell taper has to be applied (Bagaini, 2007, Sallas, 2010). This taper will allow preserving a flat spectrum on the full sweep bandwidth, but will require a longer time: for a given frequency, the sweep duration has to be increased by the square of the drive reduction. Compared to a 100% drive, emitting a frequency with a 50% drive requires spending 4 times as long on this frequency; a 25% drive requires… spending 16 times as long! As a consequence, the time spent on the taper may represent a significant amount of time, that will either increase the sweep overall duration, or for a given sweep length reduce the time

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spent on the usual 8-80 Hz full drive range, thus reducing the emitted associated energy.

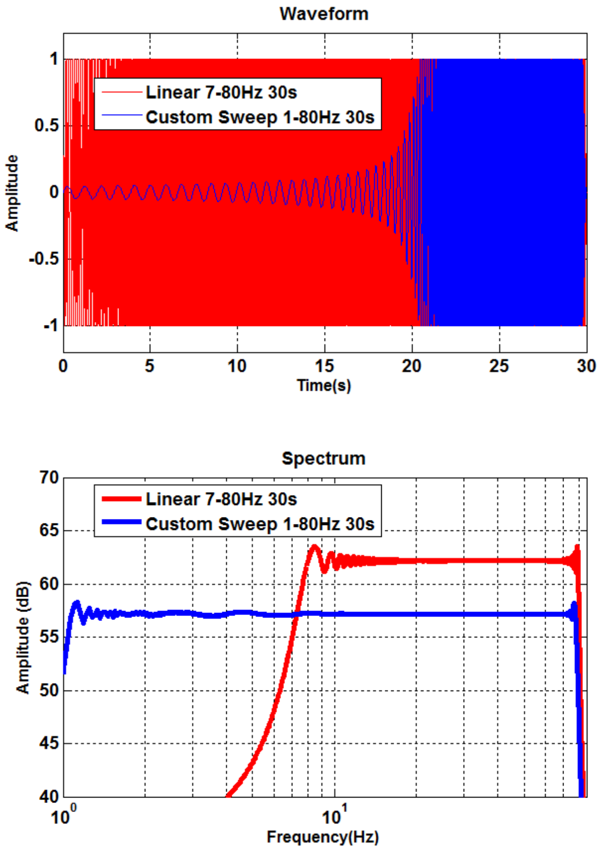

Figure 1a – A 7-80 Hz 30 s linear sweep (red), compared with a 1-80 Hz, 30 s low-dwell sweep (blue), 80% drive with a conventional heavy 62,000 lbf vibrator. The spectrum is larger for the low-dwell sweep (+ 6 Hz at full amplitude on the low-frequency side), but this decreases the 7-80 Hz emitted energy level (-5 dB).

These two consequences as illustrated in Figure 1a and 1b using a 62,000 lbf vibrator – amplitude decay or increase of sweep overall duration, or a combination of both - can be largely addressed using a low-frequency vibrator.

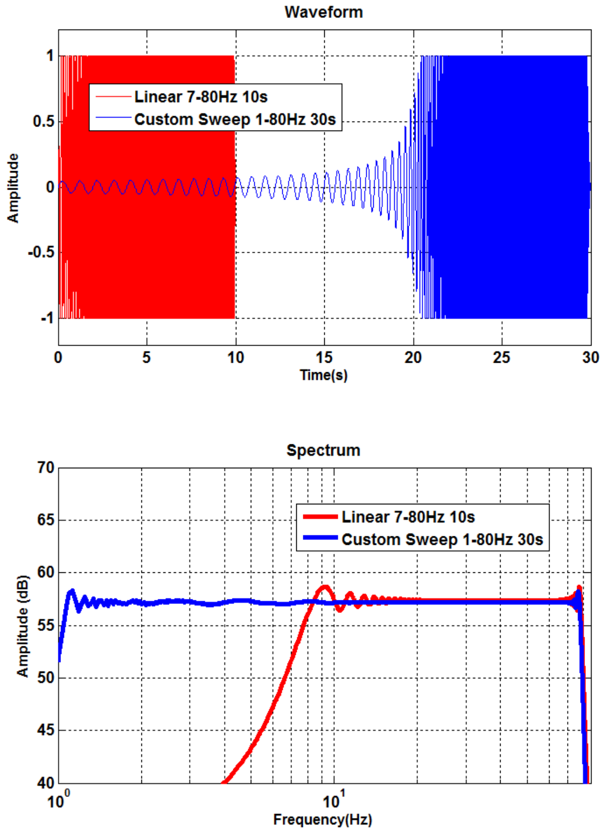

Figure 1b – Conventional 7-80 Hz, 10 s sweep (red), compared with a low-dwell 1-80 Hz, 30 s custom sweep (blue), 80% drive. The emitted energy is similar for both sweeps, but with an extra bandwidth allowed for the low-dwell sweep that requires an extra 20 s.

The sweeps in Figure 2a were designed for a 62,000 lbf vibrator, and an evolution of this vibrator that takes into account all its physical limitations to reduce the sweep full-drive start frequency, from 7 Hz to 5.4 Hz (Figure 2b). The low-frequency performances of the latter were achieved using enhanced mechanical and hydraulic features, in particular a higher and stabilized hydraulic pressure, essential for proper low-frequency emission. In addition, the vibrator electronic should be able to control the non-linear taper of the low-frequency sweep. This latter shall indeed be able to generate the accurate low-dwell ramp-up, while maintaining a low phase, a low distortion and an exploitable QC in a repeatable manner (Tellier, 2014). Figure 2a displays low-dwell sweeps designed for these two heavy vibrators, starting from 1, 2 and 3 Hz, with their equivalent amplitude spectrums.

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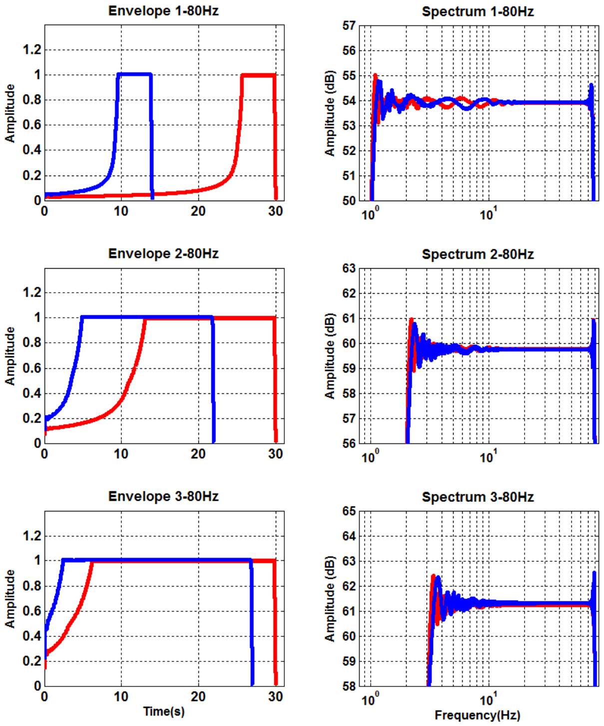

Figure 2a – Compared performances between (red) a conventional 62,000 lbf vibrator (Nomad 65) and (blue) its low-frequency evolution (Nomad 65 Neo): custom sweeps 1-80 Hz, 2-80 Hz, 3-80 Hz, drive 80%. Duration is set to 30s for the conventional vibrator, and adapted to the other vibrator to output an equivalent spectrum.

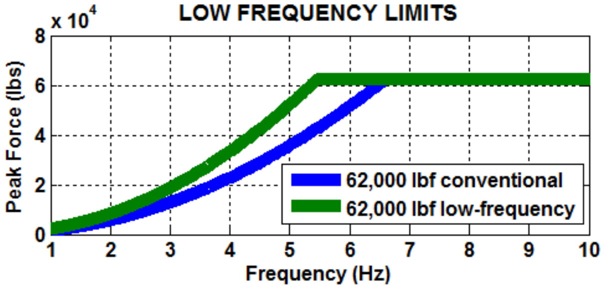

Figure 2b – Compared full-drive start frequencies of the two vibrators, and energy output from 1 Hz to these frequencies.

We can observe that an important increase of the sweep low-dwell taper length is required to reduce the sweep start frequency, with a constant level of energy, especially when getting close to 1 Hz. However, for a given start frequency the energy radiated is equivalent in amplitude and bandwidth for the two vibrators but the sweep duration is largely reduced, all the more that the start frequency decreases: 27s (-10%) from 3 Hz, 22s (-27%) from 2 Hz and 14s (-53%) from 1 Hz.

## Field experiments

Field tests were led in January 2014 in the south-west of France. One of the objectives was to validate the seismic data content obtained by those two vibrators using different sweep durations. Two 2D lines of 100 single geophones receiver point each were deployed, with 5 Hz and 10 Hz geophones spaced with 5 m intervals.

Figure 3 displays the shape of the two sweeps used, the corresponding recorded forces, and shot point spectra (after correlation) obtained for each line on the 60 geophones the most remote from the sources.

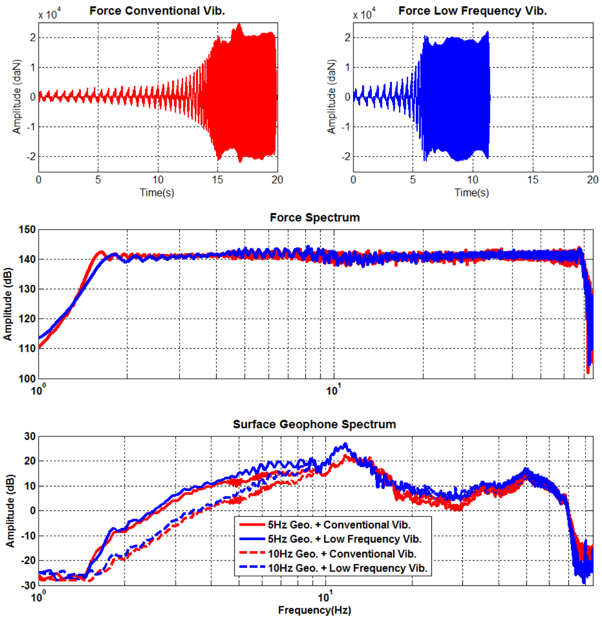

Figure 3: Sweep shapes, forces, and surface data spectra of two 1.5-75 Hz, 80% drive sweeps generated by a VE464 for a conventional 62,000 lbf vibrator (20 s, red) and its low-frequency evolution (11.5 s, blue), for two lines of sensors: 5 Hz (continuous lines) and 10 Hz (dotted lines).

The spectra of the emitted ground force (given by the weighed sum obtained with vibrator accelerometers) are equivalent for both vibrators. Shot point records confirm signals consistencies, with equivalent spectra. A clear boost in low-frequencies on the 5 Hz geophone line helps

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recovering amplitude on the lowest 10 Hz frequency range. The energy emitted and recovered in the two cases are similar, while a 43% time reduction results from the use of the low-frequency vibrator.

## Pushing further sweep duration reduction

On the land seismic market, super-heavy (80,000 lbf) vibrators have been regarded mainly as tools for single source high-density acquisition, in open areas. Their use has been limited until now: even if more and more operators require either heavy (around 60,000 lbf) or super-heavy vibrators in their bidding process, the confirmation of sweep parameters (especially drive level and length) only during crew start-up does not make it beneficial for contractors to choose the super-heavy option.

However the 80,000 lbf vibrators performance may be regarded otherwise. Fit with a heavier mass and a larger mass stroke, these vibrators are naturally intended to low-frequencies, the vibrators existing on the market offering full drive start frequency of 5 and 5.5 Hz at full-drive. This frequency can be greatly lowered if the drive is reduced to be comparable to a 62,000 lbf vibrators (e.g., 4 Hz in Figure 4).

Figure 4 superimposes on the results displayed in Figure 2a those obtained with a Nomad 90 vibrator designed for full-drive from 5 Hz, using either its 80,000 lbf or a 62,000 lbf output, in the aim to generate an emitted energy spectrum identical to the two other vibrators.

At a 62% drive (equivalent to 62,000 lbf at 80%) the 80,000 lbf vibrator sweep full-drive start frequency is decreased to 4 Hz: sweep duration is reduced to 9 s (-70%). Using the same vibrator at 80% of 80,000 lbf allows reducing even more the sweep to 7 s (-76%). In both cases the gain in sweep duration is tremendous and opens the way to new productivity records.

Some limitations nonetheless have to be taken into account: too short sweeps may not allow pressure to build up and stabilize in time, with a consequence on the low-frequency distortion level, unless the vibrator is specially designed for low frequencies and equipped with the associated adequate hydraulic fast-response hydraulic system, as the one used in the present experiment. The consequence of sweep duration is also subject to discussion, and has less impact on productivity in case of slip-sweep (Zanati 1994, Egreteau 2009, Mahrooqi 2012, Meunier 2012).

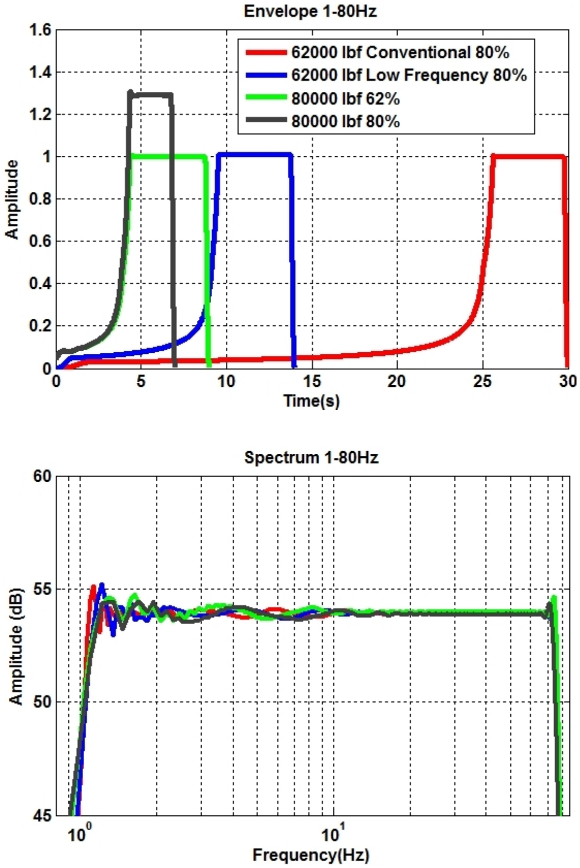

Figure 4 - Sweeps 1-80 Hz, with: (red) a conventional heavy 62,000 lbf vibrator (80% drive, 30 s); (blue) its low-frequency evolution (80% drive, 14 s); *(*green) a 80,000 lbf super-heavy vibrator used with an output equivalent to the heavy 62,000 lbf (62% drive, 9 s); and (black) the latter used at 80,000 lbf (80% drive, 7 s). Energy emitted is identical in the four cases.

## Conclusion

Low-frequency heavy vibrators, considered as broadband sources, shall also be regarded as productivity sources for very low-frequency acquisition. The use of super-heavy vibrators shall be reconsidered, from an energetic source for single-source acquisition to a powerful productivity tool. A strong reduction of the sweep duration can be expected from these vibrators, all the more when the start frequency gets close to 1 Hz, with impact on surface seismic productivity. Therefore, extra octaves, very beneficial for inversion and vertical resolution improvement, can be acquired at a lower cost.

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