



The Impact on Seismic Data Quality of an Improved Seismic Vibrator

Mike Hall, John Wei, Tom Phillips, INOVA

Introduction

Vibroseis has received a lot of attention recently, mostly to do with increasing efficiency; Bagaini (2006) reviews several such methods. There have also been investigations into the accuracy of the weighted sum signal as a measure of the Ground Force. Ground Force control, introduced by Sallas (1984), is used in almost all Vibroseis surveys. Saragiotis et al (2010) and Wei (2009) investigated this relationship with particular emphasis on simultaneous sweeping methods where an accurate Vibroseis signature is desired to suppress inter source point interference from harmonic distortion.

In this paper methods of improving the Vibroseis signature through fundamental improvements in the Vibrator itself are explored. Field tests confirmed modifications suggested by finite element modelling, Wei (2008), can improve bandwidth, stability and predictability of the Vibroseis signature. Results are shown from one site with soft surface conditions, and downhole sensors, and another with hard surface conditions. Comparisons are made between an unmodified & modified INOVA AHV -IV. The modifications involved improvements to the hydraulic system and a baseplate 2.5 times stiffer. Further control improvements for reducing harmonic distortions are also analyzed.

Data Analysis

The Low Frequencies

Figure 1 shows comparison FT plots from the soft surface site. The sweep is 1Hz to 21Hz in 20s and the data are from a geophone at 16 m downhole. The raw signals are in the top images and the filtered signals in the lower images with the unmodified Vibrator results on the left and the modified Vibrator

results on the right. The time variant filter (TVF) passes only the fundamental. There is a large increase in low frequency fundamental energy from the modified Vibrator. This is important in the search for deeper resources and in generating more accurate seismic acoustic impedance inversions.

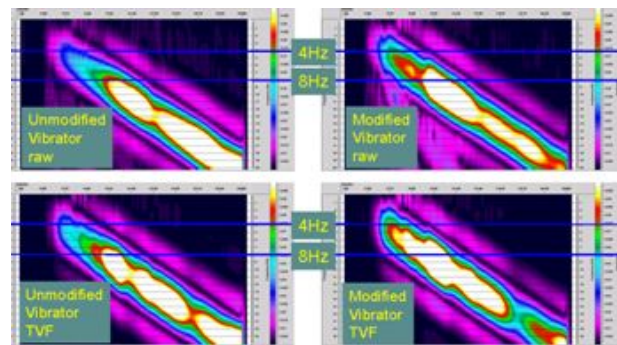


Figure 1: FT analyses of the ION AHV -IV (left) without modifications and (right) with modifications before filtering (top) and after filtering out the harmonic energy (bottom).

The High Frequencies

A comparison using the vertical element of surface sensors is shown in Figure 2. In both ground conditions the modified Vibrator has broader bandwidth with much stronger high frequency energy. The dB levels are set to the same absolute value at each site. All images in Figure 2 are after correlation with the respective pilot sweep. The 3C sensors at the site with soft surface conditions are MEMS accelerometers while the 3C sensors at the site with hard surface conditions are 10Hz multi-component geophones.

The data from the vertical component of the 3C MEMS surface sensors at the soft surface site was processed to stack. The higher frequencies from the modified Vibrator (with a 2Hz to 160Hz sweep) are preserved through the stacking process. The results for the shallow part of this stack, in Figure 3, show higher frequency energy from the modified Vibrator.



The Impact on Seismic Data Quality of an Improved Seismic Vibrator

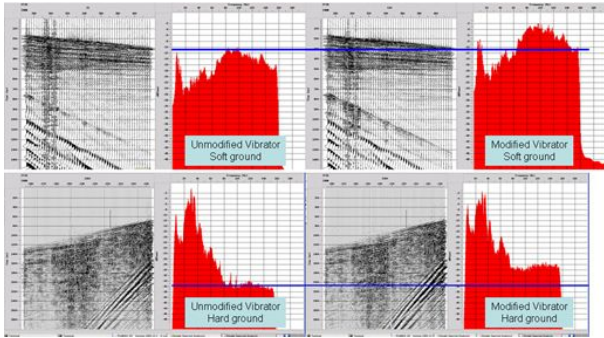


Figure 2: Seismic data and associated spectra from the INOVA AHV-IV without modifications (left) and with modifications (right) from both the soft ground (top) and hard ground (bottom).

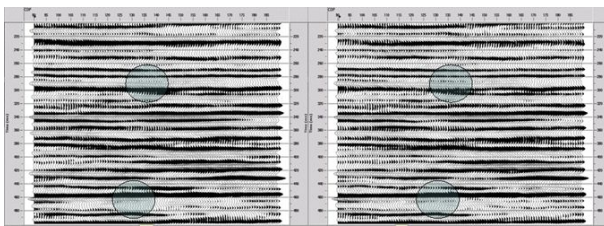


Figure 3: Comparative shallow seismic sections INOVA AHV-IV without modifications (left) INOVA AHV-IV with modifications (right), high frequencies are maintained through the stack process.

Uneven loading

Another problem of Vibroseis is that the Vibrator's signature varies with surface conditions. To simulate different surface conditions railway ties were placed under the baseplate as shown in the left side of Figure 4.

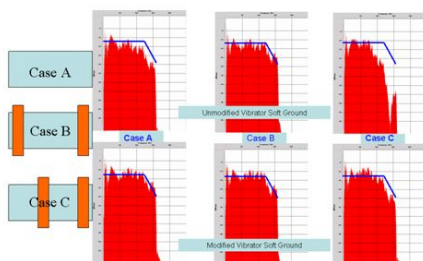


Figure 4: Spectra from an uneven loading test at the site, spectra for the unmodified Vibrator are at the top, those for the modified Vibrator are at the bottom; cases A, B and C are denoted in this figure.

Case A is full contact, case B is partial but even contact with the ground and case C is partial and uneven contact with the ground. Spectra from the 1000' deep downhole geophone are shown for each case for the unmodified Vibrator (top) and the modified Vibrator (bottom). The spectra for the modified Vibrator are very consistent while those for the unmodified Vibrator vary substantially.

The weighted sum versus measured data

The weighted sum has been termed Ground Force for a couple of decades implying that this calculated signal represents what the Vibrator puts into the ground and it is used in several Vibroseis schemes. This is a better representation of what the Vibrator puts into the ground than the pilot signal but it is not as accurate a measure of what the Vibrator actually does as we need it to be.

With a land source it is difficult to measure a far field signature due to the nature of the earth. The spectra of the weighted sum for each Vibrator are compared against the spectra from the vertical geophone at a depth of 1000ft in Figure 5. The sweep is 1Hz to 201Hz in 20s. The downhole spectrum of the modified Vibrator is improved at higher frequencies however the spectra of both Vibrators start to decay from 150Hz. The blue lines on the two right hand spectra are placed identically and the blue lines on the left hand plots have the same slope from the same frequency as on the right hand plots.

Initially it might be thought that the weighted sum signal for the unmodified Vibrator is doing what we want, matching the pilot signal with a flat spectrum. It can be seen however that the high frequency



The Impact on Seismic Data Quality of an Improved Seismic Vibrator

attenuation noted in the downhole geophone matches quite well with the decay seen on the weighted sum for the modified Vibrator. This drop off in power at a high frequency is due to supply pressure limits in the Vibrator that the feedback with the new baseplate assembly detects but the feedback system of the original Vibrator fails to detect. This strongly implies that the weighted sum with the new baseplate assembly is a truer representation of the far field signature.

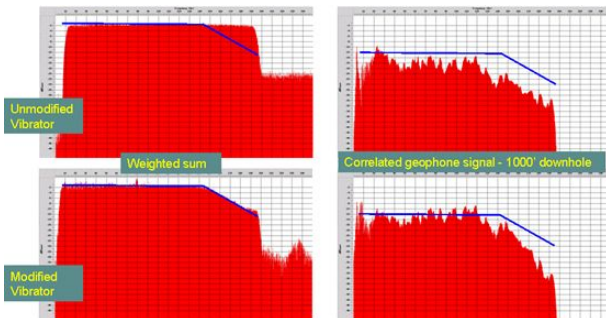


Figure 5: The weighted sum and 1000ft corrected downhole geophone spectra for (top) the INOVA AHV-IV Vibrator without modifications and (bottom) the INOVA AHV-IV with modifications

Another indication the modified Vibrator better controls what is put into the ground is in the closer relationship between the harmonics of the weighted sum and the downhole signal.

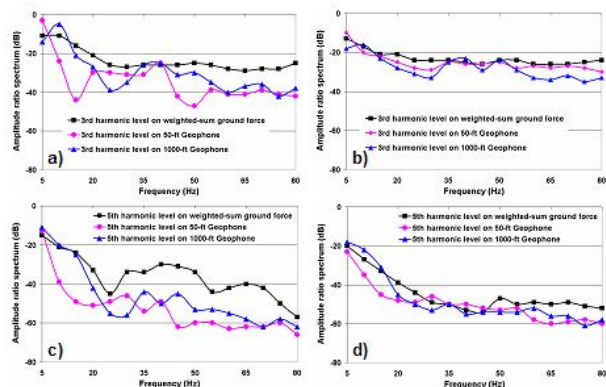


Figure 6: Odd harmonic ratios from the unmodified Vibrator (left) and modified Vibrator (right)

Harmonic Distortion Reduction

The Vibrator performance can also be improved by modifications to the control system. It is possible to characterize the transfer function of the hydraulic system including the servo valve and use the inverse of this to drive the Vibrator with a signal that attempts to cancel out the undesirable effects of the hydraulic system. This results in more energy going into the fundamental signal put into the ground rather than the harmonics, particularly below 20Hz. Results from this are shown in Figure 6 for both the unmodified and modified Vibrator, as can be seen this results in even further improvement to the signal output by the modified, or advanced, Vibrator.

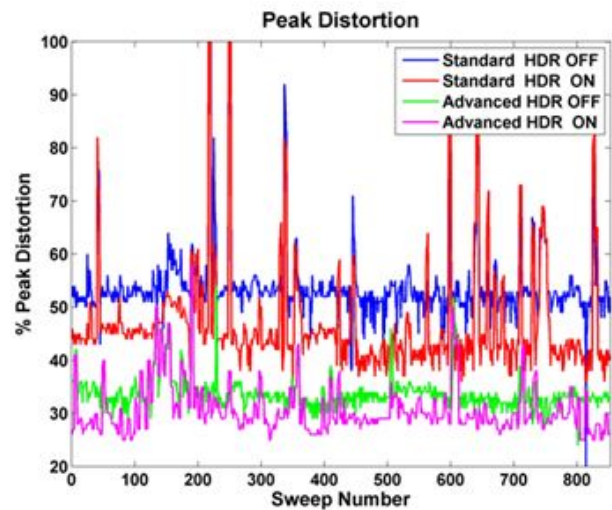


Figure 7: Harmonic distortion levels along a 2D line with the unmodified (Standard) Vibrator and the modified (Advanced) Vibrator without and with HDR

Conclusions

Modifications to a Vibrator have resulted in a Vibrator signature that is improved in bandwidth, repeatability and predictability. This development



The Impact on Seismic Data Quality of an Improved Seismic Vibrator

provides an improvement in the quality of Vibroseis data, particularly under variable ground conditions and in applications such as simultaneous sweeping methods requiring a more accurate estimate of the ground force, or Vibrator signature.

Acknowledgements

The author wishes to acknowledge John Wei and Tom Phillips with INOVA for many discussions regarding the INOVA AHV IV Vibrator, John Sallas of GeoMagic for enlightening discussion on all things Vibroseis and finally INOVA for permission to publish this paper.

References

Bagaini, C 2006, Overview of simultaneous Vibroseis acquisition methods, SEG New Orleans Annual Meeting
Sallas, J, 1984, Seismic vibrator control and the downgoing P-wave, *Geophysics* 49, pp732–740

Sargiotis, C 2010, On the accuracy of the ground force estimated in Vibroseis acquisition, *Geophysical Prospecting*, 2010, pp58, 69–80

Wei, Z, 2009, How good is the weighted-sum estimate of the vibrator ground force?, *The Leading Edge*, August 2009, pp 960–965

Wei, Z, 2008, Pushing the vibrator envelope: extending low and high frequency limits, *First Break* 26, pp37–43

Wei, Z, 2008, Design of a P-wave seismic vibrator with advanced performance, *GeoArabia*, Vol 13, No, 2, pp123–136