Emphasizing Vibrations

CGGVeritas is applying new technology to extend seismic bandwidth and maximize production

PAUL WOOD

In the article ‘Illuminating Resolution’ (GEO ExPro Vol. 8, No. 3) we described the evolution of seismic acquisition technologies that aim to achieve the geophysicists’ goals of illumination and resolution. One development featured in the article is the concept of extending the frequency content or bandwidth of seismic signals, especially at the low-frequency end, in order to achieve better vertical resolution and more accurate quantitative seismic interpretation. One of the seismic companies looking at this is CGGVeritas with its onshore and offshore broadband solutions, EmphaSeis™ and BroadSeis™.

EmphaSeis for Vibroseis

EmphaSeis has been developed to extend the low- and high-frequency bandwidth of Vibroseis surveys to enhance the delineation and characterization of fractured, shallow, or deeper reservoirs. This enhancement comes from improvements to both structural imaging and stratigraphic inversion which both benefit from a broader bandwidth. Seismic surveys that use explosives as a source are able to record very low frequencies from broad bandwidth explosions. But surveys using drilled explosives are relatively more expensive, and can have significant environmental, safety and security limitations. So most modern seismic surveys on land use Vibroseis sources where access permits. Vibroseis trucks apply a sweep over a range of frequencies into the ground using hydraulic motors that shake a baseplate, with the force opposed by a heavy weight mounted on the vehicle.

The mechanics and hydraulics of Vibroseis sources and the associated force applied to the ground are quite complex. The force that can be generated at a given frequency is constrained by various factors that affect different segments of the output spectrum, varying with the make and model of the vibrator. At very low frequencies, between 1 and 10 Hz, two of the most important parameters governing the maximum output force are the reaction mass displacement (the distance it can move up and down) and the flow rate of fluids in the hydraulic drive system. The vibrator specifications are used to calculate these low-frequency limiting curves and then in designing the EmphaSeis sweep.

In the example shown (top of page 71), when trying to maintain a constant output force at low frequencies, the main constraint on the signal is the mass displacement, the parabolic red curve. Between 4 to 10 Hz, the hydraulic fluid flow (magenta curve) becomes the dominant limit on output as the hydraulic system tries to feed a large enough volume of fluid to actuate the piston. The electronics controlling the force of the signal have to avoid exceeding these curves, or significant distortion will occur. Normal Vibroseis sweeps are linear, running smoothly through the frequency band. Tapers are applied at low and at high frequencies to gradually increase the output force of the vibrator as the sweep starts and ends to avoid an increase in distortion. In the linear sweep shown here in blue, starting at 5 Hz, the limit of flow constraint is reached at around 7 Hz, by 8 Hz the 75% drive level set for this sweep has been reached, and the flow limit is no longer exceeded for the remainder of the bandwidth. But between 7 and 8 Hz the
vibrator is overdriven, often leading to a decision to use a longer taper, resulting in lower output at low frequencies.

Non-Linear Sweep
The EmphaSeis technology applies a customized non-linear sweep that is designed to stay within the mechanical and hydraulic limitations of the vibrator as shown by the green line on the graph. In addition to generating more energy at low frequencies (in production, starting as low as 1.5 Hz), the EmphaSeis drive level can be increased to achieve higher peak force (up to 90%) in the mid frequencies. One consequence of the non-linear sweep is that more time is required to generate the low frequencies—to allow the reaction mass and fluid flow to work smoothly without distortion. This can be compensated by spending less time on generating the mid frequencies, which is possible without degrading the signal because of the higher drive level achieved at these frequencies. This sweep design allows EmphaSeis to deliver more low-frequency energy while maintaining the conventional sweep length and productivity.

Early field trials of EmphaSeis verified that lower frequencies than are recorded with linear sweeps can be recovered with the EmphaSeis custom sweep. In a test that CGGVeritas conducted together with Shell International, an additional 15 dB of signal were recorded at 3 Hz in a borehole array (representing the far-field source signature) when using an EmphaSeis sweep of 2-80 Hz.
compared to a linear sweep of 5-80 Hz. In a production test on a 2D seismic reflection line conducted with Khalda Petroleum Company/Apache in Egypt, additional low frequencies were recovered using EmphaSeis. These low frequencies could be crucial for delineating new exploration or development targets, as the additional bandwidth improves the resolution and image quality of deeper reservoirs.

**Optimizing Production**

In addition to extending the bandwidth of Vibroseis sources, CGGVeritas has developed techniques that optimize the productivity of Vibroseis crews. This is especially important in the Middle East where desert terrain allows sources to be distributed freely over a wide area with few obstructions. There is a continual need to improve image quality by reducing shot and receiver spacing and increasing the fold. So acquisition of a 3D survey over a given area would take much longer, perhaps becoming prohibitively expensive, if measures were not taken to improve production rates. CGGVeritas has also recently seen an increased need for high-productivity applications in regions like Alaska, Canada and parts of North America where seasonal constraints require crews to acquire data in a relatively short period of time. To conduct high-density surveys in these locations, a high-productivity Vibroseis technique is essential.

When 3D surveys started to become the norm rather than the exception in the Middle East, early techniques to speed up production used ‘flip-flop’ sources. One group of vibrators would move up while a second was ‘shaking’, minimizing the down time arising from changing source locations. Petroleum Development Oman introduced ‘slip-sweep’ (Rozemond, 1996), where one vibrator group would start vibrating before the previous one had finished their sweep. Because the frequency bands of their signals did not overlap (one group would be vibrating in a low-frequency band while the other was at the high end), the signals could still be decoded. In 2003, CGGVeritas introduced an in-field processing technique called High-Productivity Vibroseis Acquisition (HPVA) for slip-sweep operations that filters the harmonic distortion from the overlapping sweeps to improve image quality and increase productivity.

With the introduction of super-crews recording many thousands of channels, receiver spread layouts became large enough to support groups of vibrators, or even fleets of single vibrators, sufficiently far apart that they could vibrate simultaneously without causing interference. This technique, called Distance Separated Simultaneous Sweeping or DSSS, was introduced by BP (Bouska, 2008), which also implemented a simultaneous sweeping method, Independent Simultaneous Sweeping (ISS)™ in 2008 (Howe et al., 2008). In this method, individual Vibroseis units effectively act as autonomous units, positioned at various locations within a receiver spread, each sweeping independently when it is ready. The recorder is continuously gathering data and the records are reconstructed later.

Simultaneous source techniques, or blended acquisition such as ISS, are seen as one of the keys to future productivity gains in both land and marine acquisition. Vibroseis lends itself well to this arena by providing the opportunity to use uniquely coded sweeps for the individual sources. This enables the elementary, individual sources to be separated out from the tangle of simultaneous data much more accurately, a process known as deblending.

In a test in Saudi Arabia conducted with Saudi Aramco, CGGVeritas demonstrated that by using 18 separate vibrators, each with a unique sweep code, it was possible to log over 44,000 records in a 24 hour period (Pecholcs et al. 2010). Further, using unique sweeps with a pseudo-random character instead of linear sweeps, data quality was improved and productivity was pushed to over 45,000 records a day. The results highlighted the importance of deblending for simultaneous source acquisition as illustrated.

CGGVeritas aims to constantly improve its Vibroseis methods. Techniques such as EmphaSeis, HPVA, and V1 increase resolution while pushing the threshold and pioneering new industry records on productivity.

*EmphaSeis and BroadSeis are trademarks of CGGVeritas. ISS and DSSS are trademarks of BP.*

**References:**


