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Improving quality and safety through the use of a purposely designed truck-mounted Vibroseis for VSP surveys

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SUMMARY

Vibrators are the preferred sources for onshore vertical seismic profile (VSP) surveys. Truck-mounted units are especially useful as they are more road mobile than buggy-based units. In particular, they can be driven directly to the wellsite, resulting in improved response times, simplified logistics with fewer vehicles and personnel at the wellsite and improved transport safety.

Acquiring broad-bandwidth, high-quality VSP data, using state-of-the art vibrator equipment, however, has generally required the use of the latest buggy-mounted vibrators, compromising well-site logistics and transportation safety for VSP operations. To deliver optimum performance, two new truck vibrator models specifically designed to take advantage of all of the most recent developments in vibrator technology while retaining the logistical advantages of truck-mounted units have been developed.

These new truck-mounted vibrators offer greatly improved data quality with tests showing that they can transmit a signal with a frequency bandwidth of 6.6 octaves compared to previous models which can only transmit 2.5 octaves. Being mounted on modern truck chassis these vehicles retain all the mobility and HSE advantages of truck vibrators.

Key words: Vibroseis, VSP

INTRODUCTION

Much effort has been expended recently by the major seismic vibrator manufacturers with the objective of improving the signal emitted by their vehicles (e.g. Wei, Hall and Phillips 2011). These improvements encompass both extending the bandwidth of the generated signal and improving its quality, for example, through reductions in harmonic distortion. Unfortunately, these developments have focussed on buggy-mounted units that are preferred by the major surface seismic contractors for their off-road performance, and competitive price.

Vibrators are the preferred sources for vertical seismic profile (VSP) surveys on land with truck-mounted units being especially useful as they are more road mobile than buggy-based units. In particular, they can be driven directly to the wellsite, resulting in improved response times, simplified logistics with fewer vehicles and personnel at the wellsite, along with removing the risk associated with high centre-of-gravity loads on trailers (Figure 1).

Figure 1. Examples of safety risks associated with the transport of buggy-mounted vibrators. In the image on the left the width of the buggy is greater than the trailer. In the image on the right the buggy slid off the trailer during the loading operation.

Acquiring wide-bandwidth, good-quality VSP data in what is becoming ever more challenging sub-surface formations requires the use of the new, improved, and therefore, buggy-mounted vibrators, resulting in a compromise of both safety and logistics.

To overcome this compromise, two new truck vibrator models specifically designed to take advantage of all the recent developments in vibrator technology while retaining the advantages of truck-mounted units have been developed. In this work, we describe these two units and show their ability to generate better-quality signals and thus improve VSP data quality.

IMPORTANT VIBRATOR CHARACTERISTICS

A photo of the vibrator actuator (the component of the vibrator that generates the signal) of one of the new vibrator models is shown with its major components labelled in Figure 2. A seismic vibrator transmits a signal by means of its baseplate, which is held firmly on the ground by the weight of the vehicle. The vehicle weight is applied to the baseplate using hold-down airbags that are necessary to isolate the vehicle chassis from the baseplate vibrations above a minimum frequency (typically 2 Hz) and thus prevent it from being damaged. The reaction-mass, which sits above the baseplate, is then hydraulically driven up and down to generate the desired signal. Because force is the product of mass and acceleration the reaction-mass is only required to be a small proportion of the mass of the vehicle to allow generation of an output force that approaches the mass of the vehicle.

The force transmitted by the vibrator is approximated by the weighted-sum of the baseplate and reaction mass accelerations (i.e. their accelerations multiplied by their respective masses) (Sallas 1984). These accelerations are measured by two accelerometers, one placed on the reaction mass and one on the baseplate.

The mechanical and hydraulic characteristics of a vibrator limit its performance. As detailed by Sallas (2010), at frequencies less than ~1 Hz, the hold-down airbags can no longer isolate the vehicle from the vibrations, resulting in potentially catastrophic damage. At frequencies below ~10 Hz the output is limited by the amount that the reaction mass can move (the stroke) and the ability of the hydraulic system to provide adequate flow to move it. This second condition is far less critical and can be removed if adequately rated pumps are used and/or the sweep is designed to not dwell too long at low frequencies.

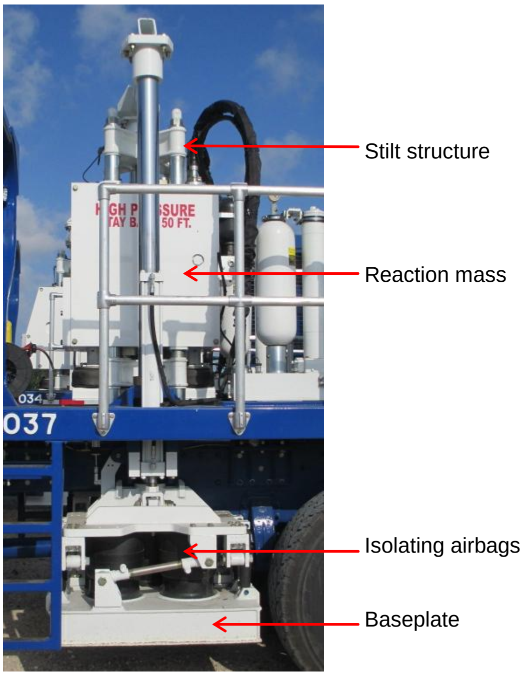

Figure 2. An image of the actuator of the new truck vibrator with major components labelled. The baseplate is in the raised position.

The hold-down mass of the vibrator is particularly important as the signal-to-ambient-noise ratio (SANR) of vibrator data is related to the maximum output force (i.e. the hold-down) multiplied by the square-root of the product of the sweep length and the number of sweeps. Thus, it is far more efficient to increase the SANR by increasing the force rather than increasing the sweep length or the number of sweeps (which can add considerably to the survey duration).

In the next section, we will describe how the new vibrators were designed and manufactured to overcome these constraints while still retaining the advantages of being truck mounted.

OPERATIONAL CONSIDERATIONS

As well as designing the vibrators to perform geophysically, they also must perform well as vehicles, both in terms of their mechanics and their safety.

Mechanically, there were two conflicting requirements: one for a vibrator that would be driven primarily off-road and the other for a vibrator that would be driven primarily on-road. The former requires a vehicle with excellent off-road ability, while the latter requires a vehicle that is road legal. To this end, two different vibrators were designed, referred to as the ‘desert version’ and the ‘highway version’ (Figure 3).

The desert version employs a 6x6 configuration with 24”-wide (54”-tall) tires. It utilises a central tire inflation system that, along with providing improved off-road performance, increases safety by automatically limiting the maximum speed depending on the current tire inflation pressure. Roll-over protection is included in both models and is the same as that used for buggy-mounted vibrators.

The highway version employs an 8x8 configuration; the extra rear axle being required to ensure that maximum axle load limits are not exceeded. This version meets all current US road and emission regulations. Although designed for the highway, this vehicle also has good off-road performance allowing it to acquire offset and 3D VSPs.

Figure 3. The two new truck vibrators, the desert version (top) and the U.S. highway version (bottom).

As both of these vehicles are based on a modern truck chassis, their performance and comfort is excellent, reducing driver fatigue and minimising the time required to move between job sites (the maximum speeds are 88 kph and 113 kph for the desert and highway models respectively).

In buggy-mounted vibrators, the reaction mass can be placed just above the baseplate (Figure 4) while in truck-mounted vibrators, the reaction mass must be mounted above the drive shaft. This high mounting can cause the reaction-mass to rock, thus increasing distortion.

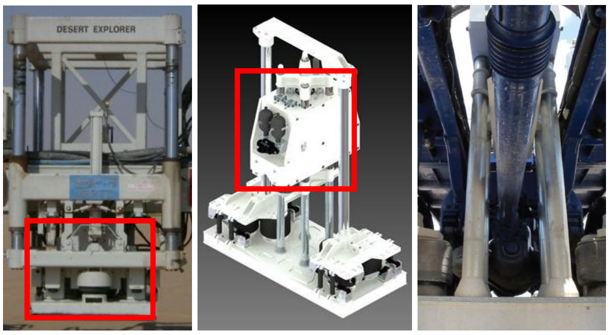

Figure 4. The position of the reaction mass on buggy mounted (left) and truck mounted (middle) vibrators. The view on the right is taken from beneath the vibrator and shows the drive shaft between the stilts.

DESCRIPTION OF THE VIBRATORS

A summary of the characteristics of the new vibrators is given in Table 1, along with those of previous 'conventional' vibrators.

Table 1. Summary of the major attributes of a previous unit and the two new truck vibrator models.

	Conventional vibrator	Q-Borehole – US Highway	Q-Borehole - Desert
Reaction-mass weight (lb)	5,800 to 6,800	8,490	11,200
Baseplate weight (lb)	3,500 to 4,500	4,020	4,020
Max. hold-down (lb)	45,000 to 51,000	54,000	63,000
Gross vehicle weight (lb)	46,000 to 52,000	59,000	68,000
Hydraulic flow rate (GPM)	120	190	190
Hydraulic pump engine (HP)	300 to 350	440	440

The near doubling of the reaction mass weight coupled with the increase in hold-down has resulted in the maximum output force of the vibrator increasing by between 20 and 40%, which allows the sweep length to be reduced by up to 50%, or, perhaps more importantly, the number of vibrators required for a VSP to be reduced. As well as the increase in force, the increase in the quality of the signal means that the useful force (i.e., excluding distortion) is likely to increase even more.

As discussed previously, the ability of the vibrator to transmit low frequencies is limited by the hydraulic flow of the vibrator. The available flow rate of the new vibrators is more than 60% higher, enabling it to transmit Maximum Displacement (MD) Sweeps[1] (Bagaini, 2008) with enhanced low-frequencies. Since the actuator is driven by its own dedicated engine mounted on the rear of the vibrator the flow rate is higher than for some buggy-mounted vibrators that share a common hydraulic system for both the drive train and actuator.

PERFORMANCE

To ensure that vibrator performance was optimal, we conducted a series of sweep tests. These tests ranged from a standard 8 to 80 Hz 12 second linear sweep to a very demanding 1.5 to 150 Hz 34 second MD Sweep.

A weighted-sum ground-force result for the linear sweep plotted in the frequency-time domain is shown in Figure 5. The harmonics generated by the new vibrator are far lower than that of the conventional vibrator, the energy of the strongest (the second) being just 0.6% of the energy of the fundamental (less than half that of the results for the conventional vibrator), in total the harmonics have energy equal to only 2.6% of the fundamental. Overall the distortion (measured by cross-correlating the pilot and the ground-force) was down by 45 dB.

For the far more demanding MD Sweep the results were also excellent (Figure 6). Distortion was slightly higher than the linear sweep, but was still at least 42 dB down.

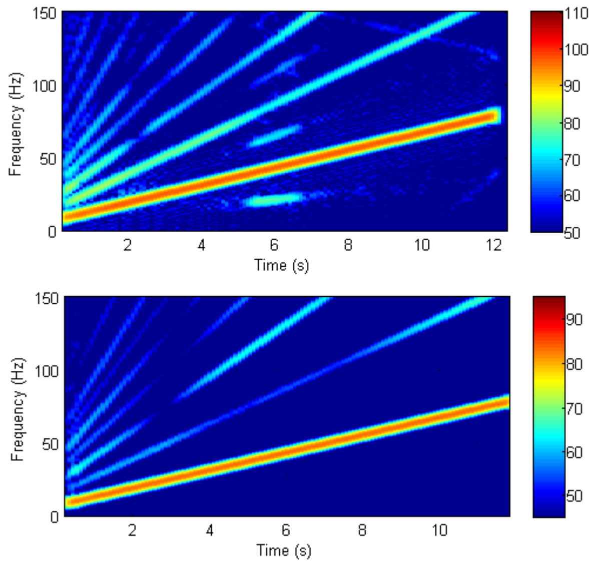

Figure 5. Frequency time plot of the ground force for an 8 to 80 Hz 12 s linear sweep using a conventional truck vibrator (top) and the new vibrator (bottom).

[1] Mark of WesternGeco

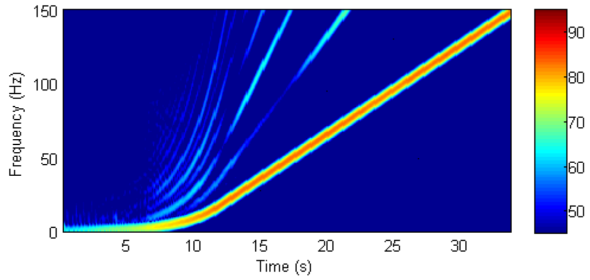

Figure 6. Frequency time plot of the ground force for a 1.5 to 150 Hz 34 s MD Sweep.

The spectrum of the fundamental component of the ground-force (i.e., after removal of the harmonics, Figure 7) shows that the vibrator was successful at transmitting energy across the full bandwidth, a total of 6.6 octaves, while the conventional linear sweep is bandwidth limited to 2.5 octaves.

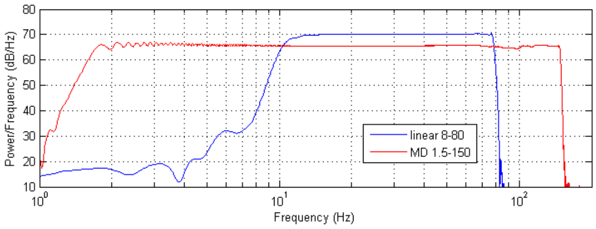

Figure 7. Spectra of the fundamental components of the ground-force for the linear and MD Sweeps.

CONCLUSIONS

The new truck vibrators offer significantly improved data quality with field trials showing that they can transmit a signal with a bandwidth of 6.6 octaves compared to previous models that can only transmit 2.5 octaves. Being mounted on modern truck chassis these vehicles retain all the mobility and HSE advantages of truck vibrators, but have the geophysical performance of modern buggy-based systems.

REFERENCES

Bagaini, C., 2008, Low-frequency vibroseis data with maximum displacement sweeps: The Leading Edge, 27, 582–591.

Sallas, J. J., 1984, Seismic vibrator control and the downgoing P-wave: Geophysics, 49, 732-740.

Sallas, J. J., 2010, How do hydraulic vibrators work? A look inside the black box: Geophysical Prospecting, 58, 3–18.

Wei, Z., M.A. Hall, and T. F.Phillips, 2011, Geophysical benefits from an improved seismic vibrator. Geophysical Prospecting, 60, 1-14.