**Tu N105 06****Higher Vibrator Hydraulic Force for Improved High Frequency Generation**

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**SUMMARY**

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For conventional deep seismic with heavy vibrators, the traditionally used sweeps had an 8-80 Hz bandwidth. Extending the bandwidth to include lower frequencies has been largely addressed over the past five years and sweeps are now starting as low as 1.5 Hz in Middle East surveys. However, generating high frequencies is essential for improving the vertical resolution and imaging thin layers. Their use remains limited until now as their recording is highly ground-dependent; moreover, several physical vibrator limitations restrain the generation of high quality high frequencies. This abstract presents how the vibrator behaves as the sweep frequencies increase, and how the phase shift between the reaction mass and the base plate makes the vibrator reach its hydraulic maximum output. A practical solution illustrated by field tests is then proposed: by increasing the vibrator hydraulic capability, an extra sweep bandwidth can be effectively generated and the conventional 80 Hz high-end sweep frequency extended.

## Introduction

Extending the conventional vibrator 8-80 Hz sweep bandwidth remains a key concern for current seismic projects. Starting the vibration at lower frequencies has been widely addressed in the recent years. This technique is spreading rapidly and is already recognized in the field (Mahrooqi 2012). The bandwidth extension for high frequency has been less addressed, especially for the strong dependence of their emission on ground types and their quick absorption. Their benefits for seismic imaging are nonetheless paramount: the narrower reflection peaks improve temporal resolution and enable detecting and imaging the thinner layers, and the denser recording geometry required for shorter wavelength recording improves spatial resolution. In addition to the ground, vibrator behavior is affected by several mechanical and hydraulic factors (Sallas 2007, Wei 2007), e.g., baseplate rigidity, baseplate coupling with the ground, phase difference between the reaction-mass and the baseplate, and servovalve bandwidth. This abstract focuses on a practical solution for improving the vibrator performance for high frequency generation through higher hydraulic peak force capability.

## Mass and baseplate acceleration phase shift

The currently recognized model to assess the vibrator energy output is the ground force estimate, given by the weighted sum formula (Castanet 1965 and Sallas 1984):

$$GF = \text{Mass}_{\text{mass}} \times \text{Acc}_{\text{mass}} + \text{Mass}_{\text{baseplate}} \times \text{Acc}_{\text{baseplate}} \quad (1)$$

When performing a sweep, the mass and baseplate contributions to the ground force change:

- At low frequencies, the mass and baseplate accelerations show little phase shift; both contribute positively to the ground force. As the mass weight and acceleration exceed those of the baseplate, the mass term of equation (1) contributes predominantly to the ground force (Figure 1, left).
- When the sweep frequencies increase, the baseplate acceleration increases as well. Part of the increasing baseplate contribution is “hidden” by the increasing phase shift between the mass and baseplate, and vibrator electronics regulate the mass acceleration to keep a constant ground force (Figure 1, right).
- At higher frequencies, the increasing phase shift causes the baseplate contribution to increasingly counter that of the mass. Once vibrator limits are reached, the ground force will start decreasing.
- The phase shift may ultimately reach 180° at the end of high-frequency sweeps. Baseplate acceleration then far exceeds mass acceleration, and despite a lesser weight, its contribution almost completely counters that of the mass. Ground force amplitude may thus account for only a few percent of the expected target.

The frequencies concerned by this phase shift depend largely on the ground properties. In vibroseis, the ground-vibrator system is commonly modelled as a second order system (Lerwill 1981). This model is simple and robust and provides high-performance results in the field. With this model, ground types can be characterized by the frequency when the phase shift reaches -90° (Figure 2). It can be referred to as the ground cut-off frequency, typically ranging from 100 to 120 Hz on a concrete pad, 60 to 80 Hz on sands, and 20 to 40 Hz on soft grounds, such as freshly ploughed fields.

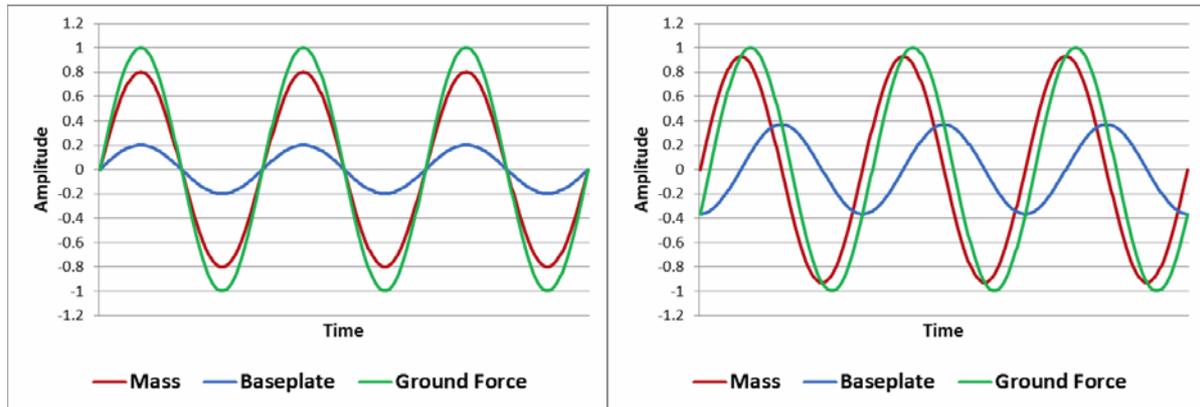
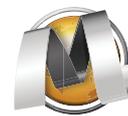


Figure 1 Reaction mass and baseplate contribution at (left) low frequency (phase shift around 0°) and (right) middle frequency (-90° phase shift on this example).

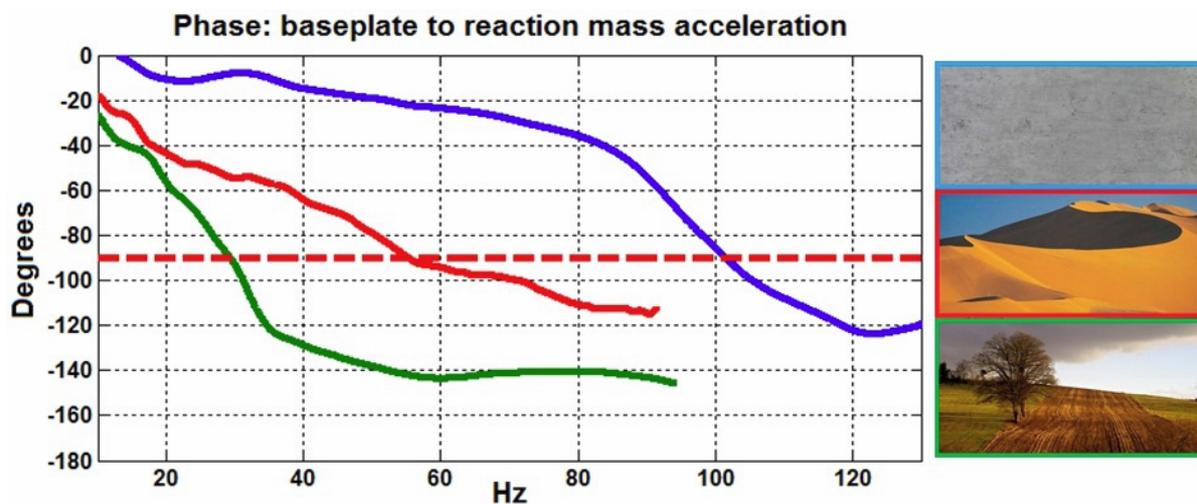
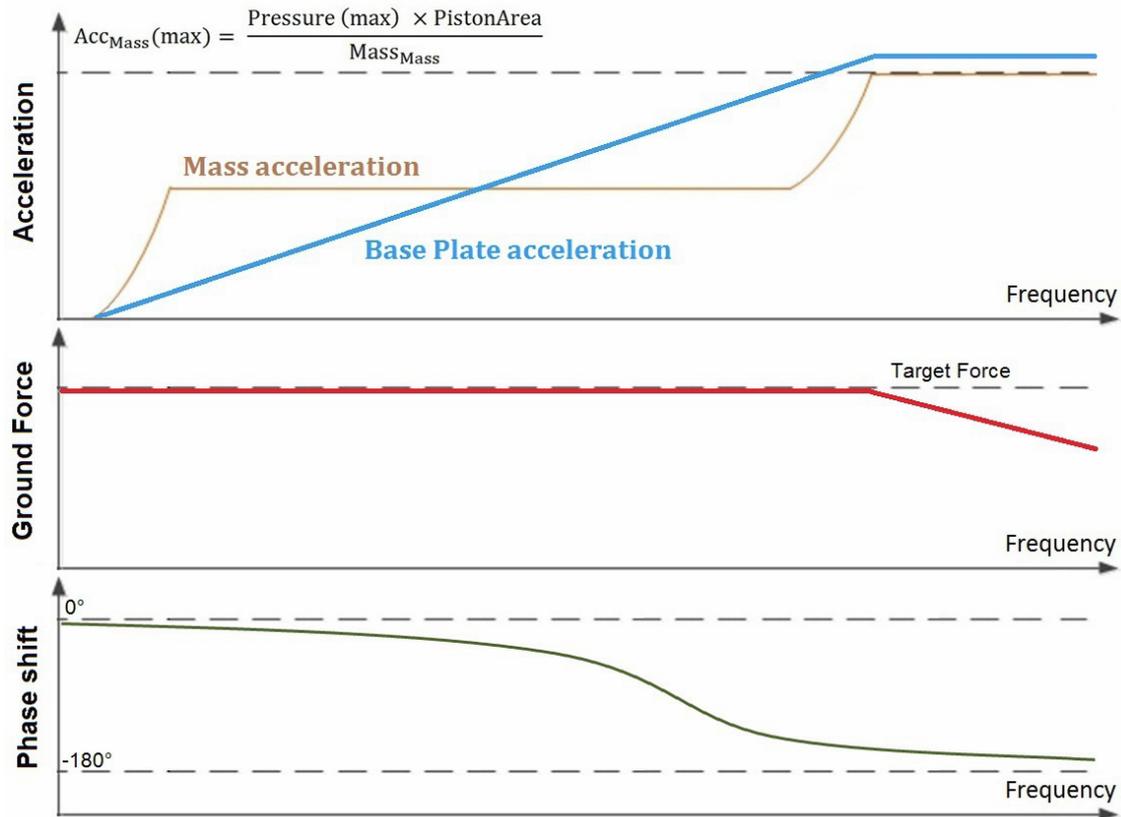
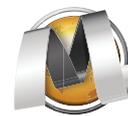


Figure 2 Phase shift between vibrator's mass and baseplate on three different ground types: concrete, sands, and ploughed fields. Field tests with a 62,000 lbf vibrator.

### Vibrator behavior at high frequencies

The phase shift consequences at high frequencies are that as frequency and phase shift increase, the baseplate contribution increasingly counters that of the mass. The vibrator, controlled to output a stable ground force, will automatically compensate the subsequent loss by increasing the mass acceleration that is directly correlated to the hydraulic force, i.e., the maximum pressure, up to its limit (Figure 3 and Figure 4, left). Once requested pressure is higher than the maximum available level, the ground force will start decreasing.

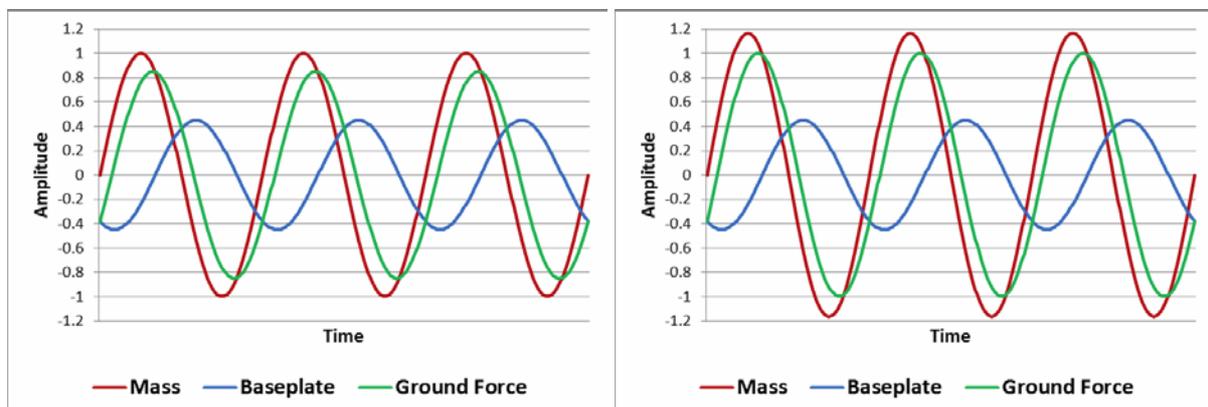
At high frequencies, note the importance of baseplate rigidity and accelerometer position: baseplate flexure and a non-optimal accelerometer position may indeed produce an erroneous weighted-sum ground force, not representative of the signal really emitted, as measured, for example, downhole or with a strain gauge testing device.



**Figure 3** Vibrator behavior with regards to frequency: (top) mass and baseplate acceleration. Mass maximum acceleration is limited by the maximum available pressure, (middle) ground force, (bottom) baseplate phase shift with reference to the mass.

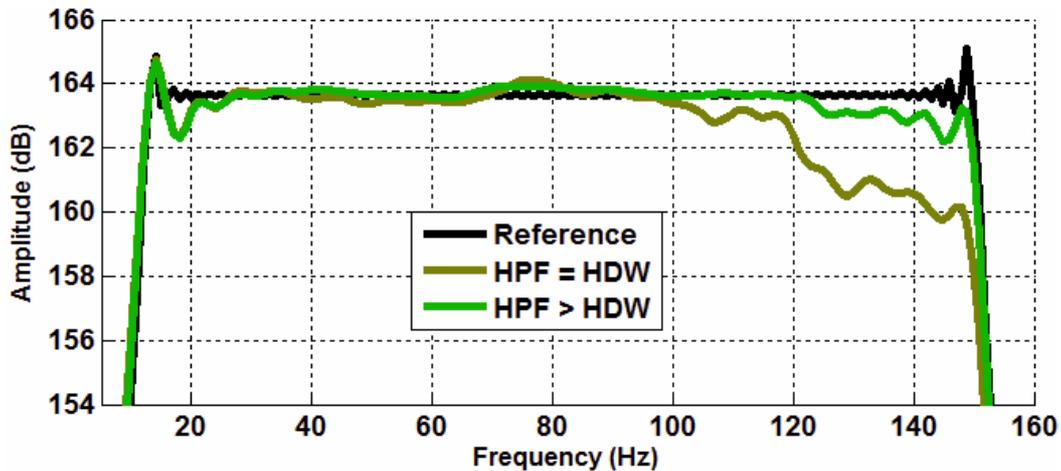
### Benefit of a higher hydraulic peak force

One solution is to use a vibrator capable of a hydraulic peak force (HPF) higher than the hold-down weight (HDW). Thanks to the vibrator electronic control, at low frequency the HPF won't exceed the HDW, so that vibrator won't "bounce". At high frequencies, when the phase shift becomes large enough for hydraulic pressure to reach its limit, the additional hydraulic capability enables increasing the mass acceleration and thus its contribution to the ground force (Figure 4, right). Ground force then remains within specification on an extra bandwidth.



**Figure 4** Reaction mass and baseplate contribution at high frequencies: (left) when reaction mass has reached its maximum acceleration, ground force starts dropping, (right) with an additional acceleration capability, ground force can be kept at target.

Field tests were performed on a 80,000 lbf HDW vibrator having a standard 90,000 lbf capability, with HPF ranging from 80,000 to 90,000 lbf (Figure 5), on a relatively soft ground area (damp earth with gravel, cut-off frequency at 60 Hz). When using a HPF superior to the HDW, the ground force remains within target for an extra 25 Hz bandwidth. Even more important benefits in high frequencies can be expected from stronger vibrator hydraulic forces.



**Figure 5** Benefits of a high HPF on the ground force: field tests performed with a Nomad 90 vibrator (80,000 lbf HDW); results for 80,000 and 90,000 lbf HPF.

## Conclusion

Vibrator limits with respect to high frequencies are progressively being pushed back thanks to technical enhancements, retention of signal fidelity being paramount to extend the usual 80 Hz sweep high-end frequency. For conventional deep seismic projects, much affected by high-frequency absorption, the current challenge is to sweep up to 120 Hz on a standard basis, as performed successfully on recent projects (Seeni 2010). The existing modern vibrators largely have this capability, while regular technical enhancements enable improving the generation of higher frequencies. Recording shorter wavelengths also supposes adapting acquisition parameters by reducing receiver spacing and avoiding arrays for both sources and receivers.

## References

- Baeten G., Hwang J., Walk W. [2012] Towards broader bandwidth and higher channel counts. 82<sup>nd</sup> Annual International Meeting, SEG, Expanded Abstract
- Castanet A., Rueil-Malmaison and Lavergne M. [1965] Vibrator controlling system. U.S. patent 3,208,550
- Lerwill W. [1981] The amplitude and phase response of a seismic vibrator. *Geophysical Prospecting* **29**, 503-528
- Mahrooqi S., Rawahi S., Yarubi S., Abri S., Yahyai A., Jahdhami M., Hunt K. and Shorter J. [2012] Land seismic low frequencies: acquisition, processing and full wave inversion of 1.5 - 86 Hz. 82<sup>nd</sup> Annual International Meeting, SEG, Expanded Abstract
- Sallas J. [1984] Seismic vibrator control and the downgoing P-wave. *Geophysics*, **49**, 732-740
- Sallas J. [2010] How do hydraulic vibrators work? A look inside the black box. *Geophysical Prospecting*, **58**, 3-17
- Seeni S., Robinson S., Denis M., Sauzedde P., Taylor R. [2010] Future-proof seismic: high-density full-azimuth. *First Break* **28**, 79-88
- Wei Z. [2007] Pushing the Vibrator Envelope – How High Can We Go? 69<sup>th</sup> conference and exhibition, EAGE, Extended Abstract