Enhancing the vibroseis technique through equipment noise reduction and optimizing the weighted sum signal

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Summary

Deconvolution of the weighted sum signal of baseplate and mass acceleration can prove marginally effective. Noise can interfere and severely limit the data quality. Identifying and reducing noise within the recording equipment has proven effective in reducing these problems. Two main sources of equipment noise are in the telemetry system commonly used for transmission and the accelerometers signal and ground force. Quantifying the noise signature and determining the degree of interference with the data is essential for deconvolving the ground force with recorded vibroseis signal.

Optimizing the placement of the baseplate accelerometer yields a better representation of the source signature imparted to the earth. The baseplate accelerometer many times is located in a physically convenient location. Far-field particle motion is generally assumed to be in phase with the measured "ground force." This is true only if the baseplate is rigid, which does not appear to always be the case at higher frequencies.

Introduction

Broadband minimum phase wavelets allow for the best seismic resolution and are necessary for optimal results on high resolution seismic reflection surveys. The vibroseis processing technique yields a zero-phase Klauder wavelet, which is classically produced by cross-correlating the signal with the recorded seismic signal. This process acts as a filter for frequencies that are not generated by the vibrating source (Brittle et al., 2001). Minimum-phase variations associated with the Klauder wavelet are tied to the acquisition of the data and geology, such as coupling, reverbations, multiple reflections and attenuation of higher frequencies (Futterman, 1962; Wuenschel, 1965; Robinson, 1967; Lines and Ulrych, 1977; Marschall and Knecht, 1986; Robinson and Treitel, 2000). Because cross-correlation is sensitive to the slightest variation away from the ideal in the actual sweep, it is naturally error-prone, considering no vibrator can produce a seismic signal identical in every way to an electronic drive signal. An alternative method involves vibroseis deconvolution, which would reinstate the true reflectivities of the subsurface by removing the seismic wavelet, theoretically leaving a spike (Yilmaz, 1987). One of the advantages of using this technique is that for the ideal case, a broadband sweep would result in a precise reflectivity response without a source signal.

There are other matters to consider. A major concern is the signal-to-noise ratio. The noise level must be controlled by ensuring good coupling of the baseplate to the ground (Brittle et al., 2001) and efficient transfer of energy through the fluid/mass system to the baseplate. Energy outputted by the source continuously attenuates mode conversions, and varies in wavelet properties as the seismic wave propagates through the top layer of soil and sedimentary sections and reflects back to the surface (Chapman et al., 1981). By controlling the force output of the source relative to holddown pressures, energy levels can be maintained to ensure that decoupling does not occur.

Since the vibrator's force output is defined by physical motion of the baseplate, its displacement, velocity and acceleration are known (Sallas, 1984). If the baseplate ceases to act as a rigid body, then phase variations can be detected by accelerometers placed on the baseplate.

Near-surface applications of seismic reflection continue to strive for increased resolution at greater depths in the subsurface. Associated with this need has come an increased demand for high-frequency vibroseis because it is non-invasive and less costly compared to other sources. To push the dominant frequencies into a higher range (120 to 300 Hz), the drive force must be increased in part due to increased attenuation (Miller et al., 2004). Delivering of high frequency energy is directly associated with the design of the vibratory source, therefore, electrical and mechanical modifications must be considered for increasing resolution of standard vibroseis units (Chapman et al., 1981).

Method

Internal noise generated from the equipment needs to be identified and reduced of eliminated if possible. The equation for the convolutional model in the frequency domain can be represented as

$$X(\omega) = R(\omega)S(\omega) + N(\omega)$$

where $X(\omega)$ is the recorded trace, $R(\omega)$ is the reflectivity, $S(\omega)$ represents the sweep, and $N(\omega)$ is measured noise. Deconvolution removes the sweep but enhances the noise, which can be written as

$X(\omega)/S(\omega) = R(\omega) + N(\omega)/S(\omega)$ (Brittle et al., 2001)

The IVI minivibs used for this study employ a unique circular baseplate design. Significant testing and evaluations have been performed on the more standard rectangular baseplates, but very limited work has been documented using the smaller circular design. Another unique component of this is the frequency range of interest. Tests were designed to evaluate vibrator frequencies between 10 to 500 Hz.

Experiments were performed for this study using equipment available at the Kansas Geological Survey. Radios are commonly used to transmit the vibrator pilot to the recording system. Unfortunately, radio equipment is a source of noise on the recorded pilot. The KGS uses a single vibrator configuration and a radio system designed and built by IVI. The transmission noise can be identified by cross-correlating the weighted sum signal calculated using the baseplate and mass accelerometers with the pilot trace. The difference between this wavelet and a Klauder wavelet represents the influence of noise and the difference between the drive signal and some variation of the actual source wavelet. This proves that the weighted sum and pilot trace are recording different signals (Fig. 1). The frequency spectrum further reveals that the calculated ground force discriminates against the higher frequencies (Fig. 2).

Another source of noise that could degrade the deconvolution of the ground force originates from the accelerometers. Dytran model 3185D was tested for a 10 sec. interval in a 0.1 to 500 Hz frequency range and the noise was directly measured (Fig. 3).

High frequency attenuation is directly associated with the design of the vibratory source and therefore, electrical and mechanical modifications must be considered for optimal resolution (Chapman et al., 1981). The weighted sum method includes the assumption that the ground force and far-field displacement are in phase. This, however, is not the case. During a sweep, the baseplate loses contact with the ground and will continue to accelerate. For this reason, the weighted sum and what is transmitted into and through the ground could be entirely different signals (Sallas, 1984). This nonlinear contact between the baseplate and ground needs to be considered. Varying degrees of rigidity can be described as a cluster of springs that are placed between the baseplate and ground. This system allows us to account for a restoring force attributed by the springs' deformation (Lebedev et al., 2004). Since the baseplate undergoes flexure, placing several accelerometers at various distances from the center of mass to study harmonics, tuning and amplitude yield a better understanding of where to record baseplate acceleration that optimally describes energy imparted to the ground. The flexure of the baseplate causes it to cease its' behavior as a rigid body, and flexes at $\lambda = 1/2m$ (Fig. 4). Since the baseplate's outer rim is coincident with a nodal point, an accelerometer in that location results in the best readings.

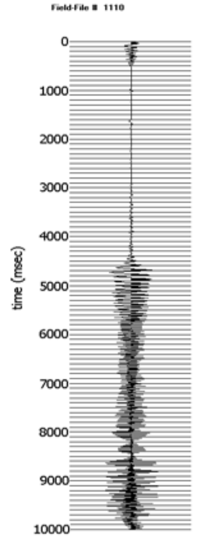

Figure 1.) Wiggle-trace of the pilot trace cross-correlated with the weighted sum signal.

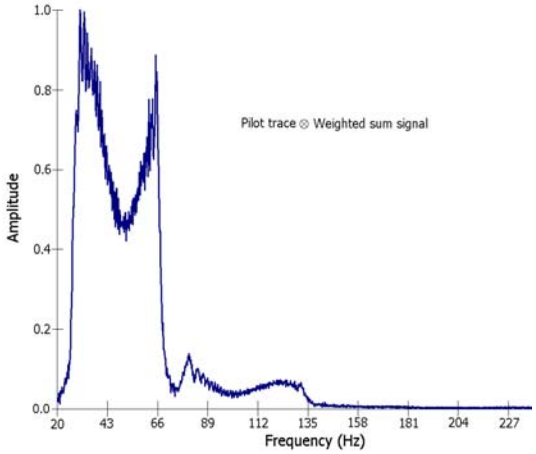

Figure 2.) Cross-correlation of the pilot trace with the weighted sum yields high-amplitude low frequencies and low-amplitude high frequencies.

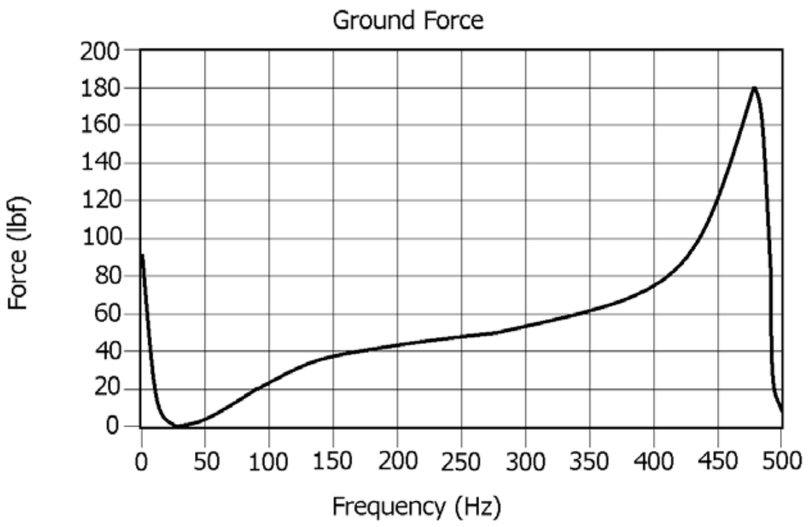

Figure 3.) Ground force plot of noise internally generated by the accelerometer model 3185D. The noise was recorded for 10 sec in a designated frequency range of 0.1 to 500 Hz.

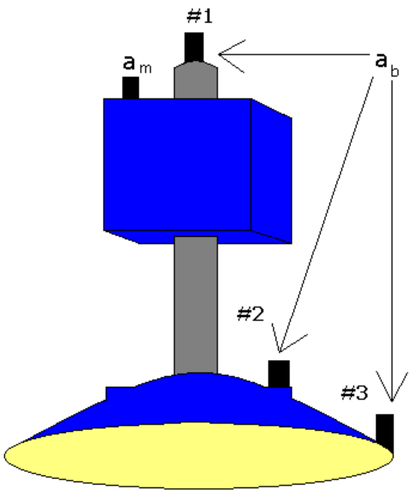

Figure 4.) Location of baseplate accelerometers a_b. Reaction mass a_m is shown. #1 depicts tradional location of the accelerometer, located on baseplate column. #2 is an intermediate position and #3 is coincident with $1/2\lambda$.

Conclusions

Deconvolving the pilot trace with the weighted sum signal will yield better results than cross-correlating with a synthetic sweep because it reinstates the reflectivities better. However, the signal-to-noise can play a significant role if the ratio is too low, causing unwanted noise to carry over into the data set. The accuracy with which the ground force is measured with a baseplate accelerometer can be significantly affected by sensor placement. Identifying and reducing sources of noise will help to maintain data quality.

The characteristic of the recorded acceleration of the baseplate will change depending on the location of the accelerometer. Traditionally, the sensor measuring baseplate motion has been placed over the top of the baseplate column. One of the problems with this is that the weighted sum signal ceases to record true ground movement once the baseplate begins to experience flexure.

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