Why would geophysicists care about vibrator servovalves?

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Summary

The industry is gradually improving the servo-hydraulic seismic vibrator, and much of this improvement is due to developing better servovalves.

Introduction

How important is this topic? Higher resolution, reduced effort, and a higher probability of recovering signals from noise result from progress toward the ultimate source goal: generate high-fidelity broad-band down-going waves.

When shopping for a home stereo, we probably won't settle for anything which produces total harmonic distortion (THD) greater than 1%. Yet we use seismic sources with 10 to 70% THD.

Is it because vibrator fidelity is difficult to attain or is it because we get what we have learned to accept? Are 4 ½ octaves all we can expect from vibrators? What will it take to get more? What is being done to improve the bandwidth limitation?

This paper addresses the answers to these questions as they relate to the vibrator servovalve. The servovalve has variable orifices which port pressurized hydraulic fluid into and out of the actuator cylinder to produce force. These orifices are an important cause of harmonic distortion.

The vibrator servovalve consists of a main stage driven by a one or two-stage pilot servovalve. The servovalve is a critical component of the vibrator, but also a weak point. When something goes wrong, a common trouble-shooting technique is to replace the servovalve.

Background

Conoco invented the seismic vibrator in Ponca City, Oklahoma in the 1960's. It was designed to produce and control baseplate velocity.

Sallas theorized (Sallas 1984) that ground force better-represents the down-going wavelet. The industry soon began to control phase and amplitude of a weighted sum approximation of ground force.

In the mid-to late 1980s two vibrator controller manufacturers introduced instruments which applied reaction mass acceleration feedback to the servovalve input signal so that the vibrator would tend toward being a force actuator rather than a baseplate velocity actuator. This reduced vibrator THD at frequencies below about 30 Hz and dampened the earth-baseplate resonance.

In 1991, hydraulic pressure feedback inside the main servovalve was introduced to the vibrator servovalve (Reust 1993), and was quickly adopted by the industry. This reduced THD at frequencies below about 50 Hz, improved phase and amplitude control, and dampened the earth-baseplate resonance.

In the 1980s and following, some vibrator manufacturers began providing hydraulic accumulators near the servovalve. (Wei *et al* 2007) This improves the hydraulic supply, thus improving vibrator fidelity.

No ultimate near-term total solutions to vibrator fidelity or bandwidth limitation are foreseen. Electro-magnetic vibrators promise very high fidelity, but they have not yet worked out. Eccentric mass vibrators can also have very high fidelity, and they have been around for many decades, but existing designs severely limit bandwidth. However, a limited amount of research and gradual improvements to servo-hydraulic vibrators are on-going.

More recent advancements

The maximum power transfer theorem, also known as Jacobi's Law, teaches that for maximum power transfer a source's impedance should match the receiver's impedance. (Thompson, 2011) Some vibrator controllers measure earth coupling impedance and adjust the servovalve input signal to better-match or compensate for impedances. (Boucard and Ollivrin 2010) Pressure feedback servovalves also tend to match source impedance to earth coupling impedance. (Reust 1993) Both techniques reduce THD and thus improve the down-going wave.

A desirable means of dealing with a technical problem is often to eliminate, rather than solve the problem. A recently introduced voice-coil style pilot valve eliminates one of three stages of hydraulic amplification in the traditional servovalve. One nonlinear hydraulic amplifier stage is replaced by a linear, low distortion electronic amplifier.

Pressure feedback servovalves have a nonlinear transfer function in their feedback loops. This nonlinearity mimics the orifice nonlinearity, and thus tends to cancel the servovalve's orifice nonlinearity. A recent development in pressure feedback servovalves increases the feedback bandwidth and gain, further reducing THD and improving phase and force control.

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The most significant nonlinearity in a servovalve occurs as the main spool is changing flow direction by crossing through the central null region. This cross-over occurs twice per cycle. At null, the spool's metering edges over-lap their flow ports in order to maintain stability keep leakage low; so, during the finite time periods at which the spool is at null, the hydraulic supply is effectively isolated from the actuator. This causes a profound impedance change, and major perturbations are seen in the ground force signal. One vibrator controller manufacturer electronically urges the main spool through the null position more rapidly to reduce the effect (Wei and Phillips 2010) and pressure feedback tends to do likewise. In addition, one servovalve manufacturer's latest product version has spool edge shaping which reduces the impedance anomaly at null, while maintaining stability and low leakage. This feature also reduces water hammer and cavitation, extending seal and servovalve life.

Examples

Figure 1 shows perturbations in both the hydraulic power supply and the ground force signal as the servovalve crosses null at 7 Hz. The broad vertical stripes intersect the valve spool position signal at its cross-over points and highlight the resultant noise in the other signals. The hydraulic P/S signal is the differential pressure between the hydraulic supply and return. The narrow vertical stripes highlight the effect of other hydraulic power supply noise on the ground force signal. These artifacts may be reflections of the larger perturbations. The high frequency noise (650 Hz) seen in the hydraulic power supply trace is caused by piston strokes of the hydraulic pumps. It becomes significant when the vibrator operates at high frequencies.

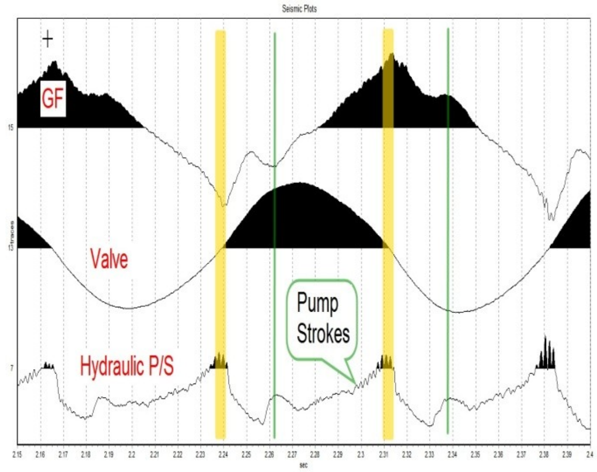

Figure 1. Noise in the vibrator output (ground force) signal caused by its servovalve and hydraulic supply.

Figure 2 compares the maximum stable force output of a miniature vibrator using two different pilot servovalves. With the voice-coil pilot, more energy can be produced. This valve has higher frequency response and is able to fully open the main valve at higher frequencies compared to the traditional pilot.

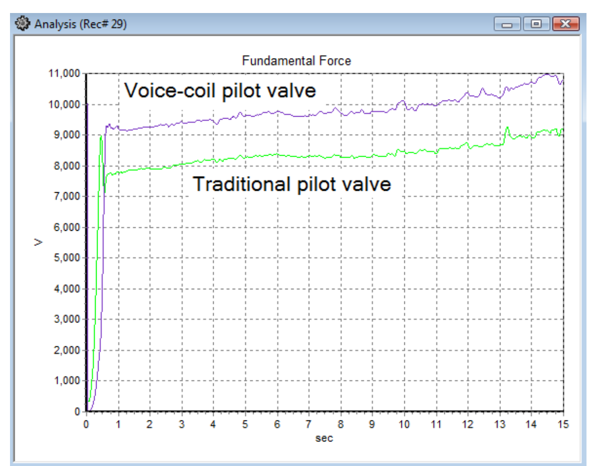

Figure 2: Maximum stable force with traditional vs. voice-coil type pilot servovalves on miniature vibrator sweeping linearly from 5 to 305 Hz in 15 sec.

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Figures 3 and 4 compare hydraulic pressure fluctuations (noise) in a servovalve's hydraulic supply and return ports with standard and shaped servovalve metering edges. In each case, a 5 to 150 Hz linear sweep was performed in 8 seconds, and all signals are plotted at the same scale. A sudden onset of higher amplitude noise in the return port indicates cavitation. Note that the onset of cavitation occurs at a higher frequency with the shaped metering edges, and the high pressure supply has much less noise.

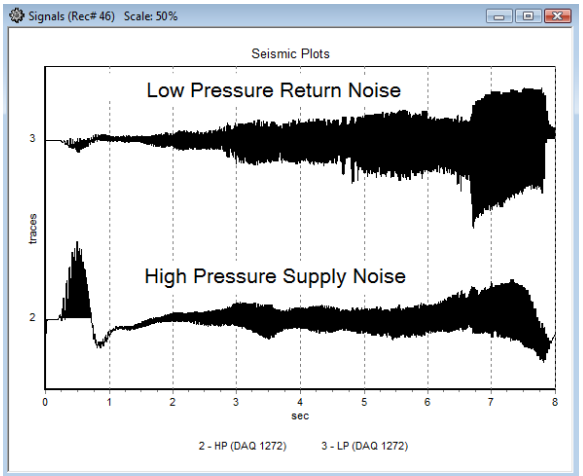

Figure 3: Pressure noise in a servovalve's supply and return ports with traditional servovalve spool metering edges

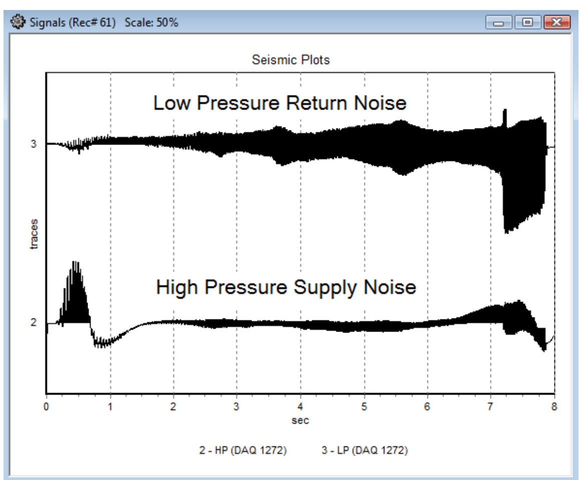

Figure 4: Pressure noise in a servovalve's supply and return ports with shaped servovalve spool metering edges.

Conclusions

Vibrator bandwidth is being increased by higher frequency response vibrator pilot servovalves. This offers higher resolution in seismic sections. This is especially useful for certain shallow targets where high frequencies may be readily recovered.

Vibrator fidelity is being improved by making changes to the servovalve main stage. Increasing pressure feedback makes the actuator more linear, and shaping the spool's metering edges reduces cavitation and water hammer.

Reliability may also be improved in the process, because the higher response pilot servovalve has fewer moving parts; and shaping the main valve's metering edges reduces cavitation.

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EDITED REFERENCES

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