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ENHANCED SERVOVALVE TECHNOLOGY FOR SEISMIC VIBRATORS[1]

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ABSTRACT

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The Pelton DR™ Servovalve Enhancement causes the natural output of a vibrator to resemble the desired output more closely. This simplifies the control problem and reduces harmonic distortion.

The traditional type of servovalve used on seismic vibrators is a flow-control servovalve. Flow is proportional to a vibrator's baseplate velocity, with respect to its reaction mass.

The new servovalve control parameter is pressure rather than flow. The differential pressure applied to a vibrator's actuator piston, multiplied by the area of the piston, equals the force applied to the vibrator's baseplate structure. This may be defined as actuator force. There is a simpler and more linear relationship between actuator force and ground force than between actuator velocity and ground force. Thus, it is better for the servovalve to control pressure into the actuator rather than flow.

A flow-control servovalve can be made to control pressure by sensing the differential pressure across a vibrator's actuator piston and applying it as a negative feedback around the servovalve main stage. This has been carried out and tested. The result is more accurate vibrator control and reduced harmonic distortion.

INTRODUCTION

A change has been made to the servovalve used on seismic vibrators. This change makes the natural response of a vibrator resemble the desired response more closely. Therefore, the corrections required of the phase and amplitude control loops are smaller, and control is more accurate. The improvement in vibrator response also reduces harmonic distortion.

A simplified block diagram (Fig. 1) illustrates the vibrator system. An electrical signal from a sweep generator is added to feedback signals and the sum is input to a 3-stage servovalve. The first stage is a torque motor which converts an electrical

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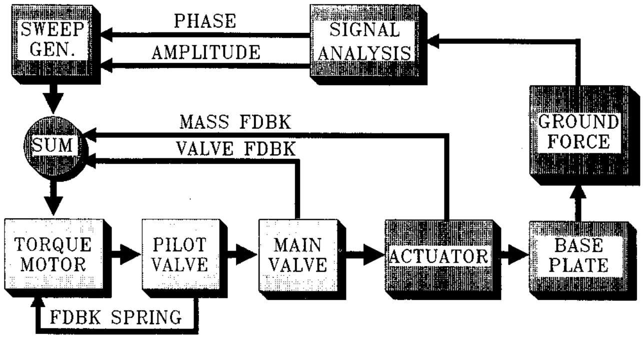

FIG. 1. Vibrator block diagram.

input into a hydraulic signal. The second stage is a spool servovalve used as an intermediate amplifier. There is mechanical feedback from the second stage valve spool to the first stage torque motor. The third stage, the main valve, is also a spool-type servovalve. An electrical transducer monitors main spool displacement and supplies a signal which is used as 'valve feedback' to monitor and control the spool's position.

The 3-stage servovalve controls a hydraulic actuator which is a double-acting hydraulic cylinder and which includes a reaction mass. The position of the piston within the cylinder is monitored by an electrical transducer whose output is used as a negative feedback called 'mass feedback' and is added to the sweep generator's output. The actuator is mechanically coupled to a baseplate which vibrates in contact with the earth's surface and produces a dynamic force on the ground.

The most common method of producing an electrical ground-force signal is to make a weighted summation of reaction mass acceleration and baseplate acceleration (Castanet and Lavergne 1965; Rickenbacker 1980; Sallas and Weber 1982). Other methods (Bedenbender and Kelly 1985; Huizer, van der Toorn and van der Voort 1987) may also be used. Thus the simplified block diagram indicates only that a ground-force signal is used, not how or where it is obtained.

Some characteristics of vibrators which make them difficult to control and which degrade the signals they transmit into the earth are:

(1) there is an earth/baseplate resonance which sometimes makes phase and amplitude hard to control;
(2) they produce considerable harmonic distortion;
(3) their operation is influenced by properties of the earth's surface.

The new type of servovalve improves on these characteristics.

THE FLOW-CONTROL SERVOVALVE

A widely used type of hydraulic servovalve is the flow-control servovalve. This type of valve is designed to meet the objective of producing output flow proportional to its input current (Thayer 1959). The ideal flow-control servovalve is insensitive to its

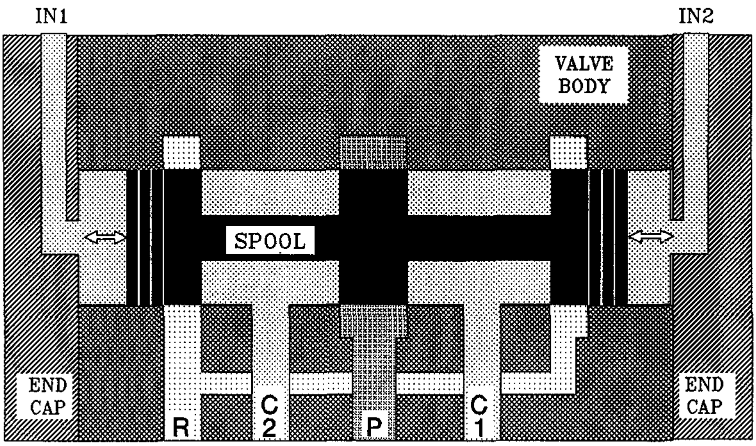

FIG. 2. Standard servovalve main stage.

load pressure and outputs hydraulic fluid at a prescribed flow rate under any load. Practically, flow does vary with load pressure and with supply pressure, and these variations may be viewed as control errors.

Figure 2 is a simplified drawing of the main stage of a flow-control servovalve. Differential pressure at inputs IN1 and IN2 causes the spool to move left or right. When the spool moves toward the right, pressurized fluid from the supply port P is in fluid connection with output port C2 and the hydraulic return port R is in fluid connection with the output port C1. The opposite port connections are made when the spool moves to the left. As the spool moves further from centre, the orifice area increases and the amount of flow increases. If the spool remains open but stationary, and if the load remains constant, then the flow rate is constant.

Flow-control servovalves are chosen for velocity control and position control applications. Flow is directly proportional to load velocity, and a flow for a time period is directly proportional to load displacement.

When a flow-control valve is used in a displacement control application, such as to lift a load and hold it, a characteristic impedance anomaly in its closed (null) position may be helpful. In order to reduce leakage in the null position, especially after the metering edges become worn, valve spools are usually machined to have a small amount of overlap. The load is virtually isolated from the hydraulic supply for some time as the spool moves through a short distance about its null position. There, the valve has its lowest output impedance, or maximum stiffness. This feature which is helpful in position control applications causes a glitch in actuator force and velocity as the valve moves through null.

THE VIBRATOR ACUTATOR

A seismic vibrator actuator consists of a reaction mass, which normally forms the cylinder wall of a double-acting hydraulic cylinder, a piston inside the cylinder and a cylinder rod which extends from both faces of the piston. The servovalve which

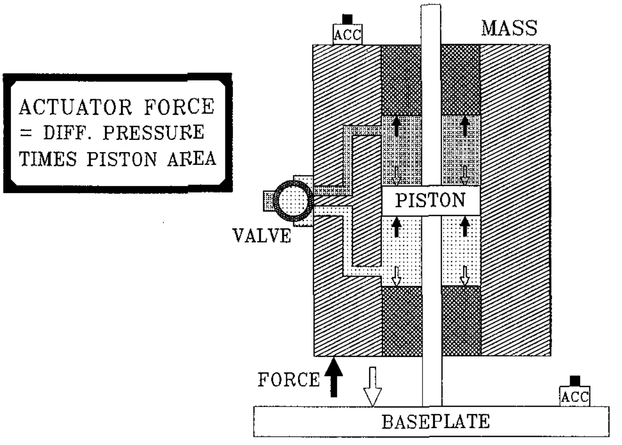

FIG. 3. Vibrator actuator and baseplate.

operates the actuator is usually mounted on the reaction mass and is then considered to be a part of the actuator (Fig. 3). The actuator's cylinder rod is attached to a baseplate which is held against the surface of the earth. The baseplate transfers a vibratory signal into the earth. The ground-force signal is now widely accepted as most descriptive of the signal which propagates into the far-field (Miller and Pursey 1954; Sallas 1984).

The actuator develops force in response to differential pressure applied to its piston. The differential pressure applied to the piston, multiplied by the surface area of one face of the piston, equals the actuator force (Fig. 3). Actuator force is applied to the baseplate and the reaction mass in opposite directions.

CHARACTERISTICS OF THE EARTH'S SURFACE

Soft, compliant soil normally has a more linear impedance than hard soil or rock; it is, therefore, a more linear load for the vibrator actuator. For example, if a vibrator baseplate load of 50 kPa pressure results in baseplate displacement of 4 mm, then 100 kPa would result in baseplate displacement of 8 mm if the earth were linear. However, most soil is sub-linear (Richart, Hall and Woods, 1970) (Fig. 4). When the

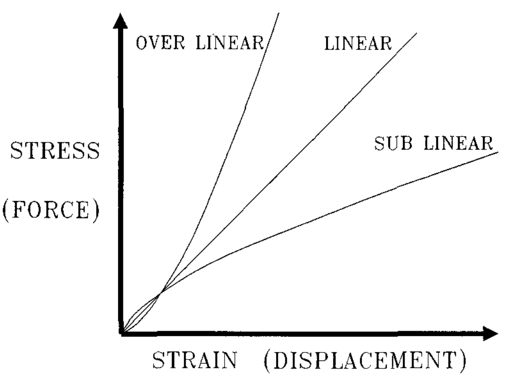

FIG. 4. Linear and non-linear relationships.

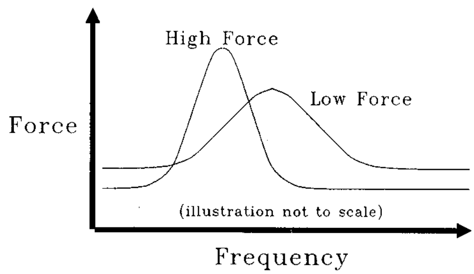

FIG. 5. Effect of sublinear earth on earth/baseplate resonance.

pressure applied by the baseplate is doubled, the displacement on sub-linear soil is more than doubled.

Rock is particularly sub-linear. On rock, the change in baseplate displacement may be nearly proportional to the square of the change in the force applied by the baseplate. The more the sub-linear surface is compressed, the softer it seems. This is indicated by the fact that the earth/baseplate resonance frequency decreases as the force level increases (Fig. 5).

For simplicity, the earth load has sometimes been modelled as a linear system (Lerwill 1981; Sallas and Weber 1982).

THE VIBRATOR WITH A FLOW-CONTROL SERVOVALVE

To control baseplate velocity was once the goal in designing and controlling vibrators. It was proposed that the ideal, though impossible, vibrator would have an infinitely heavy reaction mass, an extremely light but rigid baseplate, and no energy losses. Then, with a flow-control servovalve, the velocity of the baseplate would vary in direct proportion to input current. The vibrator's output was monitored by a velocity phone or an accelerometer on the baseplate (Thigpen, Dalby and Landrum 1975). This, together with the practical matter that no suitable pressure-control valves were available, could explain the original choice of flow-control valves for use on vibrator actuators.

The mass of the baseplate and other physical constraints cause errors in velocity control. One source of error is the mass feedback loop. It is normally closed only loosely because, along with varying load pressure, it tends to make the actuator control position rather than velocity. The tendency to control position is strongest at low frequencies and may be demonstrated by applying a step function to the torque motor input. At higher frequencies, perhaps above 35 Hz, the mass feedback loop opens up, and the actuator is more nearly a velocity control device.

As the servovalve spool passes through its null position twice during each cycle of a sine wave input, the load is virtually isolated from the hydraulic supply for a short time. The fluid column in the actuator is then very stiff. At low frequencies, the reaction mass is near its peak acceleration when the valve is at null. The inertia of the mass supported by the closed fluid column causes pressure spikes in the actuator cylinder. The pressure on the high pressure side of the actuator piston may pulse to twice the supply pressure for example, and the pressure on the low pressure side tends to pulse in the negative direction by the same amount. Fluid pressure below absolute zero is impossible thus hydraulic fluid vaporizes and causes cavitation, which erodes metal parts. The pressure pulses which cause cavitation appear on the vibrator's output signal.

A significant source of even-order harmonics in a vibrator's output is the non-linearity of the earth. When the earth's impedance is non-linear, more force is required to move the baseplate in one direction than the other. This results in distortion which is non-symmetrical about the hold-down force (even-order).

Odd-order harmonics are caused both by non-linearities in the servovalve and by mismatch of the vibrator's impedance to that of the earth. To understand how impedance mismatch results in harmonic distortion, consider the unrealistic extreme of a vibrator working into an infinite impedance. Ignore leakage and oil compression, and imagine that a vibrator actuator with a flow-control servovalve has an infinitely heavy reaction mass, and that it operates on a surface so hard that the baseplate does not move. When the servovalve first opens, the differential pressure across the actuator piston immediately rises to the supply pressure because flow is negligible. The pressure stays constant until the valve opens in the other direction. Then the pressure across the piston has the same magnitude, but is in the opposite direction. The resulting ground-force signal is approximately a square wave, rich in odd harmonic distortion.

Using flow as the valve's control parameter often results in a natural vibrator response which is quite different from the desired response.

The Pressure-Control Servovalve

The pressure-control servovalve is designed to control pressure to an actuator piston. In the ideal case, this pressure is independent of changes in the load and varies only in proportion to input current. It is important to note that with the pressure-control servovalve, input current is required either to produce or to maintain differential pressure on the actuator piston.

The pressure-control servovalve has load pressure feedback. The valve opens only enough to provide the desired differential pressure to the actuator. If the load changes, the pressure in the actuator changes and the valve spool moves to correct it.

The output impedance of a pressure-control servovalve is more consistent over the operating range of the spool. Compared to the flow-control valve, there is less of a glitch in actuator velocity and force when the spool moves through null, because feedback moves the spool as necessary to correct pressure errors. This also helps reduce cavitation in the servovalve and actuator.

The Vibrator Actuator with a Pressure-Control Servovalve

A vibrator actuator with a pressure-control servovalve can be referred to as a force control device. That is, the force it applies to the baseplate is nearly proportional to the input current. Mass feedback causes a tendency to control position at low frequencies, as with the flow-control valve. However the mass feedback loop is loosely closed and it opens up at moderate frequencies. For simplicity, the effects of the mass feedback loop will be ignored in further discussion. Load variations cause less tendency towards position control than with the flow-control valve because the pressure-control valve senses and controls load pressure. This is equivalent to continuously tuning the servovalve's output impedance for a better match to its load impedance.

From Actuator Force to Ground Force

Losses associated with the baseplate make up the difference between actuator force and ground force. Some of the actuator force is used in accelerating and bending the baseplate and some couples from the baseplate into the vehicle frame. The rest produces ground force.

The force required to accelerate the baseplate though, has a linear relationship to frequency, baseplate mass and baseplate displacement. Baseplate displacement would have a linear relationship to actuator force if earth impedance were linear. If the relationship between a vibrator's torque motor current and actuator force were linear, there would also be a linear relationship between torque motor current and ground force, providing that the earth's impedance were linear, and the baseplate were rigid and isolated from the vehicle.

In the example of a vibrator actuator working into an infinite load impedance, imagine a vibrator in which actuator pressure is proportional to torque motor input current. Then actuator force will be in direct proportion to input current, and the ground-force signal will also be proportional to input current. This compares to approximate square-wave signals for actuator-force and ground-force signals when a flow-control valve is used.

The Pelton DR™ Servovalve Enhancement

The Pelton DR™ Servovalve Enhancement is a method of converting a flow-control servovalve into a pressure-control servovalve. It involves applying load pressure feedback around the main stage of a flow-control servovalve. It adds no moving parts and is not expected to require adjustment or service.

Load pressure feedback makes the valve control actuator pressure rather than flow. Controlling actuator pressure helps to linearize the earth/vibrator system. With an ideal pressure-control servovalve, doubling the input current doubles the pressure across the actuator piston, thus doubling the actuator force. Assuming the ideal rigid baseplate with negligible mass, this would double the ground force. Then, the vibrator, from torque motor current to ground force, would be a linear device.

Figure 6 is a simplified block diagram of a vibrator with a pressure-control servovalve. It is identical to the traditional vibrator block diagram (Fig. 1) except for the addition of pressure feedback. Notice that the pressure feedback signal originates at the vibrator actuator and feeds back to the main stage of the servovalve.

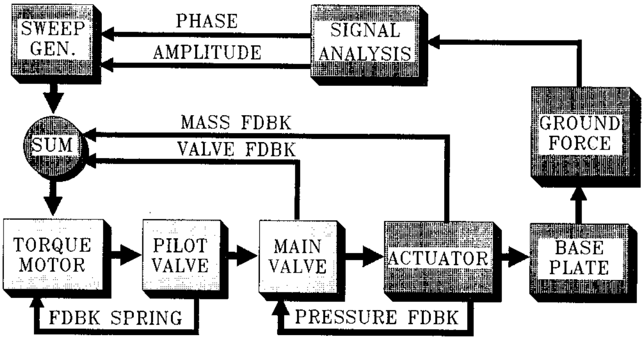

FIG. 6. Vibrator block diagram with pressure feedback.

Theoretically, it could feed back to other points, such as the pilot spool or the torque motor; or it could be converted to an electrical signal and fed back to the electrical summing junction together with valve and mass feedback. However, each stage of the vibrator adds some delay to the signal. Delay reduces the maximum loop gain which may be used, reduces the loop bandwidth, and tends to reduce the stability of the system.

The shortest path with the least delay gives the best performance in a feedback loop. A short load pressure feedback path is from the vibrator actuator to the input of the main valve. Since the pressure in the actuator comes from the servovalve, the shortest possible feedback path is from the output to the input of the valve main stage. This path is also the easiest to implement, so it was the obvious choice.

Figure 7 shows that the differential pressure applied to the actuator piston is sensed at the output of the servovalve (ports C1 and C2). This load pressure signal is inverted, restricted by orifices, and added to the pressure from the pilot valve (ports

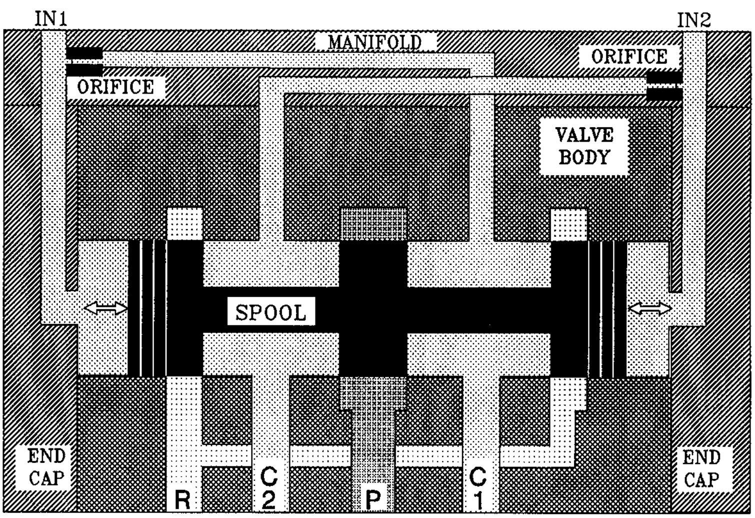

FIG. 7. Servovalve main stage with pressure feedback.

IN1 and IN2). The algebraic sum of the input and feedback pressures now accelerates the main spool of the servovalve.

Since the shortest practical feedback path was chosen, delay in the feedback loop is minimized and loop bandwidth is maximized. Therefore a significant amount of load pressure feedback can be applied, and stability at high frequencies is possible without reducing feedback gain.

Performance Results

When a vibrator operates on soft ground with nearly linear impedance, a pressure-control servovalve may not improve its performance. On soils with non-linear impedances, and especially on rock and ice surfaces, major improvements in vibrator performance have been recorded.

To see the natural response of a vibrator on a surface, it is instructive to turn the phase compensation and force control loops off, record the vibrator's output over a frequency range, and compare the results to a reference. Each control loop may be turned off by holding its input to the sweep generator at ground (earth) or some other constant voltage (Fig, 1).

When a vibrator is operated with its phase and amplitude control loops turned off, its response is referred to as the 'natural response' or the 'open-loop response' or the 'open-loop transfer functions'. The signals of interest are the 'ground-force signal' and the 'drive signal' which is the signal from the sweep generator shown in Fig. 1.

To measure open-loop response, the drive signal's AC voltage is held constant while the frequency varies, and no phase adjustments are made. To measure 'closed-loop response', the phase and amplitude inputs to the sweep generator (Fig. 1) are enabled, and the sweep generator frequently adjusts the phase and amplitude of the drive signal in an effort to make the ground-force signal match a reference signal which is also in the sweep generator but not shown for simplicity.

For all vibrator tests, typical and similar gains were used in the valve feedback and mass feedback loops so these would not enter into the comparisons. Only for the most detailed analysis, it may be useful to note that a constant time advance of 12 ms was used to take all open-loop data. This is the most common default value used in this type of vibrator control electronics.

Figures 8–11 show the results of tests on a rock surface near Del Rio, Texas. This area is known as an extremely difficult place to control a vibrator.

Figure 8 shows the open-loop response of a vibrator operating on rock using a flow-control (standard) servovalve. The output of the sweep generator was a linear sinusoidal sweep from 5 to 120 Hz with constant a.c. voltage amplitude except for a short (200 ms) cosine taper at both ends.

The desired result for the phase plot (a) is a straight line at some angle which represents delay. The desired result for the amplitude plot (b) is a straight horizontal line with a short cosine taper at the ends.

Notice the sharp resonance in the amplitude response at about 40 Hz and the corresponding effect on the phase response. The phase and amplitude control loops

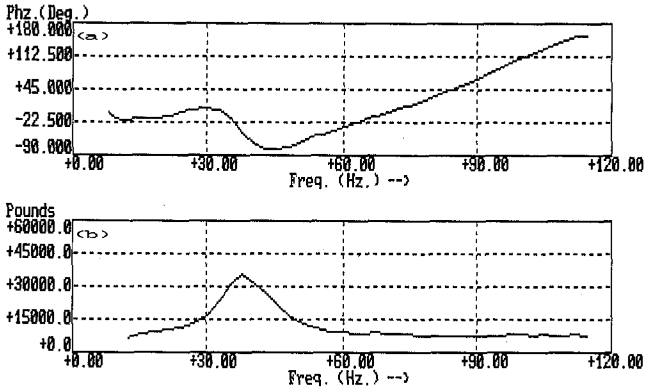

FIG. 8. Open-loop transfer functions of a vibrator with a standard servovalve on massive rock near Del Rio, Texas. (a) Phase response, (b) amplitude response.

in the vibrator control electronics are responsible for compensating for these effects and making the phase and amplitude of the vibrator constant. It is not an easy task when such sharp resonances are present. Inadequate amplitude compensation often results in the baseplate decoupling from the earth, further complicating the control problem, and causing extra distortion in the ground-force signal.

With a pressure-control servovalve, the same vibrator has the open-loop response shown in Fig. 9 at the same ground location. The fact that the ground-force output more nearly matches the desired result shows that the vibrator is acting more nearly as a force control device. The earth/baseplate resonance is no longer a significant factor to either force control or phase control. The phase response curve is more nearly a straight line, which would indicate a constant delay; and the amplitude response curve is more nearly flat, indicating a more constant gain.

With the phase and amplitude control loops turned on, the closed-loop response of the vibrator with a standard flow-control servovalve on the rock surface is shown

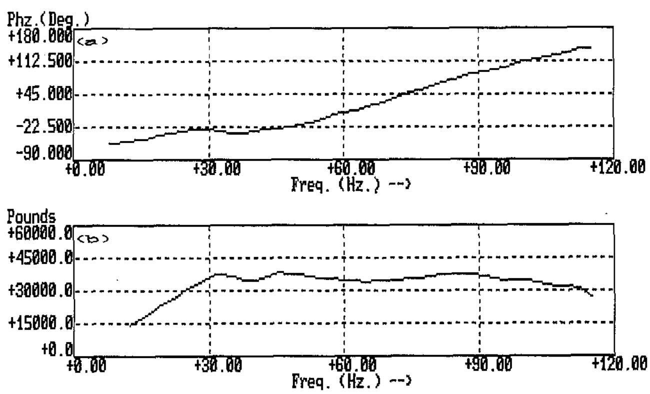

FIG. 9. Open-loop transfer functions of a vibrator with an enhanced servovalve on massive rock near Del Rio, Texas. (a) Phase response, (b) amplitude response.

in Fig. 10. These are the results on a 6 s linear 8–90 Hz sweep. Performance is poor except above the resonance frequency. The deviations in these traces are largely explained by the traces in Fig. 8, which show that the phase and amplitude control loops must compensate for. The best way to improve performance using a flow-control servovalve may be to use a lower sweep rate, to give the control loops more time to react.

The same sweep was performed with the pressure-control servovalve in the same location, and the performance was much better, as shown in Fig. 11. Here, the phase and amplitude control loops had much less work to do because they were compensating for the natural response shown in Fig. 9. With the pressure-control valve, higher phase and amplitude loop gains may be used, because stability is better. There is also less distortion.

Figures 8–11 demonstrate an example of better matching of a vibrator's natural output response to the desired response by using pressure rather than flow as the

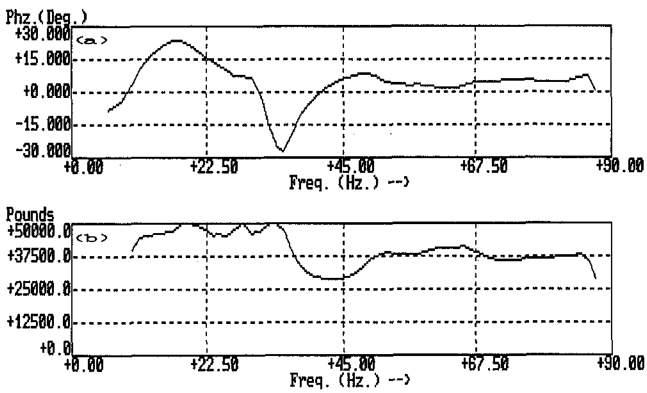

FIG. 10. Vibrator performance with a standard servovalve on massive rock near Del Rio, Texas. (a) Phase control, (b) amplitude control.

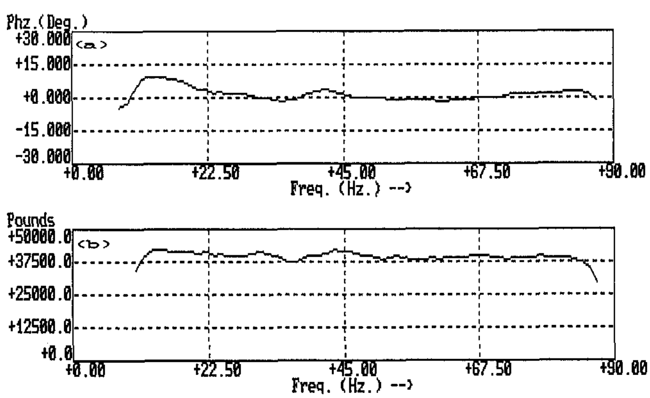

FIG. 11. Vibrator performance with an enhanced servovalve on massive rock near Del Rio, Texas. (a) Phase control, (b) amplitude control.

servovalve's control parameter; and that with this better response, the vibrator control electronics can more reliably cause the vibrator to produce the desired closed-loop response.

Figures 12–15 show the results of a test to see what happens when a vibrator with a pressure-control servovalve goes from a soft to a hard surface with no changes in loop gains, and no set-up sweeps on the new surface. The first surface was soft, rain-soaked soil in Alvin, Texas. The second surface was a 40 ton concrete pad with piers extending into the earth. It was designed to be a consistent surface on which to test vibrators.

Figure 12 illustrates the natural response of the vibrator on the soft soil (with the phase and force control loops turned off). Figure 13 illustrates the natural response on the concrete pad. A resonance at about 45 Hz degrades vibrator phase and amplitude control on the concrete pad.

The resonance is still visible in Fig. 14, which shows the natural response of the vibrator with the pressure-control servovalve on the concrete pad. But the resonance is damped significantly and has less effect on both the amplitude and phase response curves.

The vibrator took set-up sweeps on a 4 s, 8–58 Hz linear sweep on the soft soil, and then moved to the concrete pad. The first sweep was recorded with no parameter changes and resulted in the phase and amplitude performance shown in Fig. 15. The first sweep was not as good as the second, but was probably very acceptable for production. In this example, the vibrator with a pressure-control servovalve could go from one surface type to another with no down-time for parameter adjustments or set-up sweeps on the new surface. This is because the natural response of the vibrator is not very different on the two surfaces when the pressure-control servovalve is used. It tends to make the response on hard surfaces look like that on soft surfaces. Different surface types tend to look the same (soft) to the pressure-control servovalve.

Figures 16–18 show the change in harmonic distortion of a vibrator's output when its flow-control servovalve is replaced by a pressure-control servovalve. The

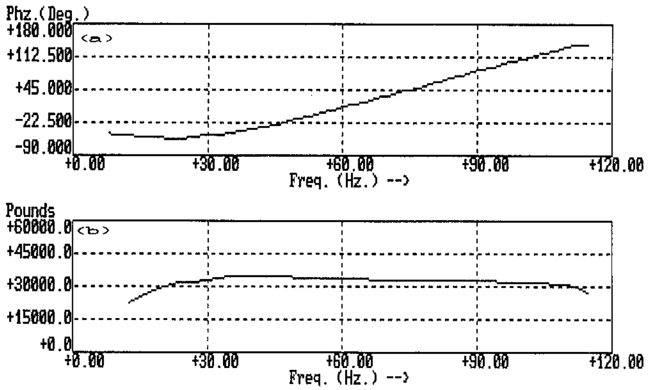

FIG. 12. Open-loop transfer functions of a vibrator with a standard servovalve on soft soil in Alvin, Texas. (a) Phase response, (b) amplitude response.

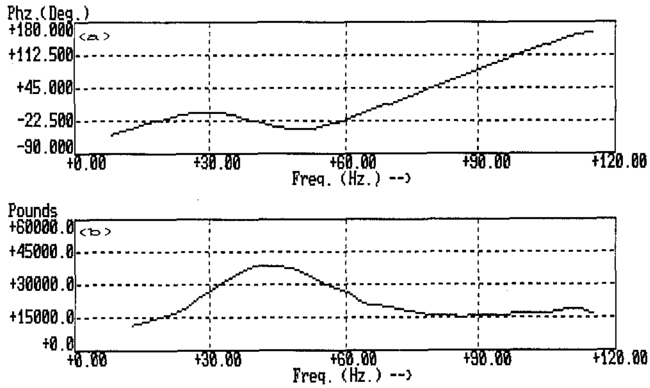

FIG. 13. Open-loop transfer functions of a vibrator with a standard servovalve on 40 ton concrete pad, Alvin, Texas. (a) Phase response, (b) amplitude response.

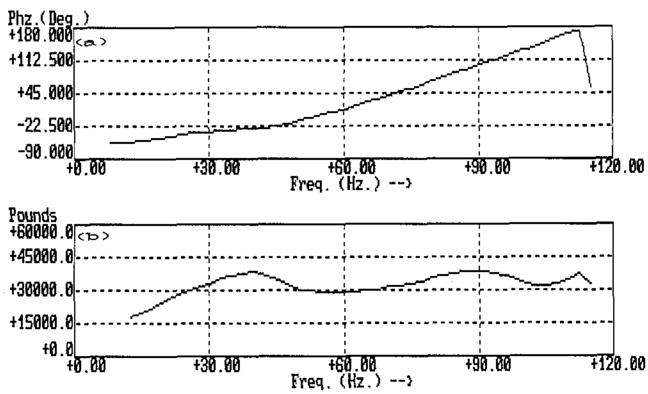

FIG. 14. Open-loop transfer functions of a vibrator with an enhanced servovalve on 40 ton concrete pad, Alvin, Texas. (a) Phase response, (b) amplitude response.

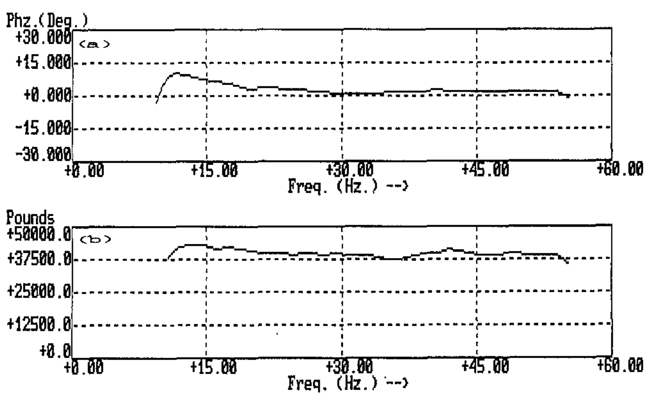

FIG. 15. Vibrator performance with an enhanced servovalve on 40 ton concrete pad in Alvin, Texas. First sweep on concrete after taking set-up sweeps on soft soil. (a) Phase control, (b) amplitude control.

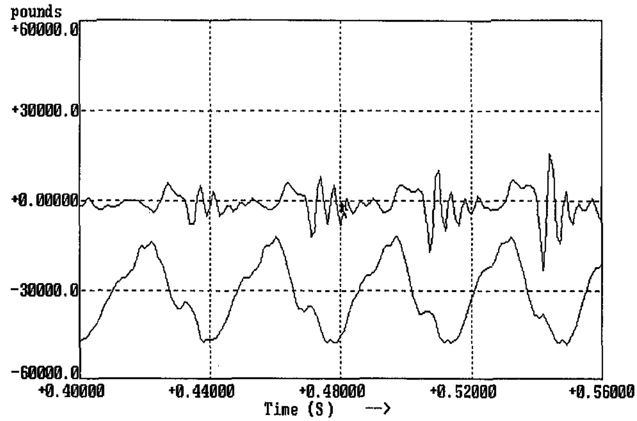

FIG. 16. Ground-force waveforms from a vibrator on thick ice on the North Slope of Alaska. (top) Flow-control servovalve, (bottom) pressure-control servovalve.

operating conditions were difficult because the vibrator was on thick ice covering frozen ground on the North Slope of Alaska. The sweep was 14–104 Hz linear, in 3 s, with 0.1 s cosine taper. The sweep was repeated with and without the Pelton DR™ Servovalve Enhancement.

Figure 16 shows raw ground-force signals during a small portion of the sweep. The top trace is the result with a flow-control servovalve and the bottom trace is the result with a pressure-control servovalve. The bottom trace was offset before plotting, by $-30\,000$ pounds for clarity. The extreme peaks and troughs of the top trace in this time window are $+16\,000$ and $-24\,000$ pounds with SEG Standard Polarity. The actual extremes of the bottom trace are $+18\,000$ and $-18\,000$ pounds. All are well below the hold-down weight of 36 920 pounds.

Phase and amplitude control loops (Fig. 1) were disabled in both cases; thus the

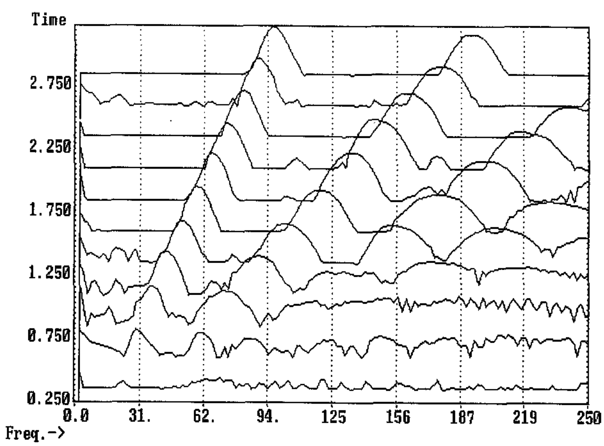

FIG. 17. Harmonic distortion of a vibrator with a flow-control servovalve on thick ice on the North Slope of Alaska.

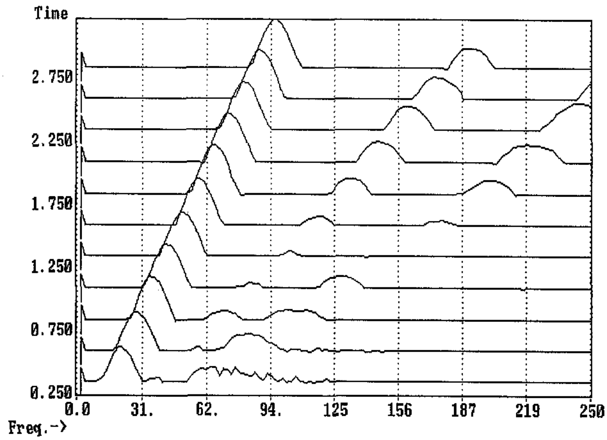

FIG. 18. Harmonic distortion of a vibrator with a pressure-control servovalve on thick ice on the North Slope of Alaska.

phase and amplitude differences shown are due to a change in the natural response of the vibrator when the servovalve was changed. Using the pressure-control servovalve greatly improved the harmonic distortion. This is due to improving the linearity of the vibrator and is an extreme example.

Figure 17 is a harmonic distortion plot of the vibrator's ground-force signal with the flow-control servovalve. This analysis was made on the entire 14–104 Hz sweep, part of which is the top trace in Fig. 16. The display shows the frequency content at successive time intervals of the sweep. The line of peaks which is most nearly vertical and farthest to the left, represents the magnitude (in dB) of the fundamental component of the signal.

The next line of peaks to the right, at about twice the angle from the vertical, respresents the second harmonic. The next line to the right represents the third harmonic.

Figure 18 is the harmonic distortion plot made from the sweep, part of which is the bottom trace in Fig. 16. The enhanced servovalve was in use. The series of strong peaks is the fundamental. The second and third harmonics are present, but much smaller than with the flow-control valve.

Figure 19 shows two seismic records from the same geophone groups, made on a 3D prospect near Odessa, Texas. The crew had eight Model 18 vibrators of similar configuration and condition except that only four had the enhanced servovalve. The vibrators with the standard servovalve were positioned at a vibrator point, and took a number of sweeps (probably six) without moving. The data acquisition system recorded the results from the geophone spread. Then the second group of vibrators, with the enhanced servovalves, was carefully positioned to occupy the same baseplate locations. They took the same number and type of sweeps. The results were recorded in exactly the same way, without moving any geophones or the roll-along switch.

Later, in a processing centre, the resulting data taken with the first set of vibrators was vertically stacked and correlated, and subjected to the entire processing

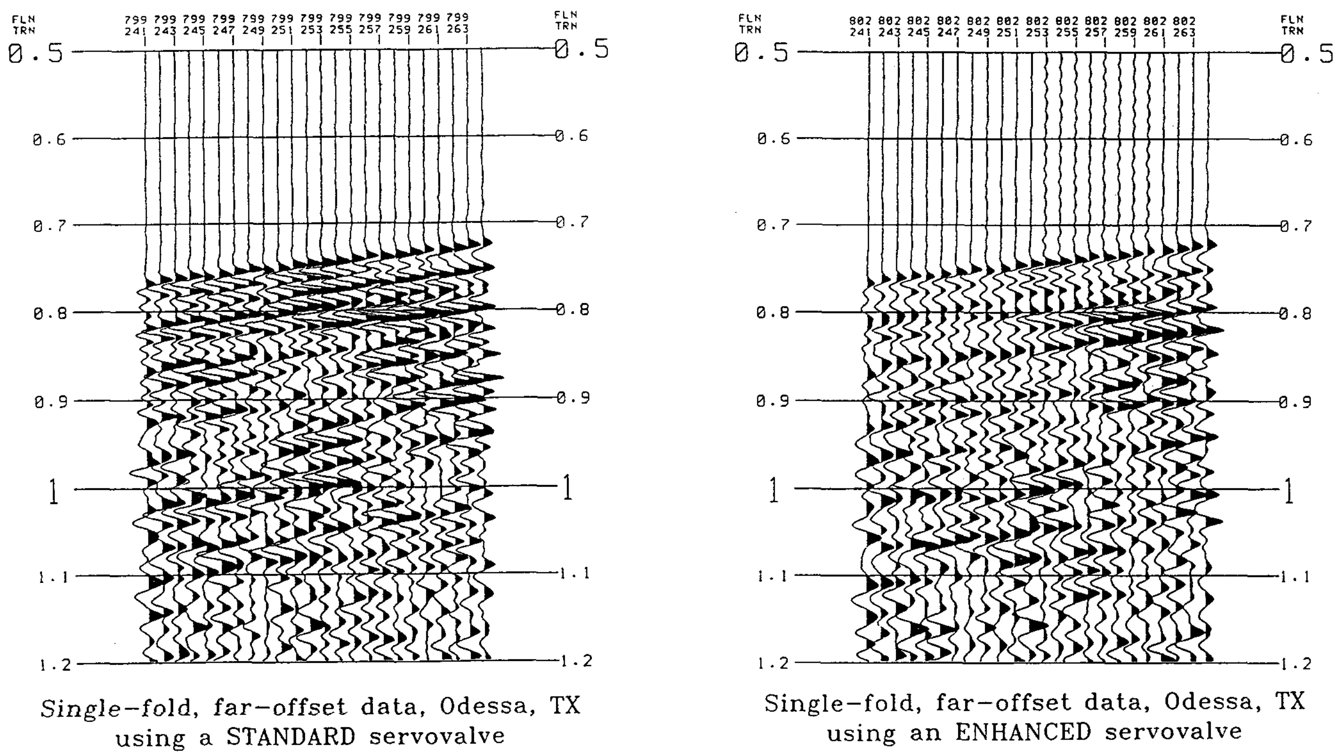

FIG. 19. Stacked, correlated, fixed-gain data sections from four vibrators on limestone. (left) Flow-control servovalves, (right) pressure-control servovalves.

sequence planned for the prospect, except that gains were fixed. The data taken with the second set of vibrators was processed in the same manner, using the same gains.

The record on the left shows results using standard servovalves. It is more noisy, especially around the first breaks, than the record on the right. The record on the right shows results using enhanced servovalves. It can be seen that the reflection at about 900 ms seems more continuous here and is easier to pick than in the record on the left.

In conclusion, the test results show that with a pressure-control servovalve, there is less difference between controlling a vibrator on soft soil and on hard rock. Also, moving from one surface type to the other has less effect on performance. In addition, the earth/baseplate resonance is damped and has less effect on phase and force control. Finally, harmonic distortion is reduced and record quality is improved. Therefore, using pressure rather than flow as the servovalve control parameter is an improvement for seismic vibrators.

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Notes

1. United States and foreign patents on the Pelton DR™ Servovalve Enhancement are pending.
2. DR is a trademark of Pelton Company, Inc.

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