United States Patent [19]

Bedenbender et al.

[11] **3,929,206**

[45] **Dec. 30, 1975**

[54] **SERVO HYDRAULIC TRANSDUCER AND METHOD OF OPERATION**

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[73] Assignee: **Texas Instruments, Corp.**, Dallas, Tex.

[22] Filed: **Apr. 30, 1973**

[21] Appl. No.: **355,838**

[52] **U.S. Cl.** **181/114**; 181/113

[51] **Int. Cl.²** **G01V 1/04**

[58] **Field of Search** .... 340/15, 17; 181/.5 EC, 181/.5 VM, 113, 114

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Primary Examiner—Maynard R. Wilbur
Assistant Examiner—T. M. Blum

[57] **ABSTRACT**

An improved servo hydraulic transducer and method of operating is disclosed. The transducer includes a vibrator and hydraulic lifts connected to an improved hydraulic system. The hydraulic system includes a pump pumping hydraulic fluid at a rate between the maximum average and minimum average from a source thereof into a manifold and high pressure system for a frequency sweep of the vibrator. The high pressure system supplies the hydraulic fluid required by the vibrator in addition to that supplied by the pump during the low frequencies of the sweep, and stores under pressure hydraulic fluid excessive to the vibrator requirements during the high frequencies of the sweep and slack time between sweeps. The hydraulic lifts include a chain and sprocket arrangement for each lift interconnected by a synchronization shaft. An unequal force on one of the hydraulic lifts produces through its chain and sprocket arrangement a moment on the synchronization shaft which is transferred through the chain and sprocket arrangement of the other lift to equalize the bearing force between the hydraulic lifts.

11 Claims, 19 Drawing Figures

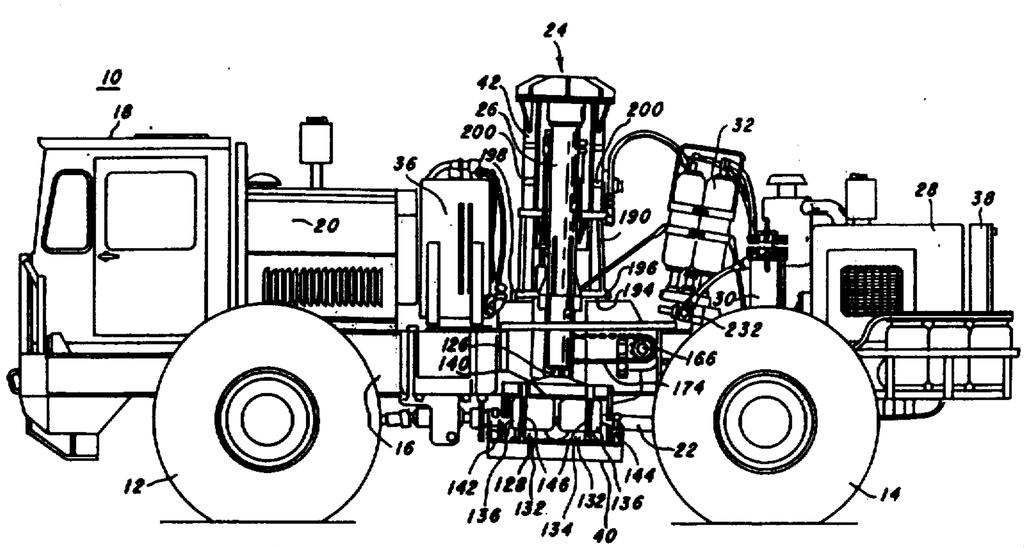
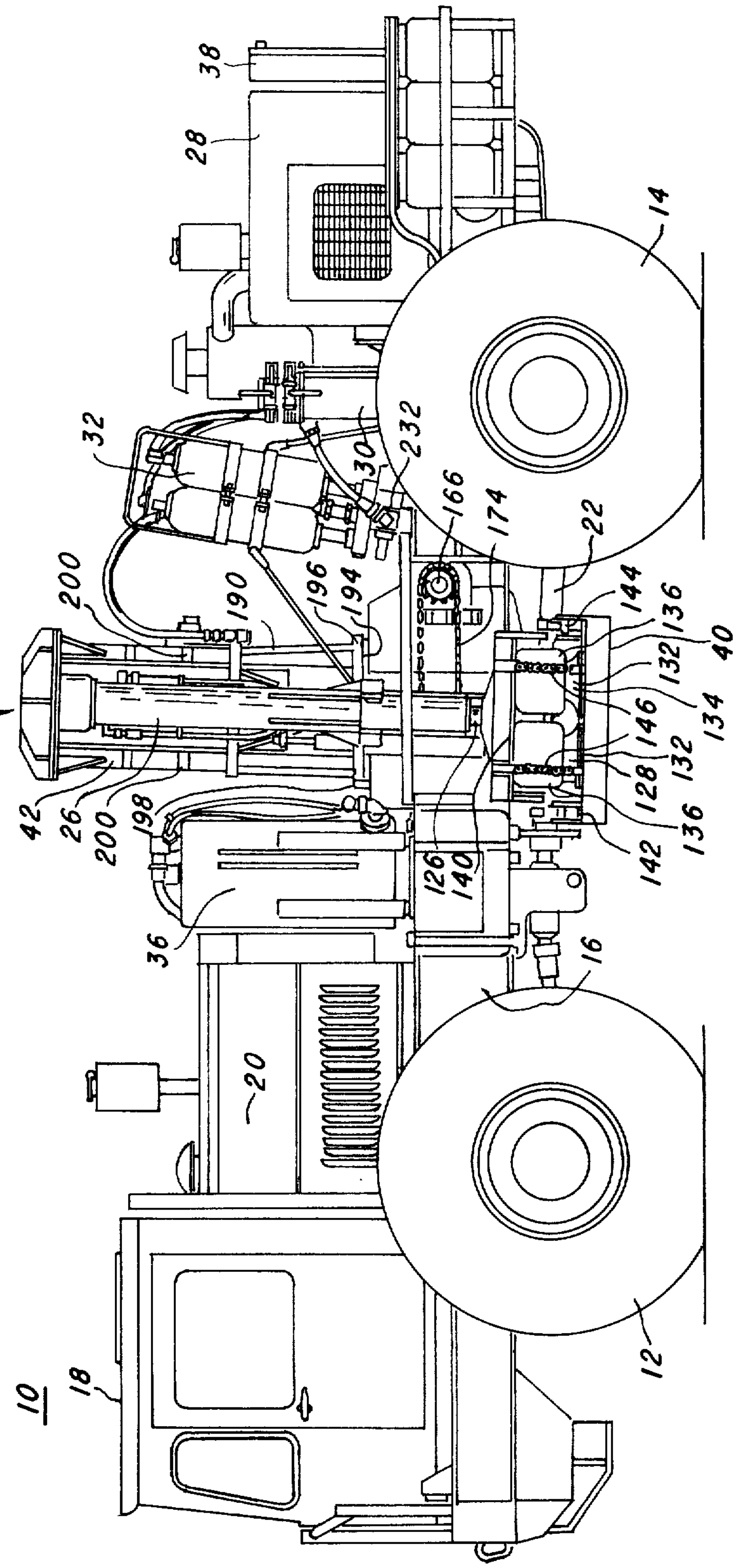


Fig. 1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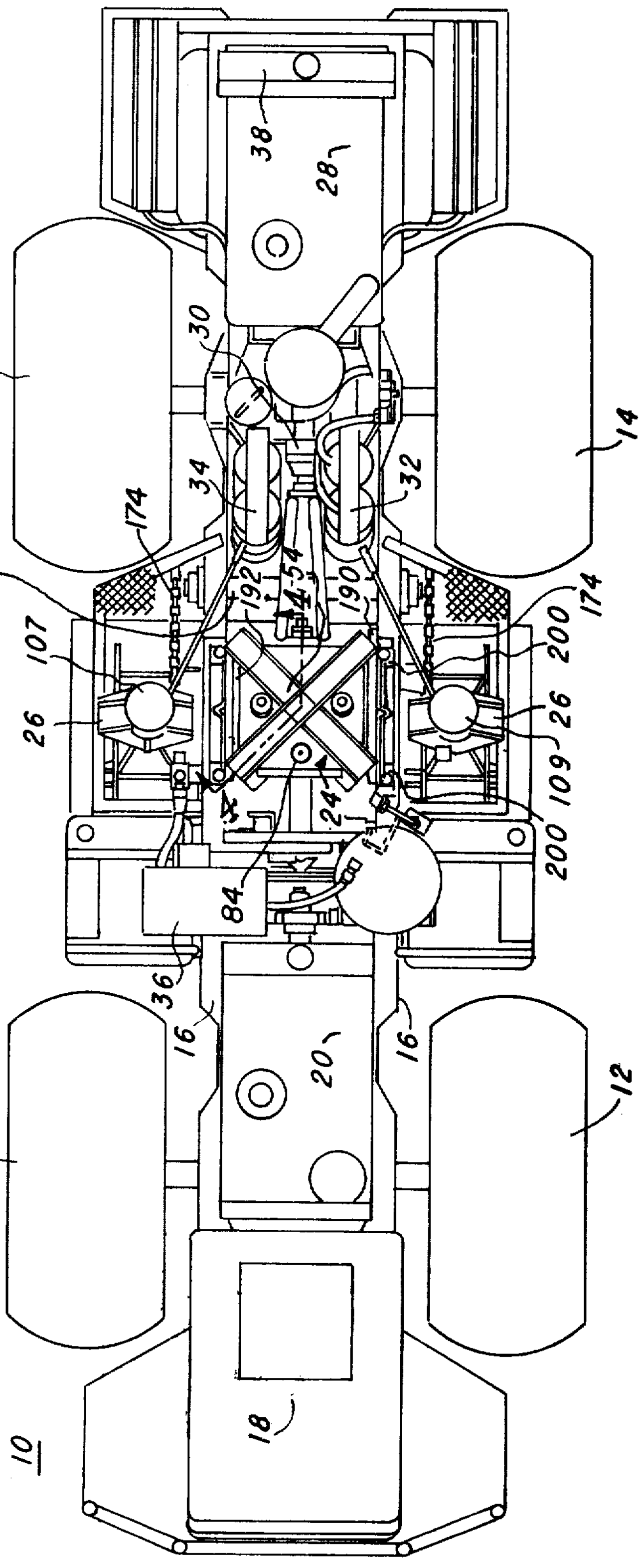
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192
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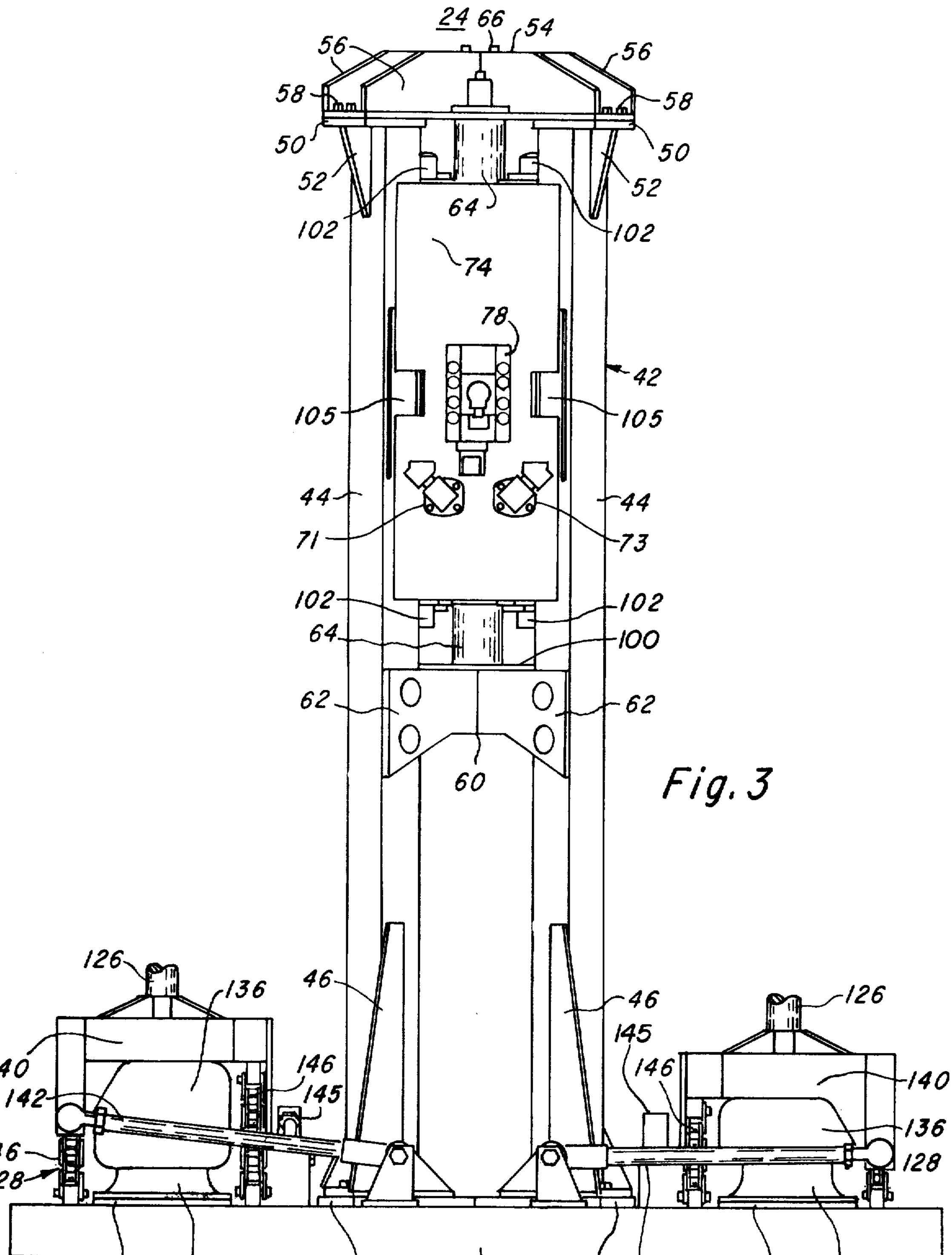
4
54

Fig. 2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66
54
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52
52
64
102
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74
78
42
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105
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44
71
73
102
102
64
100
62
62
60
126
136
126
46
46
140
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146
128
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40
48
142
130
132

Fig. 3

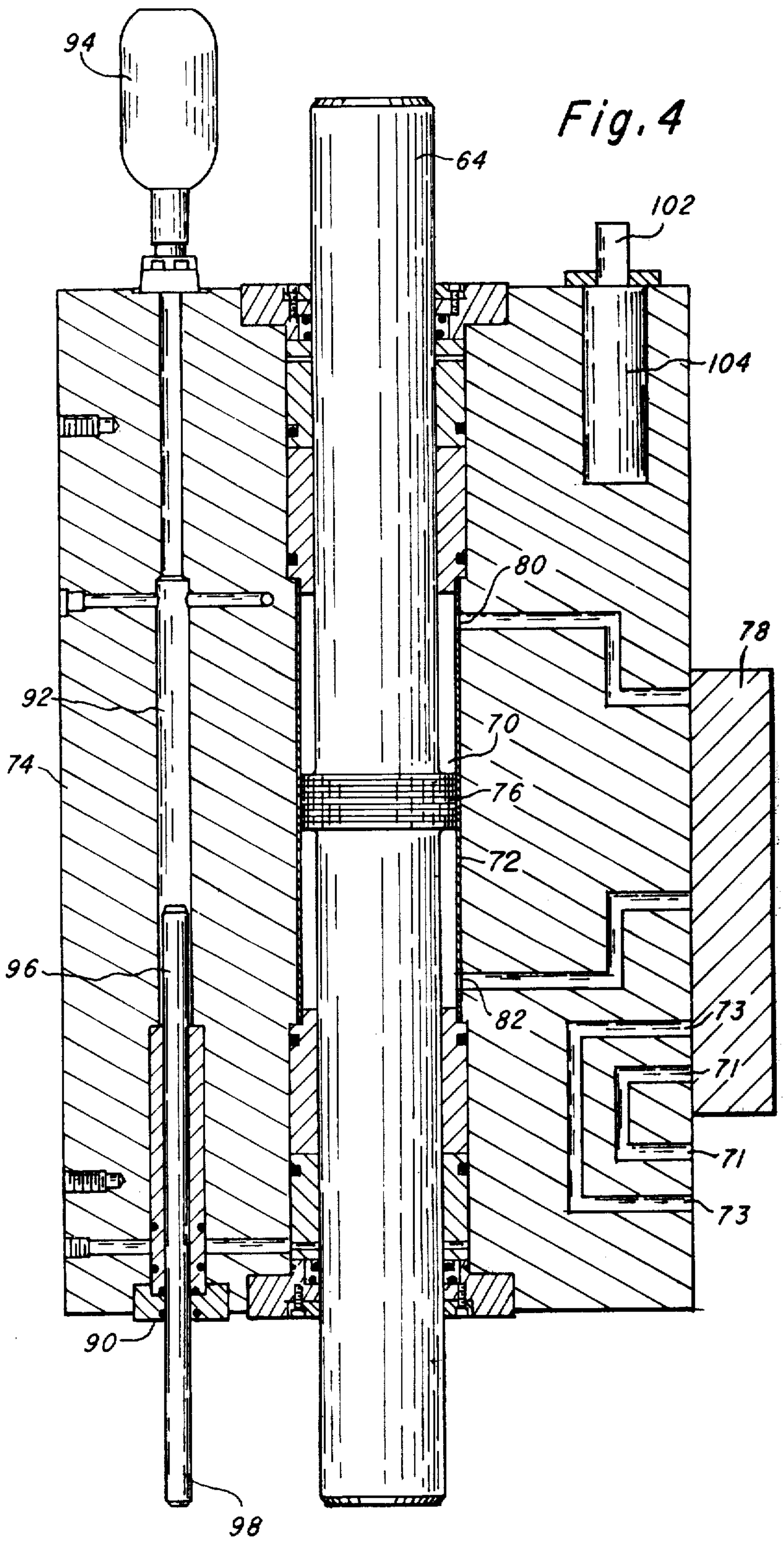
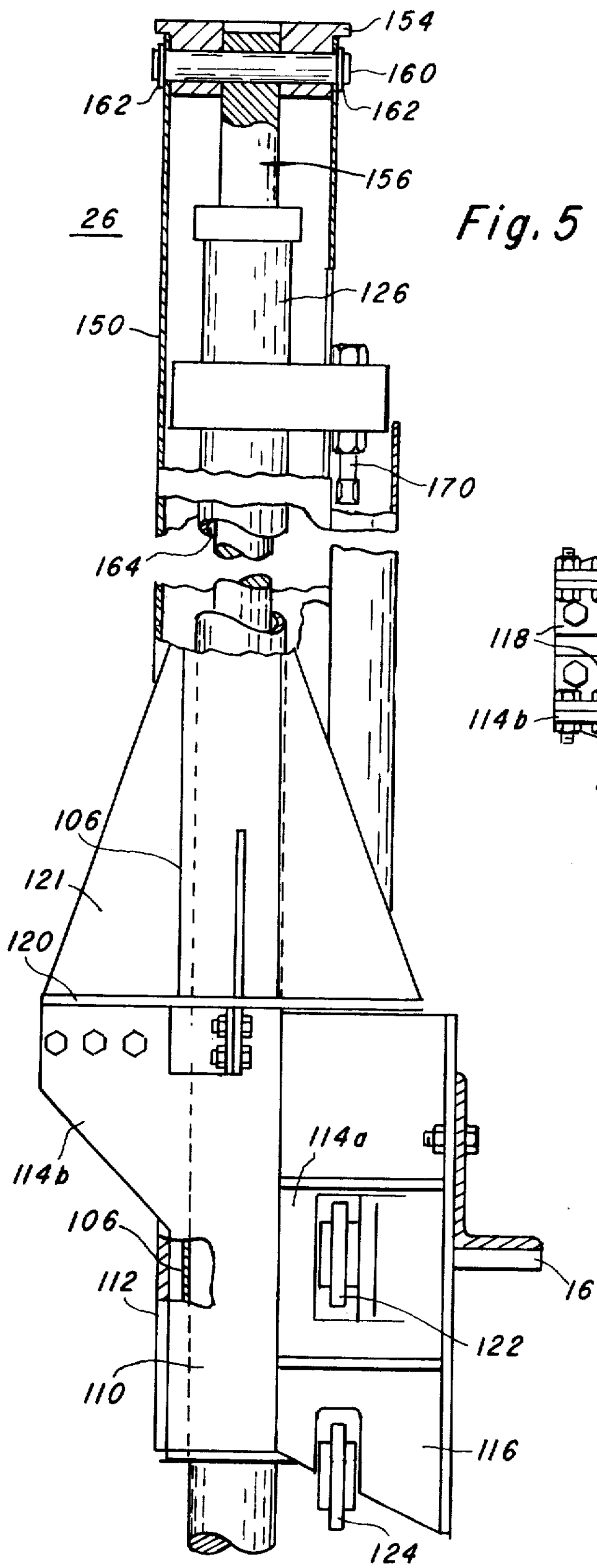


Fig. 4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160
162
162
156
26
126
150
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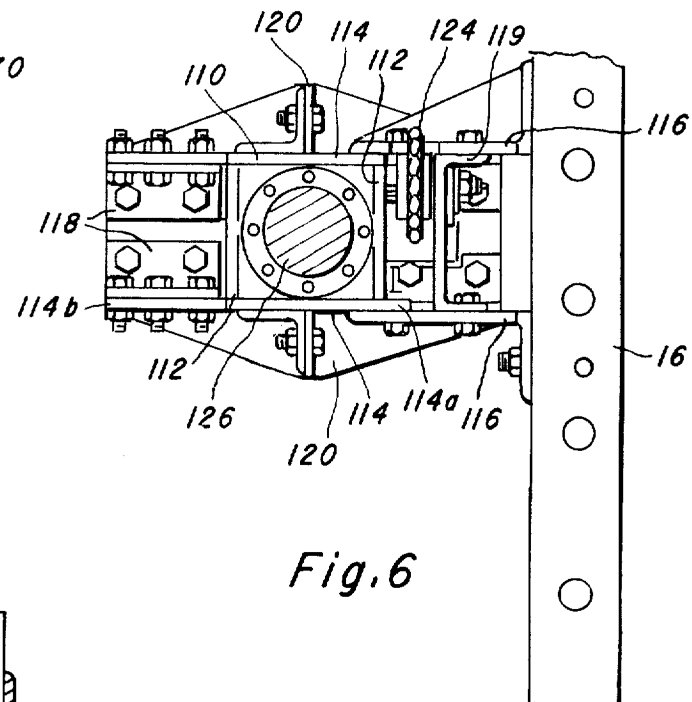
164
106
121
120
114b
114a
106
112
16
110
122
116
124

Fig. 5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118
114b
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114a
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Fig. 6

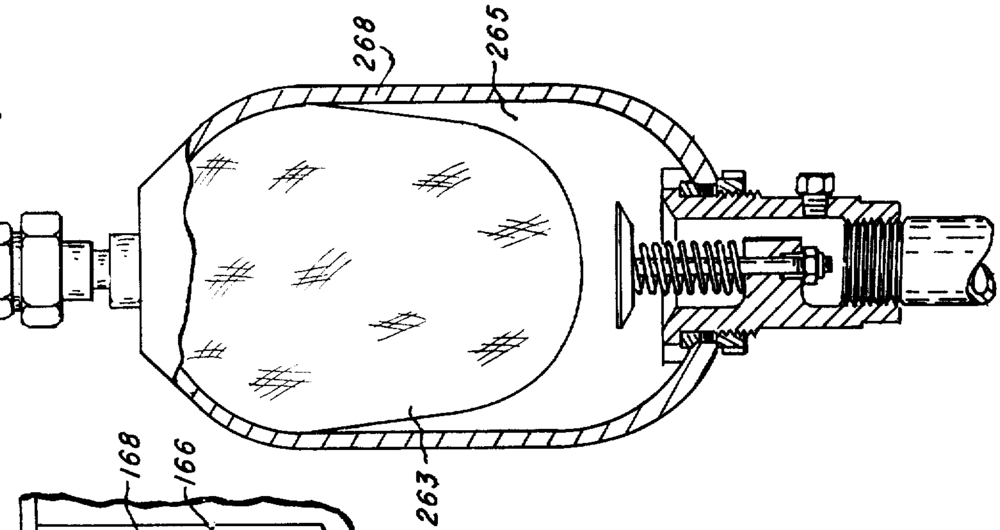
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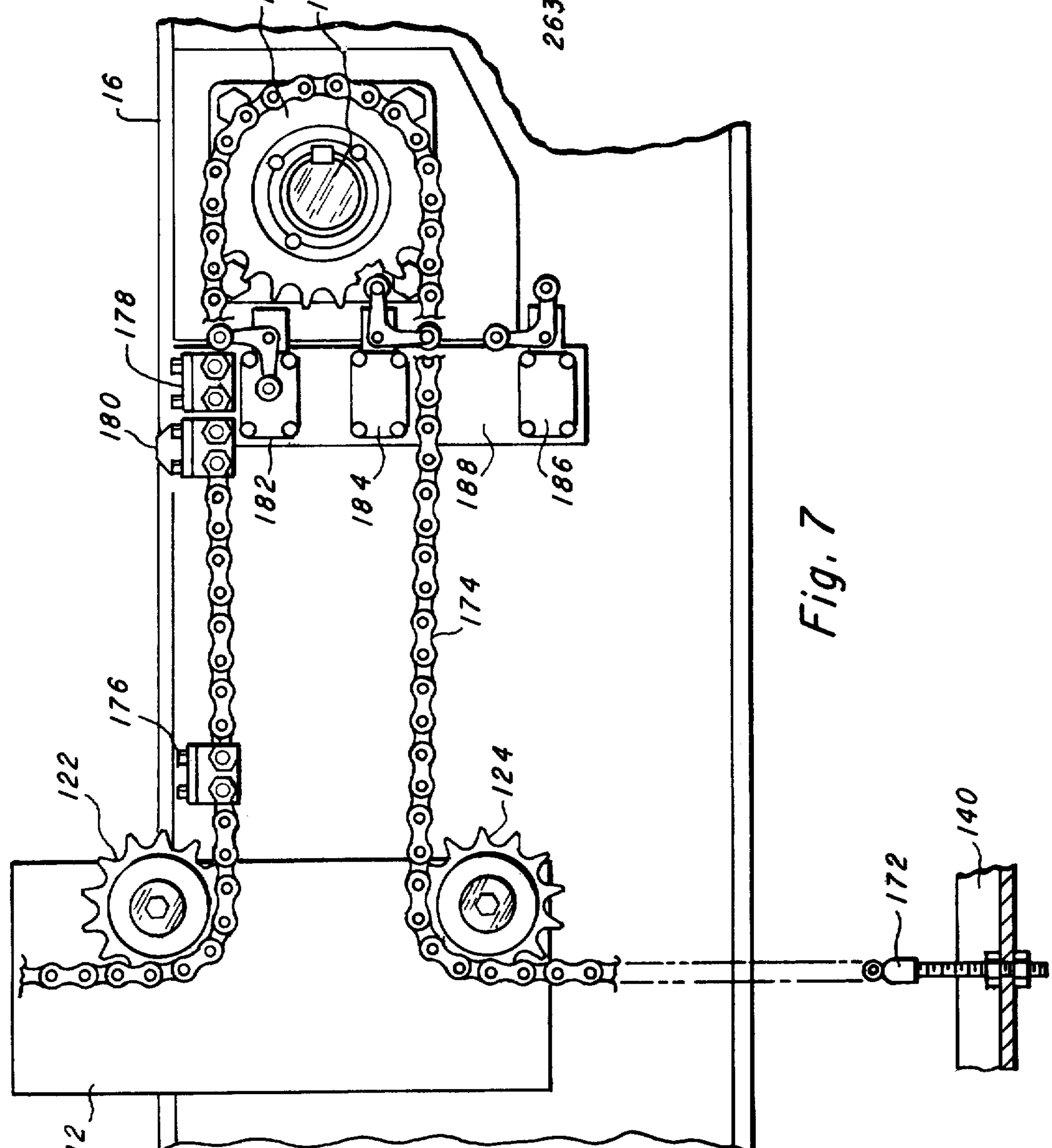
Fig. 9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168
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186
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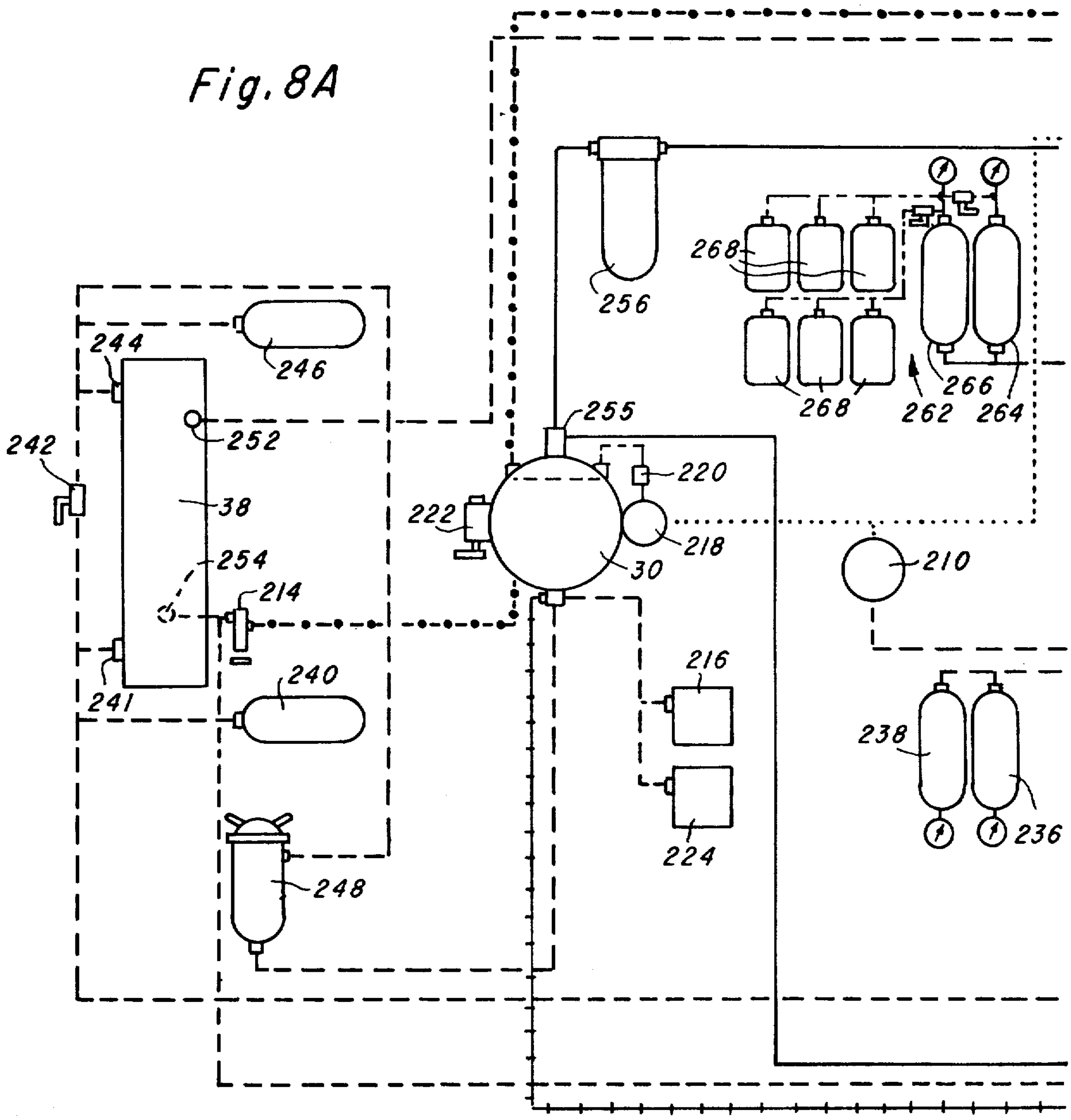
122
124
172
140
112

Fig. 7

Fig. 8A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264
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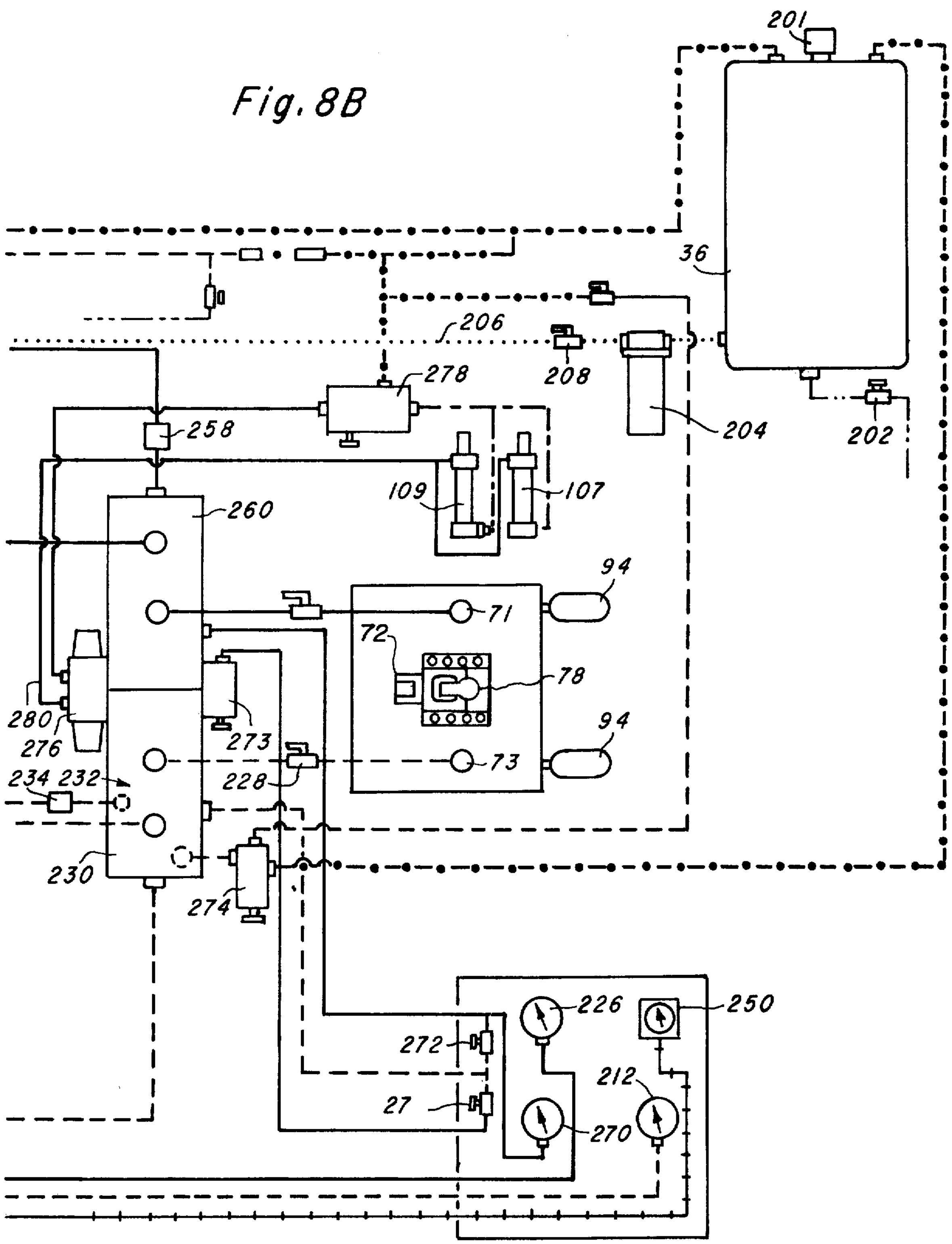
236
248

Fig. 8B


201
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202
109
107
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273
94
73
234 232
228
230
274
226
250
272
212
27
270

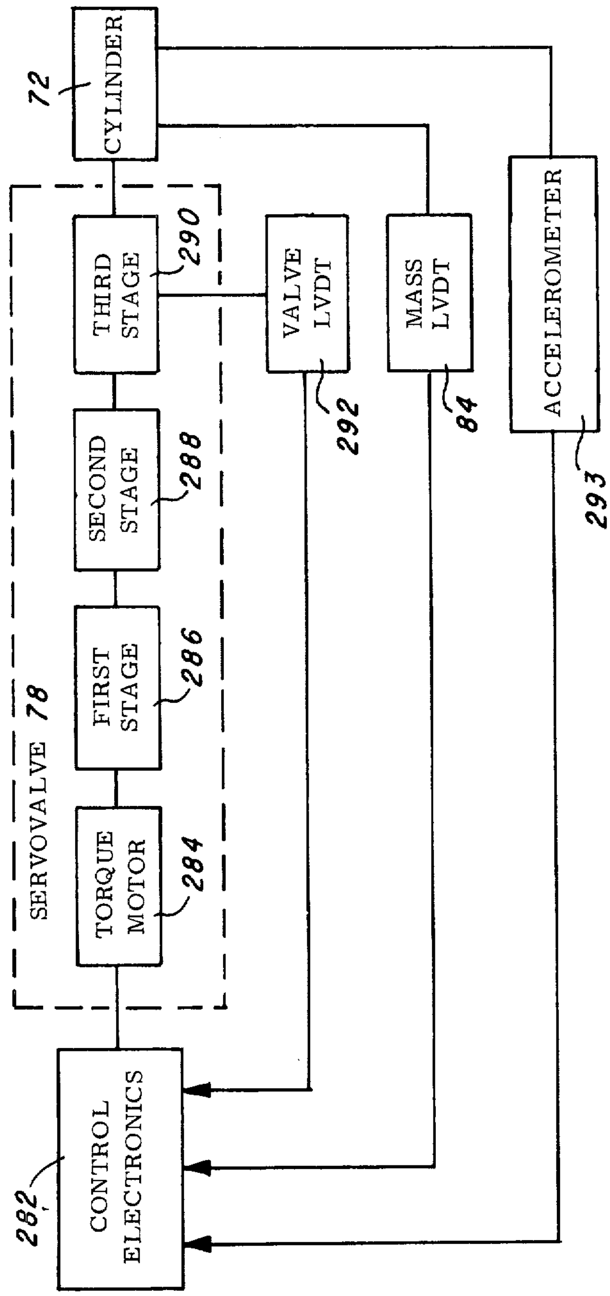

CYLINDER
72
SERVOVALVE 78
THIRD STAGE
290
SECOND STAGE
288
FIRST STAGE
286
TORQUE MOTOR
284
VALVE LVDT
292
MASS LVDT
84
ACCELEROMETER
293
CONTROL ELECTRONICS
282

Fig. 10

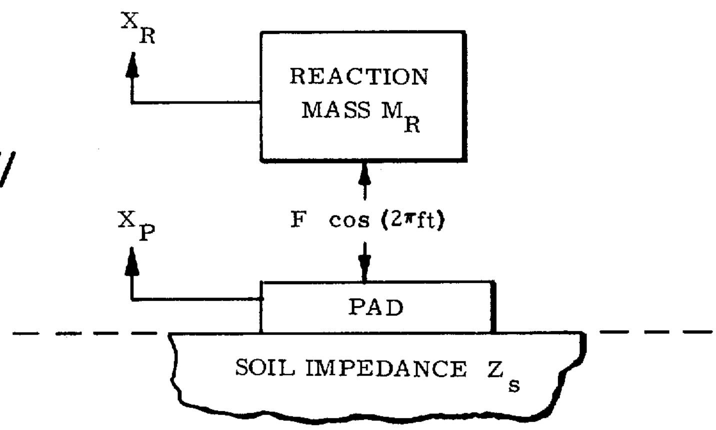


Fig. 11

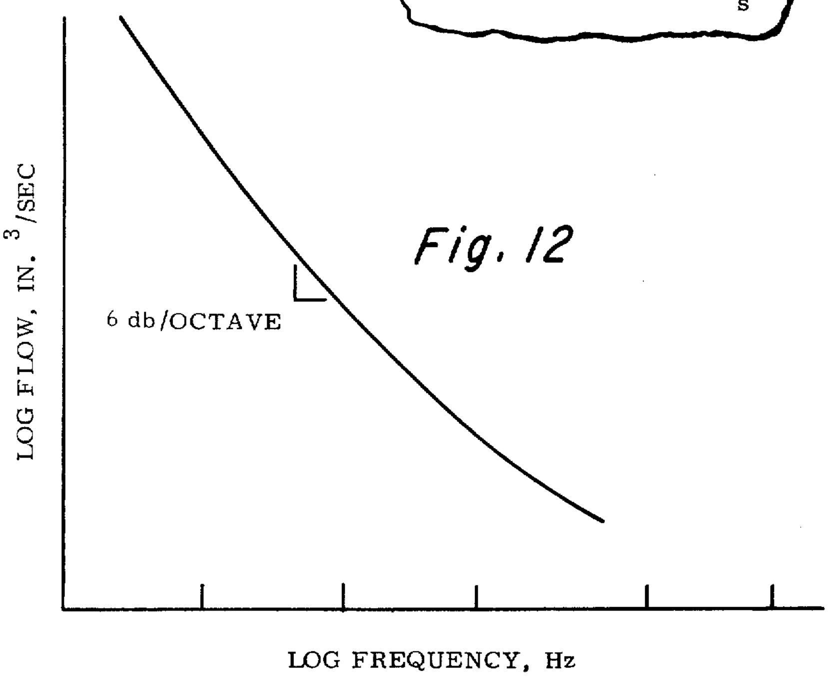


Fig. 12

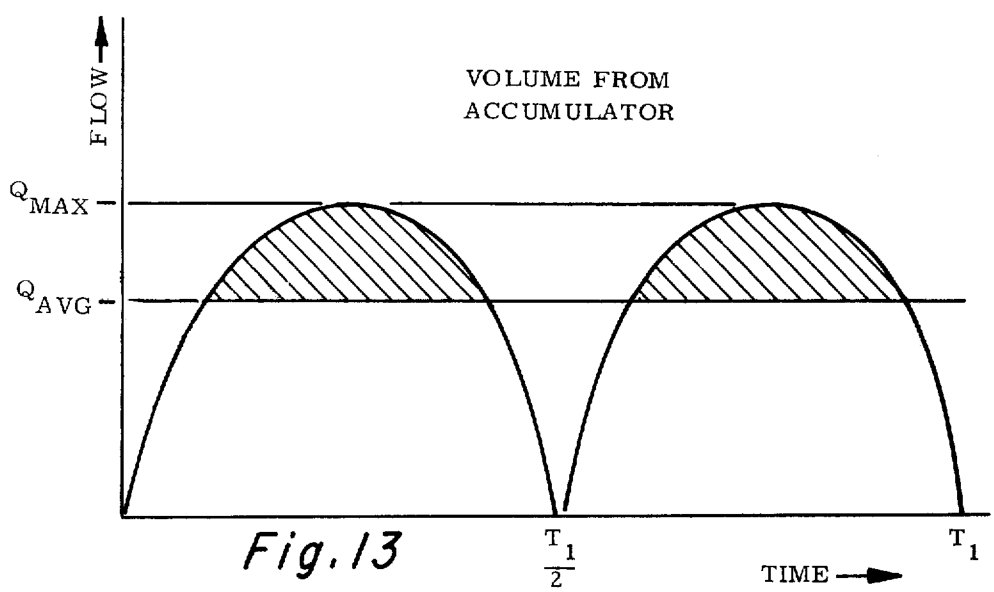
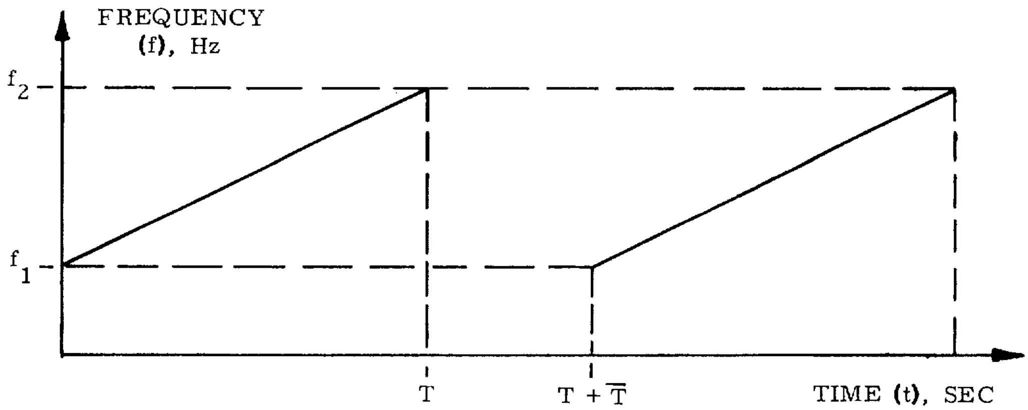


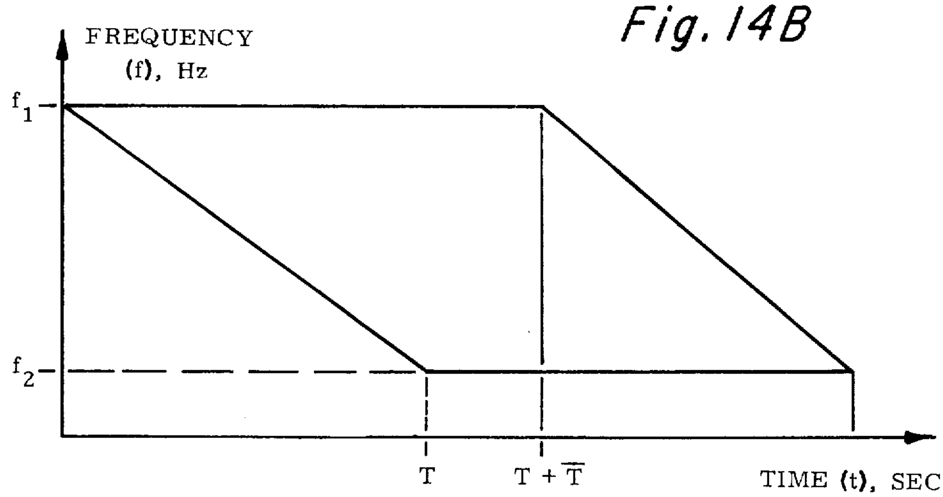
Fig. 13

Fig. 14A



UPSWEEPS

Fig. 14B



DOWNSWEEPS

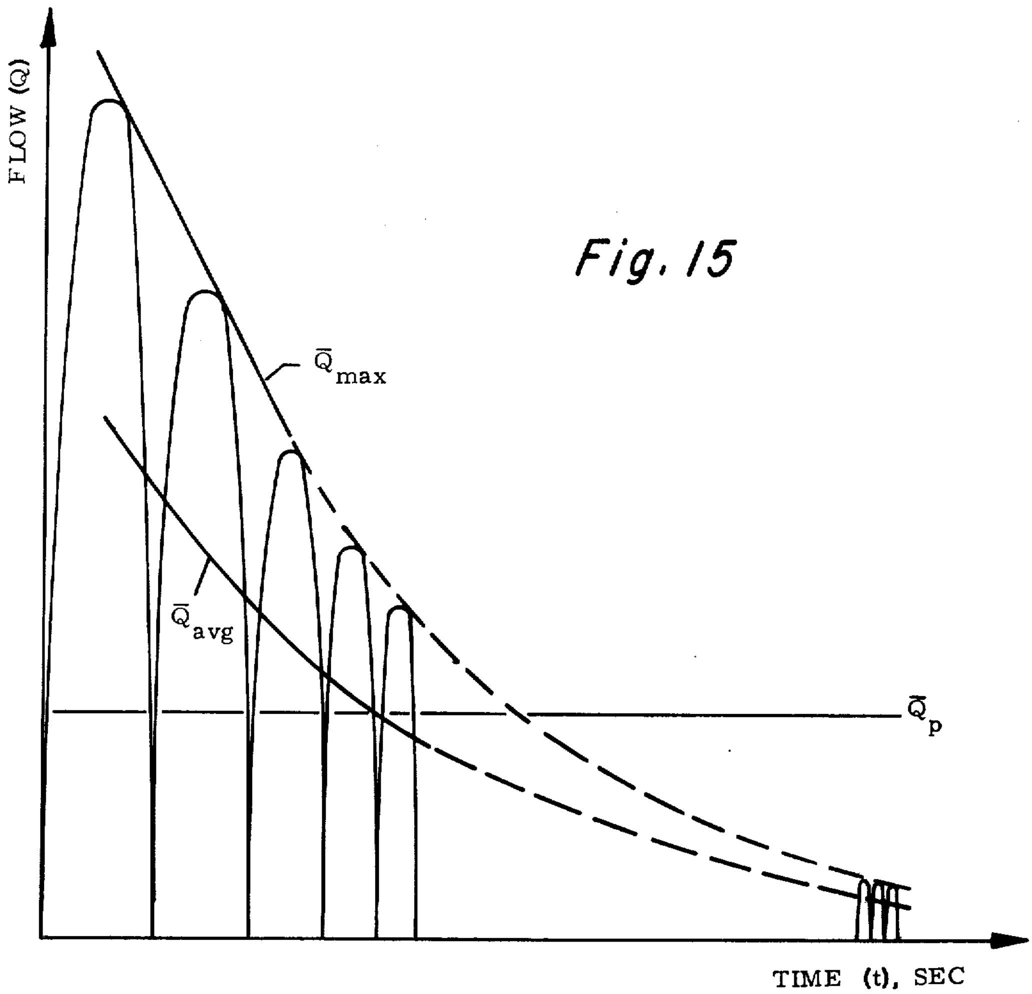

FLOW (Q)
$\bar{Q}_{max}$
$\bar{Q}_{avg}$
$\bar{Q}_p$
TIME (t), SEC

Fig. 15

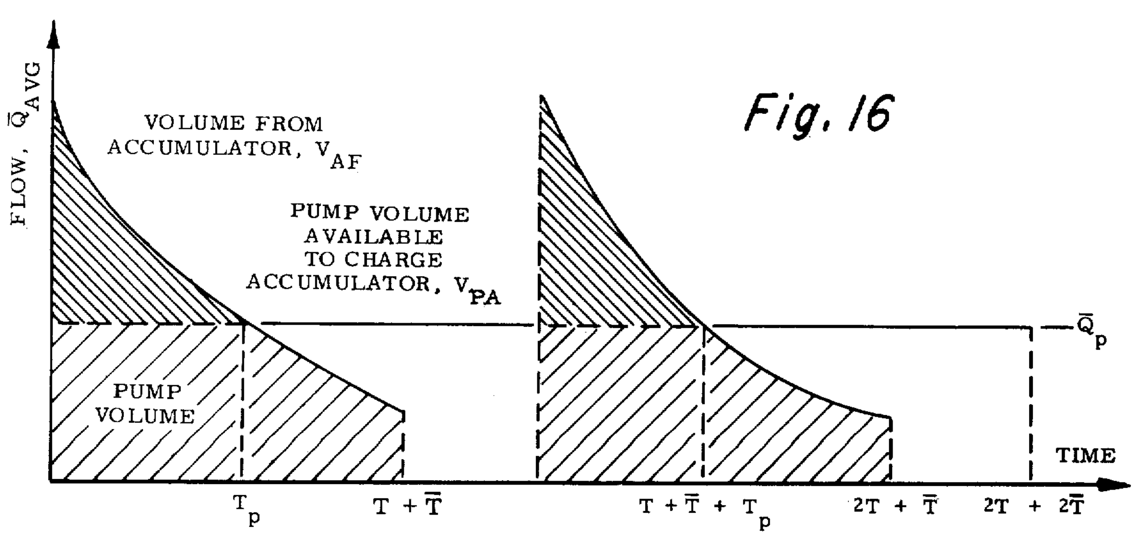
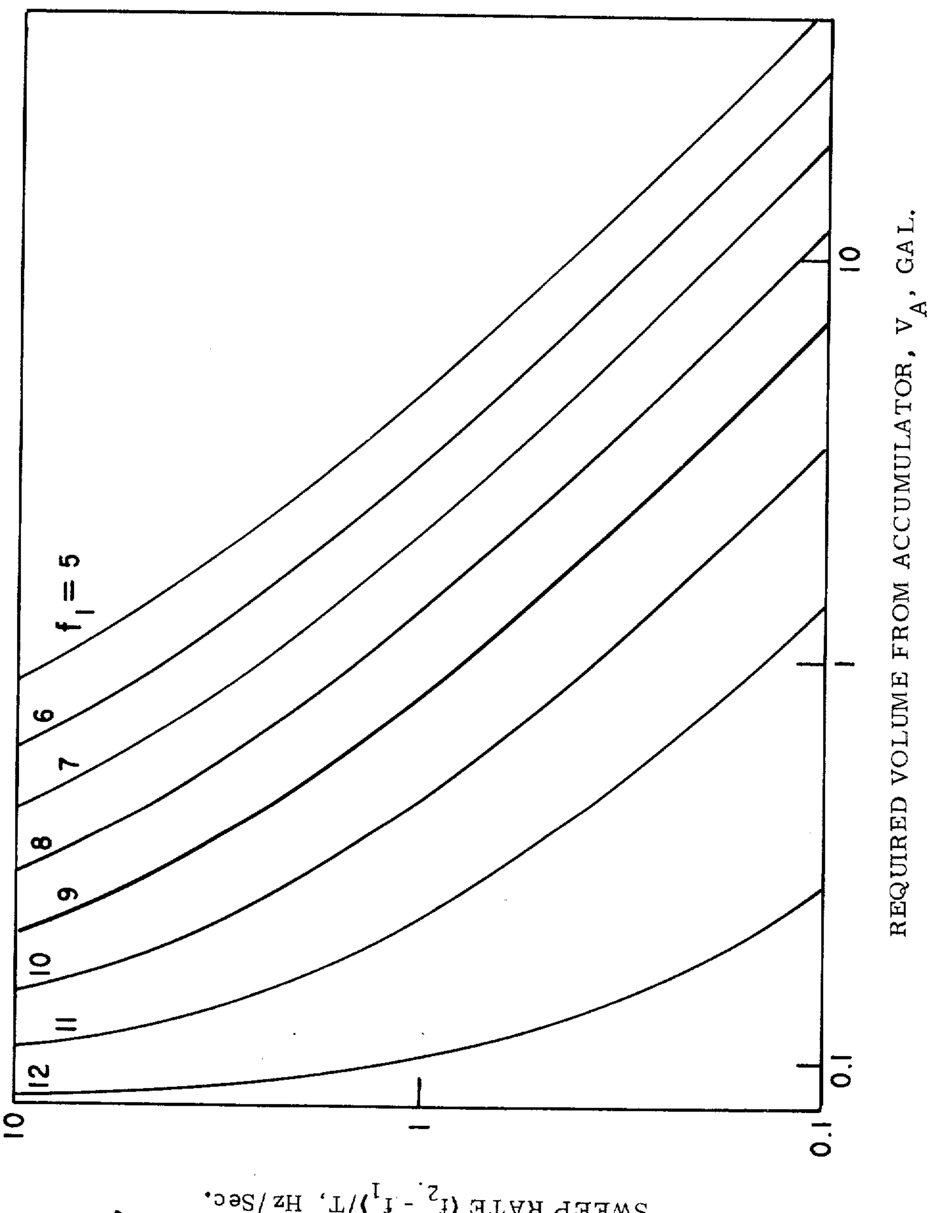

FLOW, $\bar{Q}_{AVG}$
VOLUME FROM ACCUMULATOR, V_{AF}
PUMP VOLUME AVAILABLE TO CHARGE ACCUMULATOR, V_{PA}
PUMP VOLUME
$\bar{Q}_p$
TIME
T_p
$T + \bar{T}$
$T + \bar{T} + T_p$
$2T + \bar{T}$
$2T + 2\bar{T}$

Fig. 16



$f_1 = 5$
6
7
8
9
10
11
12
10
1
0.1
0.1
1
10
REQUIRED VOLUME FROM ACCUMULATOR, V_A, GAL.
SWEEP RATE $(f_2 - f_1)/T$, Hz/Sec.

Fig. 17

SERVO HYDRAULIC TRANSDUCER AND METHOD OF OPERATION

This invention relates generally to improvements in the art of seismographic surveying of the type utilizing a mechanical vibrating energy source or transducer, and more particularly to an improved hydraulically driven system for generating continuous seismic signals having swept frequencies.

In the past, many seismic surveying systems have used a continuous wave seismic signal generated in the earth by a vibrator or seismic transducer. These vibrator assemblies generally have been comprised of a base plate or pad retractably mounted upon a truck type vehicle for transport to a desired field location. Upon arrival at a selected source location, the pad was lowered by a hydraulic lift mechanism into contact with the earth's surface and then the truck lifted on the pad by the hydraulic lift mechanism to provide a hold down force upon the pad. Prior lift systems have utilized a pair of load bearing columns, a pair of hydraulic lift cylinders and a synchronizing system to insure coordinated movement of the columns. Where the lift cylinders have extended above the vibrator, they have been mechanically interconnected by a rigid stress member; otherwise a hydraulic interconnection system has been used for synchronization. The pad was vibrated by a double rod-end-piston extending upwardly and downwardly in a mass type cylinder. The mass of the cylinder varied from several hundred to several thousand pounds. An actuator, usually hydraulic, was used to reciprocate the cylinder mass or reaction mass relative to the base plate through a short stroke at predetermined frequencies. The equal and opposite force of reaction reciprocated the base plate through a short vertical stroke at corresponding frequencies, thereby moving the surface of the earth and inducing the desired seismic signal in the earth.

The hydraulic actuator consisted of a pump pumping oil under high pressure from a reservoir through a manifold into a high pressure accumulator and through a servovalve for selectively introducing oil into the cylinder. Oil from the high pressure system was alternately introduced by the servovalve into the cylinder above and below the piston to vibrate the weight bearing cylinder. The oil was returned through the servovalve alternately from below and above the piston into a low pressure accumulator used for dampening oil surges prior to forcing the oil into an oil cooling system for cooling the oil before it was returned to the high pressure system by the pump. The high pressure accumulator in prior system has been a relatively small volume accumulator and used only to smooth out the peaks of the sinusoidal supply required by the vibrator. The pump capacity (Q_p) was fixed at approximately the average flow (Q_{avg}) required for the lowest desired operating frequency (f_1) using the following formula:

$$Q_p = Q_{avg} = \frac{0.636\, pA^2}{2\pi f_1 M_R},\ \text{in}^3/\text{sec}$$

where

p = hydraulic pressure, psi
A = hydraulic piston area, in^2
f_1 = the operating frequency, Hz
M_R = reaction mass, $(\text{lb} \cdot \text{sec}^2)/\text{in}$

The high pressure accumulator size was determined at the lowest operating frequency. The accumulator had to supply a volume equal to the difference between the instantaneous peak flow (Q_{max}) and the average flow (Q_{avg}) required by the vibrator during the period (T_1) of the lowest operating frequency. This volume is represented by the following formula:

$$V_{AS} = 0.59\, T_1\, Q_{max},\ \text{in.}^3$$

A problem with the prior art is the large size of the hydraulic system required for a mechanical vibrator to produce desired seismic vibrations. A further problem lies with the lift system which is prone to seizure when the mechanical vibrator pad is positioned on uneven earth surfaces.

Thus it is an object of the present invention to provide an improved transportable seismic transducer assembly.

Another object of the invention is to provide a seismic transucer assembly with an improved mechanical synchronizing system for insuring coordinated movement of the lift columns with the hydraulic lift system.

Still another object of the invention is to provide an improved hydraulic system for a seismic transducer in which high pressure accumulators are used to supply a major part of the high hydraulic flow for the low frequency portion of the sweep to approximately double the effective power output of the transducer.

Briefly stated the transportable seismic transducer constituting the subject matter of the present invention comprises a vehicle such as, for example, a truck, tractor or tractor drawn trailer supporting a retractable novel transducer or vibrator system. The rectractable transducer is suspended by a pair of hydraulic lifts having a novel mechanical synchronizing system to insure coordinated movement of columns of the hydraulic lifts.

In accordance with a more specific aspect of the present invention, the transducer of the portable transducer has a base plate or pad which is lowered into contact with the earth by means of the hydraulic lifts mounted upon the transporting vehicle. After bringing the pad into contact with the earth, the hydraulic lifts raise the vehicle on the pad to provide a hold down force for maintaining the pad in contact with the earth during vibration of the transducer. The novel mechanical synchronization system for the hydraulic lifts includes a chain and sprocket arrangement for each hydraulic lift. The chain from one hydraulic lift runs over a sprocket at one end of a synchronization shaft, and the chain from the other hydraulic lift runs over a sprocket at the opposite end of this shaft. An unequal force on one of the hydraulic lifts produces through its chain and sprocket arrangement a moment on the synchronization shaft which is transferred through the chain and sprocket arrangement of the other lift to the other lift to equalize the bearing force between the hydraulic lifts.

With the base plate or pad anchored to the ground the vibrator is vibrated to send out into the earth through the pad a series of vibratory "sweeps". These sweeps are ordinarily a linear change of frequency with time. Each sweep may be from a low (about 5Hz) to a high (about 80 Hz) frequency upsweep or a high to low frequency down sweep. The vibrator includes a weighted cylinder, often referred to as the reaction mass, reciprocately mounted on a double rod-end-piston having the ends thereof connected to the base plate. The cylinder or reaction mass is reciprocately actuated by pressurized hydraulic fluid introduced alternately in the cylinder above the below the piston. The novel hydraulic system comprises a pump capable of pumping a prescribed amount of the total hydraulic fluid required for each sweep and a high pressure accumulator system having sufficient capacity and pressure force to provide the remainder of the total fluid required for each sweep.

It has been found that with the practice of the present invention the hydraulic pump and engine used to drive the vibrator of the prior art device can be reduced more than one-half in capacity and produce the same results as the prior art devices, or for the same hydraulic pump and engine the displacement amplitude of the reaction mass can be approximately doubled to increase the amplitude of the seismic signal. Further objects and features of this invention will become obvious from the following description when taken in conjunction with the drawings in which:

FIG. 1 is a side view of a buggy mounted transducer constituting an embodiment of the present invention;

FIG. 2 is a top view of the buggy mounted transducer shown in FIG. 1;

FIG. 3 is an end view of a transducer constituting an embodiment of the present invention;

FIG. 4 is a partial cross-sectional view of the transducer taken along lines 4—4 of FIG. 2;

FIG. 5 is a partial elevational view with portions broken away to show details of one of the hydraulic lifts;

FIG. 6 is a cross-sectional view of the hydraulic lift of FIG. 5 taken along line 6—6 of FIG. 5;

FIG. 7 is a partial view of the hydraulic lift synchronization and lift control system;

FIGS. 8A and B are schematic diagrams of a hydraulic system for the vibrator or transducer assembly constituting an embodiment of the present invention;

FIG. 9 is a cross-sectional view of the high pressure accumulator utilized in the hydraulic system shown schematically in FIG. 8;

FIG. 10 is a schematic drawing of the electronic controller for the transducer;

FIG. 11 is a schematic model of the vibrator transducer;

FIG. 12 is a plot of required hydraulic flow versus transducer operating frequency;

FIG. 13 is a plot of flow versus time for a fixed frequency;

FIGS. 14A and B are representations of frequency sweeps versus time;

FIG. 15 is a plot of hydraulic flow versus time for an upsweep;

FIG. 16 is a plot showing the hydraulic flow pattern plotted against time;

FIG. 17 is a plot showing the required volume from the high pressure accumulator plotted versus sweep rate.

Referring now to the drawings for a detailed description of the improved portable seismic transducer assembly in which there is shown (FIG. 1) a vehicle **10** having front and rear wheels **12** and **14**, respectively, which support a chassis comprised generally of frame channels **16**, a cab **18**, and a conventional engine **20**. The engine **20** is connected to drive the rear wheels **14** by a conventional drive train including a drive shaft **22**.

The seismic transducer or vibrator assembly **24** (FIGS. 1 and 3) is disposed between the front and rear wheels and connected to the frame members **16** of the truck by a lift system **26** hereinafter described. A prime mover or engine **28**, main hydraulic pump **30**, high pressure accumulator system **32**, low pressure accumulator system **34** (FIG. 2), hydraulic fluid tank **36**, hydraulic fluid cooler **38** and associated hydraulic plumbing may be located on the frame members **16** as shown in FIGS. 1 and 2.

The transducer or vibrator assembly **24** (FIG. 3) includes a base plate or pad **40** which may be fabricated in any suitable manner to provide a flat lower base plate surface for engaging the surface of the ground. A transducer frame **42** comprising four vertically disposed frame members **44** extends upwardly from the base plate **40** to a point well above the drive shaft **22** of vehicle **10** (FIG. 1). The lower halves of the four frame members **44** (FIG. 3) are reinforced by gusset plates **46**. Bottom foot plates **48** are connected to the four vertical members of the frame **42** and the frame is bolted or otherwise attached to the base plate member **40**. Top plates **50** are connected to the tops of the frame members **44** and are braced by gusset plates **52**.

An upper cross-member **54** is formed by intersecting channels **56**. The outer ends of the channels **56** are bolted to their respective top plates **50** by bolts **58**. A lower cross-member **60** is constructed similarly to the upper cross-member **54** in that it comprises intersecting channel members **62** having their outer ends welded to points intermediate the four transducer frame forming vertical members **44**. The intersections of the upper and lower cross-members **54** and **60** are adapted to receive the ends of a double rod-end piston member **64**. The upper and lower ends of the rods of the piston member **64** are securely connected to the intersections of the cross-members **54** and **60**, respectively, by a plurality of bolts or screws **66**.

The piston member **64** has a piston **70** (FIG. 4) within a cylinder **72** formed within a reaction mass **74**. Piston **70** is provided with conventional piston rings **76** for insuring a sliding, fluid-tight seal with the interior of the cylinder **72**. Hydraulic fluid is introduced into the cylinder **72** alternately on opposite sides of the piston **70** from a manifold control means such as, for example, a standard four port servo control valve **78** directing high pressure oil alternately through upper and lower hydraulic ports **80** and **82**. High pressure oil is supplied to the servovalve through a high pressure passage **71** and low pressure oil flows from the servovalve through passage **73**. Passages **71** and **73** are connected by hoses to a manifold **232** (FIG. 1) external to reaction mass **74** (FIG. 4). Thus, it will be evident that as hydraulic fluid is introduced through the lower port **82** into the cylinder **72** (FIG. 4) below the piston **70** the reaction mass **74** is driven downwardly relative to the piston member **70**, and therefore relative to the pad **40** (FIG. 3). Conversely, when hydraulic fluid is introduced through the upper port **80** (FIG. 4) into the cylinder above the piston **70** the reaction mass **74** will be driven upwardly. As the reaction mass **74** is driven downwardly, an upwardly directed reaction force is applied to the pad **40** (FIG. 3) and when the reaction mass is driven upwardly, a downwardly directed reaction force will be applied to the pad **40**. The amount of hydraulic fluid introduced into the cylinder **72** (FIG. 4) is controlled to vibrate the reaction mass **74** to produce varying frequencies of a given frequency range of a sweep.

In normal operation, the reciprocation of the reaction mass **74**, (FIGS. 3 and 4) is maintained centered between the upper and lower cross-members **54** and **60** by means of a linear variable-differential transducer (LVDT) **84** (FIG. **2**) having its electrical coils (not shown) mounted in a well provided therefor in the reaction mass **74** (FIG. **3**). These coils surround a core member (not shown) which is attached to the lower cross-member **60.** The electrical output of the LVDT **84** is coupled to an electronics controller hereinafter described (FIG. **10**). Additional reaction mass support is provided by a pair of strut type arrangements **90** (FIG. **4**) mounted in the reaction mass **74.** Each strut arrangement (FIG. **4**) includes a cylinder **92** having its upper end connected to a hydro-pneumatic accumulator **94** such as, for example, Greer Hydraulics Inc., Model No. A108-200. The accumulator is pressurized with a suitable gas such as nitrogen to a pressure of 1,500 psi. A rod type piston **96** having a bearing end **98** in engagement with a stop plate **100** (FIG. **3**) attached to the lower cross-member **60** is mounted in the cylinder **92** (FIG. **4**). The volume of the cylinder **92** above the rod type piston **96** and the oil volume of the accumulator is filled with oil and connected by a passage (not shown) to a high pressure passage **71.** A substantially constant force occurs to aid in centering the reaction mass about the vibrator piston **70** (FIG. **4**). Nevertheless, to guard against the eventuality that the reaction mass member **74** may become uncentered and strike either of the upper or lower cross-members, bumper studs **102** (FIG. **4**) of a pair of shock absorbers **104** extend outwardly from each of the upper and lower faces of the reaction mass **74** to engage the upper and lower cross-members **54** and **60** (FIG. **3**) to cushion and dissipate any striking force of the reaction mass **74.**

To prevent the reaction mass **74** from rotating around the piston member **70**, two anti-rotation plates **105** are attached to two of the transducer frame members **44** which upon rotation of the reaction mass **74** engage the edges of the reaction mass **74.** The transducer frame members **44** and anti-rotation plates **105** thus act as rotation stop members for the reaction mass **74.**

A novel synchronized hydraulic lift system **26** (FIGS. **1, 2** and **5**) interconnects the transducer to the vehicle frame members **16.** This system is comprised of two identical lift units **107** and **109** (FIG. **2**) disposed on opposite sides of the transducer; each lift unit is mounted in a bushing box assembly **110** (FIG. **5**) attached to frame members **16.** As the lift units and attachment journals are similar only one of each need be described. The bushing box **110** (FIGS. **5** and **6**) comprises a first pair of oppositely disposed plates **112** which are parallel to the frame members **16** and a second pair of oppositely disposed plates **114** which are normal to the frame members **16.** Plates **114** extend beyond plates **112** to form ear portions **114*a*** and **114*b*.** Ears **114*a*** are bolted to angle irons **116** which are rigidly secured by bolts or welds to one of the vehicle frame members **16.** Ears **114*b*** and angle irons **118** attached to plate **120** support gussets **121** extending upwardly of the casing **150** (FIG. **5**) in support thereof. Angle irons **116** have a channel bar **119** (FIG. **6**) attached between them to support a pair of idler sprockets **122** and **124** (FIG. **5**) in a vertically spaced and aligned relation one to the other for a lift synchronization chain and sprocket arrangement hereinafter described. Portions of the channel **119** and angle irons **116** are cut away to provide openings therein for feeding a chain (FIG. 7) to the idler sprockets **122** and **124** (FIG. 5).

The hydraulic lift unit includes a hydraulic lift cylinder **126** slidably mounted within a bushing **106** which is a part of bushing box **110.** The lift cylinder **126** has its lower end connected adjacent a side of pad **40** by a vibration isolation means **128** (FIGS. **1** and **3**). The vibration isolation means permit a static hold down load to be applied to the base plate **40** while permitting free vertical reciprocation of the base plate relative to the truck to isolate the truck from the vibrating structure and also for transmitting a tension force from the vertical lift columns **126** to the base plate **40** so that the transducer or vibrator assembly **24** can be lifted for transport. Each isolation means **128** (FIG. **1**) comprises two lower mounts **132** for supporting a pair of air springs **136** and an upper shoe **140.** The upper shoe **140** has its lower face engaging the upper ends of the air springs **136** and its upper surface connected to the hydraulic lift cylinder **126.** To prevent lateral displacement of the hydraulic lift cylinder **126** relative to the base plate **40** through lateral movement of the air springs **136,** three tie rods **142, 144** and **145** (FIGS. **1** and **3**) are positioned at ends of the vibrator isolation means **128.** Each tie rod **142, 144** and **145** has one end pivotally connected to the base plate **40** and its other end pivotally connected to the upper shoe **140** adjacent its outer edge. To relieve stress on the air springs during lift of the vibrator pad **40**, a pair of chains **146** are attached at each air spring to the sides of the upper shoe **140** and to the base plate **40.**

The lift cylinder **126** (FIG. **5**) is mounted in an outer casing **150** which terminates at the bushing box **110** and is fastened with the bushing box **110** to the vehicle frame member **16.** The upper end of the casing **150** is closed by a flanged annular cap **154** in which is mounted the rod **156** of lift cylinder **126.** The rod **156** is retained in position by a pivot shaft **160** passing through the lift unit casing **150** and cap **154** and retained therein by retaining rings **162.** A piston (not shown) is attached to rod **156** in the cylinder **164** of the lift cylinder **126.** Hydraulic fluid is introduced into the lift column cylinder above and below the piston to force the lift cylinder **126** selectively either downwardly to lower the pad **40,** to raise the truck from the ground, or upwardly to raise the pad.

The novel lift system described above thus uses a lift cylinder which is also the load bearing column. In prior art lift systems a hydraulic lift cylinder separate from and eccentric to the lift column is used. A prior art lift system is shown in U.S. Pat. No. 3,306,391 issued 28 Feb. 1967. The novel lift synchronizing means described hereinafter may be used either with a prior art lift cylinder and column arrangement or with the novel lift cylinder arrangement described herein.

The novel mechanical synchronizing system (FIGS. **1** and **7**) is for synchronizing the operation of the hydraulic lift units and therefore the raising and lowering of the opposite ends of the pad **40.** It will be appreciated that if the vibrator pad **40** comes to rest upon uneven ground or if a portion of it comes to rest upon a protruding rock or log, or uneven distribution of the lowering force and hold down force on the hydraulic lifts will result. If this unequal force is not equalized, one hydraulic lift will assume a greater share of the work required to lift the truck assembly; such unequal stress could result in a seizing of the lift columns. A function of the mechanical synchronizing system is to equalize the operating forces on the hydraulic lift units.

The novel mechanical synchronizing system comprises a sprocket and chain arrangement for each lift coupled to a synchronizing shaft **166** (FIG. 7) mounted in the vehicle frame members **16**. Each sprocket and chain arrangement is identical, thus only one is described. The sprocket and chain arrangement comprises: the idler sprockets **122** and **124**, which as previously mentioned are mounted in the lift column assembly chassis attachment box means **110** (FIG. 5); a sprocket **168** (FIG. 7) mounted on an end of the synchronizing shaft **166**; a first adjustable chain support clamp **170** (FIG. 5) rigidly secured to the lift cylinder **126** adjacent its upper end and in line with the idler sprockets **122** and **124**; a second adjustable chain support clamp **172** (FIG. 7) attached to the upper shoe **140** at the lower end of the lift cylinder; and a chain **174**. The synchronizing shaft **166**, being journaled in the frame members **16** behind the lift mechanism and on the centerline between the idler sprockets **122** and **124**, the sprocket **168** is positioned rearwardly of the idler sprockets and intermediately to them. Chain **174** has one end attached to the first or upper chain support clamp **170** (FIG. 5) and runs along the lift column casing **150**, around idler sprocket **122** (FIG. 7), along the vehicle frame member **16**, around sprocket **168** back along the vehicle frame member **16**, around idler sprocket **124** and along the lift column to the lower chain support clamp **172**.

It will be appreciated that, with each hydraulic lift equipped with the above described chain and sprocket arrangement, the lift carrying weight in excess of the weight carried by the other lift will transfer through sprocket **168** an equalization force or moment to the synchronization shaft **166** and through the chain and sprocket of the other lift to the other lift column to synchronize lift column movement and to equalize the loads between the lifts.

The mechanical synchronizing system includes a novel lift control mechanism on one side of the vehicle only which includes one or more cams adapted to coact with one or more switches to control the operation of the hydraulic lifts. The control mechanism as shown (FIG. 7) includes three cams **176, 178,** and **180** and three limit switches **182, 184** and **186.** The cams **176–180** are positioned on that portion of chain **174** extending between sprocket **168** and sprockets **122** and **124** and have arms extending outwardly away from the chain in a spaced relation one to another to engage the three limit switches **182–186.** The switches are mounted in a vertical line upon a channel **188** attached to one of frame members **16** adjacent the side of sprocket **168** nearest to idler sprockets **122** and **124.** Each switch **182–186** includes a rocker arm outwardly spaced one to another to align rollers mounted on the ends of the arms with corresponding cams **176–180** for engagement selectively with the cams. The cams **176–180** are positioned typically on the chain **174** as follows: with the lift assembly in the full up position cam **176** is positioned adjacent sprocket **122**, cam **178** is positioned adjacent sprocket **168** and cam **180** is positioned immediately before cam **178.** Cam **176** and switch **182** are referred to as a pad half lift cam and switch. Cam **176** is so positioned with respect to switch **182** that movement of the cam **176** with a prescribed amount of lift travel (about **15** inches) from the full up position will trip switch **182** to lift the pad **40** a desired distance off the ground. With cam **176** in this position, minimum pad lift is obtained; to increase pad ground clearance the cam **176** is moved toward the sprocket **168.** The cam **178** and switch **184** are referred to as a sweep interlock cam and switch. Additional lift travel (about 5 inches) from the full up position brings cam **178** in contact with switch **184** to activate the switch and enable an electronic controller for the transducer after the pad hits the ground and the truck is partially lifted (about 2 inches). This switch alleviates the possibility of activating the vibrator while the pad is in the air. By moving cam **178** toward sprocket **168**, the interlock switch **180** will be tripped later, that is, at a lower pad position; by moving the cam **178** away from sprocket **168** the interlock switch will be tripped earlier, that is, at a higher pad position. Cam **180** and switch **186** are referred to as a truck half lift cam and switch. Farther lift travel (about 2 inches) will cause cam **180** to trip switch **186** and stop the truck a farther distance (about 4 inches) off the ground. For more truck lift, cam **180** is moved away from sprocket **168** and conversely, for less truck lift cam **180** is moved toward the sprocket **168.** The chain and sprocket arrangement can be constructed so that for a chain pitch of one inch, the movement of cam **180** one chain link on the chain will result in a 1 inch change in pad lift. For adjustments of less than one inch, all three cams may be moved by adjusting the adjustable chain clamps **170** and **172** on the top of the lift column and on the foot piece.

For transporting the seismic transducer without assistance of the hydraulic lift system, a pair of support frames **190** and **192** (FIGS. **1** and **2**) are provided to support the transducer **24** in the raised position. The support frames **190** and **192** are similar in construction and comprise tubular members welded into a trapezoidally or square shaped frame of which one side **194** forms a tubular axis member which is pivotally connected to the vehicle frame **16** by a pair of journals **196** and **198.** Dogs **200** are attached to the transducer frame **42** so as to engage the upper member of frame **190** and support the transducer assembly **24** at the proper height. The journals **196** and **198** are positioned on the frame of the truck so that the pivotal support frame may be retracted from the transducer and remain back against the lift column assembly so as not to impair operation of the vibrator.

The hydraulic lifts and transducer cylinder **72** (FIG. **4**) are provided hydraulic fluid by a hydraulic system shown schematically in FIGS. **8A** and B. The operation of the hydraulic system will first be described. Then the basis for and operation of the novel part of the hydraulic system which is one object of this invention will be described.

The hydraulic system (FIGS. **8A** and B) comprises a hydraulic fluid container **36**, hereinafter referred to as tank **36**, equipped with a fillerbreather **201**, a tank drain **202**, and a suction filter **204.** An oil line **206** couples the tank through a tank shut off valve **208** to a prime pump **210.** The prime pump **210** may be an electrical pump operated from the battery of the vehicle. The prime pump **210** pumps oil into a low pressure system until the low pressure system is filled and under a pressure of approximately **150** psi as measured by a charge pressure gage **212** mounted in the panel of the vehicle cab **18.** The low pressure system is provided with a relief valve **214** set at 150 psi to maintain the pressure of the low pressure system at this stage of operation at 150 psi.

With the pressure in the low pressure line at **150** psi, the main pump driver or engine **28** (FIG. **1**) is started and the prime pump **210** (FIG. **8A**) is shut off automatically by a prime pump shut off pressure switch **216**. The engine **28** drives charge pump **218** to maintain the pressure in the low pressure system at about 150 psi. Charge pump **218** is provided with a relief valve **220** which is set at approximately 180 psi as an additional protection means. The oil pumped by charge pump **218** makes up any internal leakage in the system and the remainder is dumped by relief valve **214** through the case of pump **30** back to tank **36** thus affording cooling for pump **30**. The speed of engine **28** is then increased and the pump displacement control **222** of the main pump **30** is moved to the open position thereby permitting the main pump **30** to pump oil from the low pressure system into a high pressure system. The pump displacement control **222** is provided with a pressure override control which is set for 3,000 psi pump pressure to maintain pressure within the high pressure system at 3,000 psi. If the pressure within the low pressure system ever falls below 100 psi, a pressure switch **224** which is set at 100 psi is activated to shut down the main pump engine **28**. The pressure of the high pressure system is measured at the main pump output by gage **226** (FIG. **8B**) mounted in the panel of vehicle cab **18**.

The low pressure side of the main pump **30** (FIG. **8A**) is coupled to the outlet of the low pressure system. The low pressure system has as its inlet the low pressure port of the servovalve **78** (FIG. **8B**). The servovalve **78** is attached to the vibrator cylinder **72**. The low pressure port of servo valve **78** is coupled through a vibrator cylinder shut off valve **228** to the low pressure side **230** of manifold **232**. The low pressure side of the manifold **232** has a prime pump check valve **234** coupled to prime pump **210**, to allow prime pump **210** (FIG. **8A**) to charge the low pressure system but to keep low pressure system oil from feeding back to charge pump **210** when it is shut off. The low pressure outlet of manifold **232** (FIG. **8B**) is coupled to two low pressure accumulators **236** and **238** (FIG. **8A**) adjacent to the manifold for removing surges in fluid flow out of the manifold and to a third surge preventing accumulator **240** located adjacent to the oil cooler **38** for removing any reverse fluid flow surges in the low pressure system resulting from the introduction of the fluid into the oil cooler **38**. The accumulator **240** is coupled to the junction of an oil cooler inlet **241** and a cooler bypass valve **242**. An oil cooler outlet **244** is coupled to the junction of the cooler bypass valve **242** and to another surge preventing accumulator **246** to further dampen any surges occurring in the low pressure system. The accumulators **236, 238, 240** and **246** may be, for example, Greer Hydraulic Inc. Hydro-Pneumatic Accumulator, Model No. 30A5TB, charged to a gas pressure of 90 psi when system has zero pressure. The outlet of the accumulator **246** is coupled to a filter **248** to remove any contaminate particles larger than **3** microns in size. The outlet of the low pressure filter **248** is coupled to the low pressure side of the main pump **30**. The low pressure side of the main pump **30** is connected to an oil temperature gauge **250** (FIG. **8B**) located on the panel of the vehicle cab **18**. The oil cooler **38** (FIG. **8A**) is provided with an air bleed pipe **252** which is coupled to the tank **36** (FIG. **8B**) to aid in removing air from the hydraulic system. The oil cooler **38** (FIG. **8A**) has a second outlet **254** coupled also to the relief valve **214**. The relief valve **214** being set at 150 psi opens at that pressure to permit oil to flow from cooler outlet **254** through the case of main pump **30** into the tank **36**.

The high pressure side of main pump **30** is coupled to the input of the high pressure system. The high pressure system comprises the main pump outlet which is coupled to a filter **256** to remove any particles of approximately 3 microns or above in size. The filter output is coupled to a high pressure check valve **258** (FIG. **8B**) located at the high pressure side **260** of manifold **232**. The high pressure check valve is to remove any surges in the high pressure system for reflecting back to the pump. The high pressure side **260** of manifold **232** is coupled to a high pressure accumulator system **262** (FIG. **8A**) and to the high pressure port of servo valve **78** (FIG. **8B**) which controls injection of the high pressure fluid into the vibrator cylinder **72** of transducer **24** (FIG. **3**). The piston in the vibrator cylinder **72** divides the high pressure system from the low pressure system at one end of the hydraulic system and the main pump **30** (FIG. **8A**) acts to divide the high pressure and low pressure systems at the other end of the hydraulic system. The high pressure accumulator system **262** comprises a pair of accumulators **264** and **266**. The high pressure accumulators **264** and **266** may be Greer Hydraulics Inc. Hydro-Pneumatic Accumulators, Model No. 30A-5TB. These hydro-pneumatic accumulators have a nominal fluid volume **265** of 5 gallons and a gas volume **263** of 1,095 cubic inches and are constructed as shown in FIG. **9**. The hydro-pneumatic accumulators are modified to increase their volume of gas by connecting their gas bladder ports to a plurality of gas bottles **268** (FIG. **8A**). Each gas bottle has a volume of approximately 1,800 cubic inches. The gas volume of gas bottles **268** and the gas bladders of the high pressure accumulators **262** and **264** are filled with a suitable gas such as, for example, nitrogen at a pressure of 2,800 psi prior to actuation of the high pressure pump. With the pump producing a pressure above that of the accumulators, e.g., 3,000 psi, the pump forces oil into the oil chambers of the accumulators **264** and **266** to compress the nitrogen in the bladders and bottles to an equalizing pressure of 3,000 psi. The novel usage of the high pressure accumulators and nitrogen supply, to be described in more detail hereinafter, is one way in which the improved transducer of this invention is distinguished from prior art transducers. The oil pressure in the high pressure side **260** of the manifold **232** is measured by a high pressure accumulator oil pressure gauge **270** (FIG. **8B**) mounted in the panel of vehicle cab **18**. A bypass valve **272** is coupled to the high pressure side **260** of manifold **232** to allow bypassing oil from high pressure to low pressure systems without passing through vibrator cylinder **72**. Bypass valve **272** is closed when the vibrator is in operation. To protect the high pressure system against damaging high pressure, a relief valve **273** is set at 3,600 psi. The outlet of relief valve **273** is coupled to the low pressure side of manifold **232**. To protect the low pressure system from damaging pressure a relief valve **274** is coupled to the low pressure side of manifold **232**. The relief valve is set to open at **240** psi and the outlet of the valve is connected to the tank **36** so that oil escaping through the relief valve is collected in the tank.

The hydraulic system for the hydraulic lifts of the transducer comprises a lift valve **276** coupled to a high pressure port of the manifold **232** and to an adjustable pressure reducing valve **278**. The pressure reducing valve **278** may be adjusted to introduce oil under pressure to the lower portion of the lift cylinders to provide a desired truck lift pressure to the lift units **107** and **109** (FIG. **2**). Oil from the lift units **107** and **109** is returned through the lift valve **276** (FIG. **8B**) to a low pressure port of manifold **232**. Oil under high pressure is also coupled from the lift valve **276** through line **280** to the upper or pad lift side of the lift cylinders of lift units **107** and **109** (FIG. **2**).

The operation of the transducer assembly is controlled by an electronics controller **282** (FIG. **10**) having its output coupled to a torque motor **284** of servo valve **78.** Because of the high flow rate involved in the system of FIG. **8,** the servo valve **78** is a three stage valve. The first stage **286** which might be a flapper valve stage is coupled to the torque motor **284** and to the second stage **288;** the second stage is coupled to the third stage **290,** and the third stage output is controlled by a slidable spool member for selectively introducing oil into the vibrator cylinder **72.** The slidable spool member reciprocates to alternately open and close the high pressure channel leading to the upper and lower portions of the vibrator cylinder **72** while closing and opening alternately the upper and lower portions of the vibrator cylinder **72** to the low pressure return channel of the servo valve. The spool of the third stage **290** is coupled to a linear variable-differential transducer **292** whose output is fed back to the electronic controller **282.** The electronic controller combines the information from the LVDT 84 mounted in the vibrator cylinder **72** and with information from an accelerometer (not shown) attached to the transducer frame **42** and produces an adjusted sweep signal for proper control of the torque motor **284.** The electronic controller **282** may be, for example, a TI controller available under Part No. 139,066-2 which includes a function generator for generating sweep signals within the transducer assembly **10,** or it may be an Electro-Technical Laboratory's Model No. SHV200 Controller. The Electro-Technical Laboratory's Model No. SHV200 includes a receiver for receiving sweep signals generated remotely to the transducer assembly **10.**

In operation the transducer truck **10** is moved to a marked source location in an area of seismic operation and the hydraulic system is activated as follows. The electric prime pump **210** is activated to pressurize the low pressure side of the hydraulic system to about 150 psi. At this point the main pump engine **28** is started and the prime pump shut off. The main pump **30** pumps oil from the low pressure side into the high pressure side to pressurize the high pressure side to about 3,000 psi pressure. When the high pressure has reached 3,000 psi, oil has been stored on the oil side of the accumulators **264** and **266** until the pressure on the gas side is raised from its inactive pressure (2,800 psi) to its force equalizing pressure of about 3,000 psi; at this point the pressure in the manifold will also be 3,000 psi.

The hydraulic system having been brought up to pressure is ready to operate the transducer assembly. The hydraulic lift units **107** and **109** are activated by opening the lift valve to permit oil to flow from the high pressure side of manifold **232** through line **280** into the hydraulic lift units **107** and **109** to raise the transducer assembly **24** off the frame support **190.** The frame support **190** is then pivoted away from the transducer assembly **24** to clear it for operation. The lift valve **276** is then reversed to permit oil to flow from the high pressure side of manifold **232** through reducing valve

278 to lift units **107** and **109** to lower the base plate from its raised position into contact with the ground and to raise the truck off the ground until the truck half lift cam **180** trips the truck half lift switch **186** to stop the hydraulic lift system. When the lift synchronizing chain **174** has reached this position, the sweep interlock cam **178** has tripped the sweep interlock switch **184** to enable the vibrator controller to operate.

With the pad **40** firmly held down by the truck, the electronic controller **282** feeds sweep information to the servo valve torque motor to manipulate the servo valve to selectively introduce oil into the cylinder **72.** The control electronics **282** utilizes the three feedback loops of sensors **292, 84** and **293** (FIG. **10**) to cause the transducer to operate in accordance with the desired sweep signal.

Having described the operation of the hydraulic system in general it is appropriate to further describe the novel high pressure accumulator system and distinguish it from prior art.

FIG. **11** shows a much simplified model of the vibeator transducer. F cos (2 π ft) is the alternating force imposed by the hydraulic cylinder between the reaction mass M_R and the ground pad; f is frequency, Hz, and t is the time/sec. The soil impedance Z_S is a complex function of earth properties and frequency; however, it is usually assumed for design purposes that the soil impedance plus the mass of the ground pad is large and thus that the ground pad has no displacement ($X_p = 0$). This is not strictly true, of course, but it has been found that the zero pad displacement model is adequate for specifying hydraulic system parameters.

From FIG. **11** with $X_p = O$ it is seen that the displacement and velocity of M_R are, respectively

$$X_R = \frac{-F \cos(2\pi ft)}{4\pi^2 f^2 M_R},\ \text{in}$$

$$\mathring{X}_R = \frac{F \sin(2\pi ft)}{2\pi f M_R},\ \text{in/sec}$$

The force amplitude exerted by the hydraulic piston is F = pA when p = hydraulic pressure, psi, and A = hydraulic piston area, in^2. The flow supplied to the hydraulic piston must be

$$Q = A\mathring{X}_R = \frac{pA^2 \sin(2\pi ft)}{2\pi f M_R},$$

in^3 sec.

The peak flow is

$$Q_{max} = \frac{pA^2}{2\pi f M_R},$$

in^{3}sec. and the average flow is

$$Q_{avg} = 0.636\ Q_{max},\ \text{in}^3\text{/sec.}$$

For a given design p, A, and M_R are fixed and a plot of required flow Q_{avg} (or input power which is proportional to Q_{avg}) appears as in FIG. **12.** It may be seen that lowering the lowest operating frequency from, for example, 10 Hz to 5 Hz would require twice as much input power; i.e., twice as much pump and engine capacity.

In prior art vibrators, as noted earlier, the pump capacity Q_p is fixed at approximately Q_{avg} for the lowest desired operating frequency f_1. A high pressure accumulator is used to provide the difference between Q_{avg} and the instantaneous peak flow Q_{max}. The accumulator volume is determined at the lowest operating frequency such as shown in FIG. **13** in which T_1 is the period of the lowest operating frequency. The accumulator must supply the volume V_{AS} represented by the shaded area since the pump can supply only Q_{avg}. An accumulator is chosen which will deliver this volume of oil with a pressure drop which is acceptable (for example, a pressure drop not greater than 200 psi in a 3,000 psi system).

In exploration usage, a vibrator is always operated with a changing frequency sweep because of the nature of the correlation process used in the data analysis method. These sweeps are ordinarily a linear change of frequency with time. The sweep may be from low to high frequency (upsweep) or high to low (downsweep) as shown in FIGS. **14A** and B. There is a slack time $\overline{T}$ between sweeps when the actuator is not vibrating. Since the theoretical flow requirements for upsweeps and downsweeps are the same, only the flow requirement for an upsweep is discussed.

Because of the sweep requirement it is not necessary to provide a pump large enough to develop Q_{avg} at the lowest desired frequency as done in prior art vibrators. The novel high pressure system of this invention reduces significantly the required pump size and power input.

The vibrator flow requirement varies with time over an upsweep as shown in FIG. **15**.

One function of the novel high pressure accumulator system is to provide enough flow to meet the maximum fluid flow ($\overline{Q}_{max}$) peaks at each cycle of the sweep above the average flow ($\overline{Q}_{avg}$) as taught by the prior art. However, the pump is not required to supply $\overline{Q}_{avg}$ corresponding to the lowest operating frequency as in prior art systems. A second function of the novel high pressure accumulator system not used in prior art systems is to utilize the high pressure accumulator to store hydraulic energy so that the flow curve $\overline{Q}_{avg}$ can be obtained while the pump supplies a continuous flow of only $\overline{Q}_p$ (FIG. **15**) such that when the required average flow $\overline{Q}_{avg}$ is greater than the pump flow $\overline{Q}_p$ the vibrator is taking flow from the accumulator in addition to full pump flow, but when the pump flow $\overline{Q}_p$ is greater than the required flow $\overline{Q}_{avg}$, the pump rebuilds the accumulator's fluid volume and pressure.

The average flow pattern for two sweep periods is shown in FIG. **16.** When $\overline{Q}_{avg} > \overline{Q}_p$ the vibrator is taking flow from the accumulator in addition to full pump flow, but when $\overline{Q}_{avg} < \overline{Q}_p$ the pump can build the accumulator back up as well as supply the vibrator. During the slack time between sweeps (from T to $T + \overline{T}$ and from $2T + \overline{T}$ to $2T + 2\overline{T}$) full pump flow can go to the accumulator. The volume taken from the accumulator per sweep is in accordance with the following formula:

$$V_{AF} = \int_0^{T_1} (\overline{Q}_{avg} = \overline{Q}_p)\, dt.$$

The volume put into the accumulator per sweep by the pump is in accordance with the following formula:

$$V_{AP} = \int_{T_p}^{T} (\overline{Q}_p - \overline{Q}_{avg})\, dt + \overline{Q}_p \overline{T}.$$

For the most efficient hydraulic system, the volume taken from the accumulator (V_{AF}) should equal the volume put into the accumulator (V_{AP}) per sweep by the pump. By equating the above-mentioned formulas, an equation is obtained which can be solved for either $\overline{T}$ or $\overline{Q}_p$ if the other is known; that is, for given sweep parameters (T, *f*, and f_2). Having solved the equation for either $\overline{T}$ or $\overline{Q}_p$, the volume of hydraulic fluid needed from the accumulator can be computed from the formula for V_{AF}. V_{AF} is the volume to supply the flow $\overline{Q}_{avg}$. An additional volume is required to reach the maximum flow $\overline{Q}_{max}$. This added volume of hydraulic fluid is computed conservatively from the above-mentioned prior art formula ($V_{AS} = 0.59$ I,Q_{max}, in_3) using the maximum flow Q_{max} figured for the lowest operating frequency f_1. The total volume of hydraulic fluid which must be supplied during the sweep is then given by the formula

$$V_A = V_{AS} + V_{AF}.$$

Volume V_{AS} taught by prior art is normally much smaller than V_{AF} and thus not a major part of the present invention.

By way of further illustration, an example of a typical transducer will be given. Assume the following transducer parameters:

System pressure, p	= 3,000 psi
Vibrator piston area, A	= 10 in^2
Weight of reaction mass	= 4,000 lb
Pump capacity $\overline{Q}_p$	= 60 gpm
Engine power required	= 117 HP.

In order to determine the required accumulator volume it is convenient to plot the volume V_A delivered from the accumulator against the sweep rate $(f_2 - f_1)/T$ (FIG. **17**) for the above parameters. A sweep rate of 1 Hz/sec is about the slowest required and a low frequency limit of f_1=5Hz is desirable. For these conditions the accumulator must deliver $V_A = 4.6$ gal. (FIG. **17**).

An accumulator volume is selected and pressure drops for different conditions are calculated. For this example a total high pressure accumulator volume of 57 gal. is selected. This accumulator will deliver the required 4.6 gal. during any practical sweep with a pressure drop of 200 psi or less.

The accumulator itself may be a single bladder type (FIG. **9**) or a piston type, as a multiplicity of smaller accumulators. It may also be made up of one or more individual accumulators connected to a remote nitrogen supply as described in the hydraulic system of FIG. **8.** In that system which is also for the transducer being here discussed, two bladder type accumulators (FIG. **9**) each capable of accepting 5 gal. of oil are used with 23.5 gal. of nitrogen for each accumulator in remote pressurized tanks.

Had this transducer example been considered using the teachings of prior art, the pump capacity would have been determined by the formula

$$Q_p = \frac{0.636\, pA^2}{2\pi f M_R} \text{in}^3\text{/sec.}$$

This formula given a required pump capacity of Q_p = 152 gpm requiring about 296 horsepower. A high pressure accumulator is still required to get from Q_{avg} to Q_{max} as previously explained. In this case if the pressure drop is limited to about 200 psi, an accumulator volume of approximately 3 gal. is required.

Although a single embodiment of the invention has been described, it will be apparent to the person skilled in that art that various modifications to details of construction shown and described may be made without departing from the scope of the invention.

What is claimed is:

1. A transportable hydraulic seismic transducer comprising:

a. a transport means for transporting hydraulic seismic transducer;

b. a vibrator means attached to the transport means, for producing mechanical vibrations;

c. a pad rigidly secured to the vibrator for generating acoustical energy in the earth responsively to the vibrations of the vibrator; and

d. a hydraulic system means operatively connected to the vibrator means for vibrating the vibrator to produce varying frequencies through a given frequency range for a sweep, including (i) a source of hydraulic fluid, (ii) pump means connected to the source of hydraulic fluid for pumping continuously throughout the sweep hydraulic fluid from the source at a volume rate less than the maximum average volume required for the vibrator to produce the varying frequencies of the sweep; (iii) a power source connected to the pump for driving the pump; (iv) a high pressure accumulator coupled to the pump means for storing hydraulic fluid under pressure between sweeps and during the period of the sweep at which the pump volume exceeds the requirements of the vibrator means; (v) manifold means coupled to the pump means and high pressure accumulator for alternately introducing hydraulic fluid into and withdrawing hydraulic fluid from the vibrator means; and (vi) a control means connected to the manifold means for controlling the amount of hydraulic fluid introduced into the vibrator whereby the vibrator is activated to produce the varying frequencies of the sweep.

2. A transportable hydraulic seismic transducer comprising:

a. a transport means for transporting a hydraulic seismic vibrator to a seismic source location;

b. a vibrator means for producing mechanical vibrations mounted upon said transport means;

c. a pad rigidly secured to the vibrator for generating acoustical energy in the earth responsively to the vibrations of the vibrator; and

d. a hydraulic system means operatively connected to the vibrating means for vibrating the vibrator to produce varying frequencies of a given frequency range of a sweep including: (i) a hydraulic fluid pumping means connected to the vibrator manifold for supplying the manifold with hydraulic fluid continuously throughout the sweep at a volume rate less than the maximum average volume required for the vibrator to produce the varying frequencies of the sweep; (ii) pressurized storage means coupled to the manifold for storing hydraulic fluid under pressure between sweeps and during the period of the sweep the volume supplied the manifold exceeds the vibrator means requirements; and (iii) a control means connected to the manifold means for controlling the amount of hydraulic fluid introduced and removed from the vibrator means whereby the vibrator is activated to produce the varying frequencies.

3. A transportable seismic transducer comprising:

a. a transport means for transporting a hydraulic seismic vibrator;

b. a vibrator means for producing varying frequencies through a given frequency range of a sweep, said vibrator means carried by said transporting means;

c. a pad rigidly secured to the vibrator means for generating acoustical energy into the earth responsively to the vibration frequencies of the vibrator;

d. a pair of lift columns mounted upon the pad and slidingly secured to the transport means in positions to extend substantially vertically on opposite sides of the transport means; and

e. hydraulic means carried by the transport means for actuating the lift columns and vibrator means for selectively raising and lowering the columns relative to the truck and for raising and lowering the transporting means as to the lift columns and for activating the vibrator means to produce varying frequencies of a given frequency range of a sweep, said hydraulic means including; (i) means for supplying hydraulic fluid to a manifold for the lift columns and vibrator means at a volume rate between the maximum average and minimum average volume required for the vibrator to produce the varying frequencies of the sweep; (ii) selective means connected to the manifold for introducing selectively hydraulic fluid into lift cylinders of the lift columns and into the vibrator means; (iii) a pressurized storage container coupled to the manifold for storing hydraulic fluid under pressure during the slack time between sweeps and during the period of the sweep the pump volume exceeds the vibrator means requirements; and

f. a controller means connected to the selector means of the manifold into the hydraulic lift cylinders and to the vibrator.

4. A method for operating a transportable hydraulic seismic transducer comprising:

a. transporting a hydraulic seismic vibrator to a marked location for a seismic source;

b. actuating a prime pump to fill the low pressure side of a hydraulic system and raise the pressure therein to a selected pressure;

c. activating a charge pump while deactivating the prime pump to fill the hydraulic system;

d. activating a main pump to supply at a constant volume rate a manifold and high pressure accumulator with hydraulic fluid until a selected pressure is developed in the manifold and the high pressure accumulator on the high pressure side of the hydraulic system;

e. actuating a valve on the manifold to introduce hydraulic fluid into lift cylinders to lower a vibrator pad into contact with the earth and then raise the truck from the ground to supply a hold down force on the vibrator pad;

f. actuating a controller means coupled to a torque motor of a servo valve to supply hydraulic fluid to the vibrator for producing varying frequencies through a given frequency range of a sweep, said high pressure accumulator and main pump providing required hydraulic fluid through the manifold to the cylinder during the low frequency operation of the vibrator and said pump supplying fluid through the manifold to the vibrator for producing the high frequency vibrations of the sweep and to the high pressure accumulator to recharge the hydraulic fluid portion and to pressurize the pressure portion of the accumulator for repeated sweep operations of the vibrator; and

g. actuating the valve for the lift cylinders to permit the transporting means to be lowered to the ground and to permit fluid to flow into the lift column cylinders to raise the vibrator pad from the earth in preparation for movement of the portable vibrator to a new source location.

5. A transportable hydraulic seismic transducer comprising:

a. a transport means for transporting a seismic vibrator to a seismic source location;

b. a vibrator means attached to the transport means;

c. a pad rigidily secured to the vibrator means for generating acoustical energy into the earth responsive to the vibration frequencies of the vibrator means;

d. column means connected to the pad and slidingly secured to the transport means in position to extend substantially vertically on opposite sides of the transport means;

e. a means carried by the transport means and connected to the lift columns for raising and lowering the lift columns relative to the transport means and for raising and lowering the transport means as to the lift columns;

f. a synchronizing means interconnecting the lift columns and transport means for synchronizing the raising and lowering of the lift columns and for equalizing work between the lift columns comprising a synchronizing shaft rotatably attached to the frame of the transport means, and a synchronizing shaft drive means coupled to the lift columns and synchronizing shaft operatively responsive to movement of the lift columns to synchronize their movements and to equalize the work of said lift columns.

6. A transportable seismic transducer according to claim **5**, wherein said synchronizing shaft drive means comprises: sprockets mounted adjacent each end of the synchronizing shaft, and link chains having links engaging the teeth of the sprockets and ends attached adjacent upper and lower ends of the lift columns whereby the raising and lowering of the lift columns result in a corresponding movement in the chains and a driving force on the synchronizing shaft sprockets to impart a lift synchronizing moment on the synchronizing shaft and a work equalizing force on the lift columns.

7. A transportable seismic transducer according to claim **6**, wherein one of said chains includes a switch actuating means, and a lift columns control switch supported by the transport means in the path of the switch actuating means carried by the chain whereby the lift columns control switch is manipulated by the switch actuator means to control movement of the lift columns.

8. A transportable hydraulic seismic transducer according to claim **5** further comprising a plurality of limit switches and switch activating means coupled to the synchronizing shaft for selectively actuating the switches to control movement of the lift columns.

9. A transportable hydraulic seismic transducer comprising:

a. a transport means for transporting a hydraulic seismic vibrator to a seismic source location;

b. a vibrator means for producing mechanical vibrations mounted upon said transport means;

c. a pad rigidly secured to the vibrator for generating acoustical energy in an elastic media responsively to the vibrations of the vibrator; and

d. a hydraulic system means operatively connected to the vibrating means for vibrating the vibrator to produce varying frequencies of a given range of a sweep including:

i. a hydraulic fluid pumping means connected to the vibrator manifold for supplying the manifold with hydraulic fluid at a volume rate required for the vibrator to produce the varying frequencies of the sweep;

ii. a pressurized storage means coupled to the manifold of the vibrator including a high pressure transfer barrier accumulator system having a hydraulic fluid containing portion and a gas pressurized portion, said fluid portion and pressurized portion being responsive to the hydraulic fluid pumping means and vibrator requirements for alternately receiving hydraulic fluid from the manifold under increasing pressure of the pressurized portion and forcing hydraulic fluid from the fluid containing portion into the manifold to maintain the volume of hydraulic fluid required by the vibrator during a sweep; and

iii. a control means connected to the manifold means for controlling the amount of hydraulic fluid introduced and removed from the vibrator means whereby the vibrator is activated to produce the varying frequencies of the sweep.

10. A transportable hydraulic seismic transducer according to claim **9**, wherein said means for supplying hydraulic fluid to the manifold of a vibrator comprises a source of hydraulic fluid, pump means connected to the hydraulic fluid source for pumping hydraulic fluid from the source at a volume rate between the maximum average and minimum average volume required for the vibrator to produce the varying frequencies of the sweep, and a power source connected to the pump.

11. A method for operating a transportable hydraulic seismic transducer comprising:

a. selectively introducing hydraulic fluid into hydraulic lift cylinders attached to a transport means to lower a vibrator pad into contact with the earth and lift the transport means to supply a hold down force on the pad;

b. activating a pump for pumping hydraulic fluid at a volume rate less than the maximum average volume required by a seismic vibrator to produce a series of varying frequencies within a given frequency range of a sweep into a manifold and a high pressure accumulator or a hydraulic system for a seismic vibrator, said pumping of hydraulic fluid continuing throughout the sweep; and

c. actuating a servo control mechanism to selectively introduce hydraulic fluid from the manifold into the vibrator for vibrating the pad with said high pressure accumulator supplying the additional volume of hydraulic fluid required by the hydraulic system of the vibrator during one portion of the sweep and storing under pressure the hydraulic fluid excessive to vibrator requirements during another portion of the sweep.

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