Aug. 26, 1969 W. B. GOODMAN 3,463,251

PNEUMATIC TRANSFORMER COUPLING FOR SONIC PILE DRIVER

Filed May 23, 1967 2 Sheets-Sheet 1

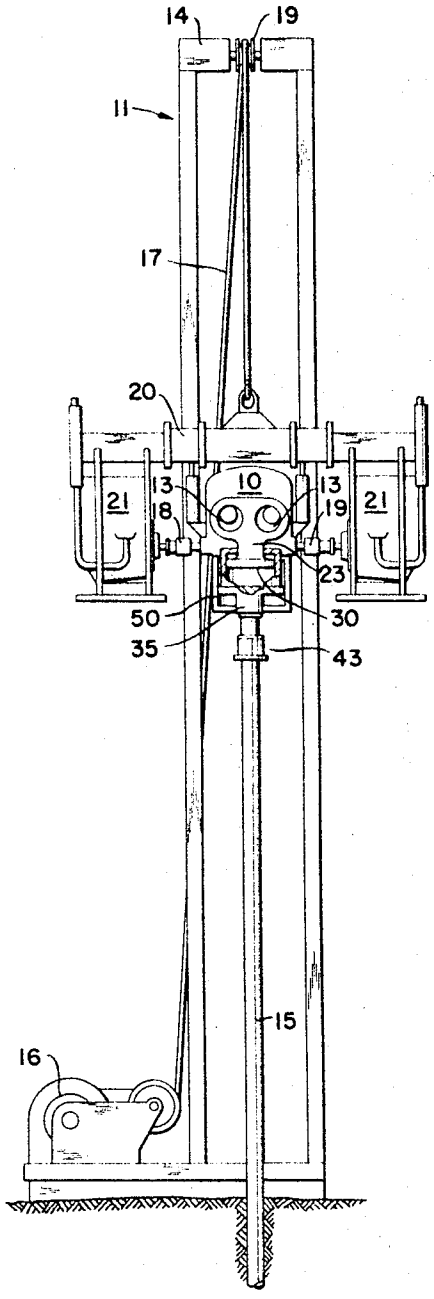


FIG. 1

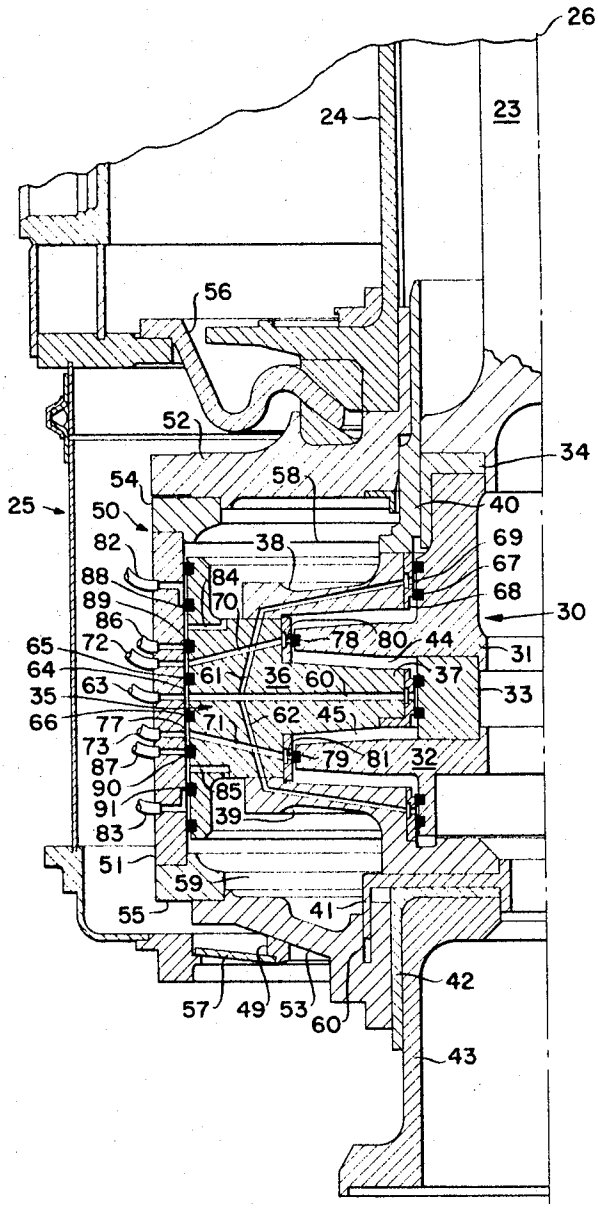


FIG. 2

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PNEUMATIC TRANSFORMER COUPLING FOR SONIC PILE DRIVER

Filed May 23, 1967 2 Sheets-Sheet 2

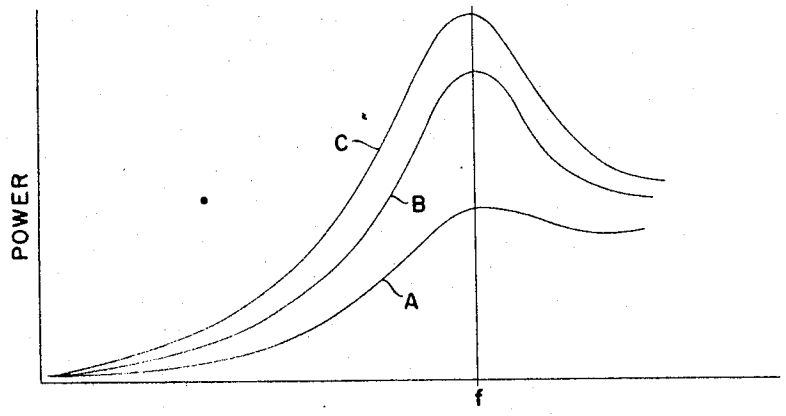


FIG. 3

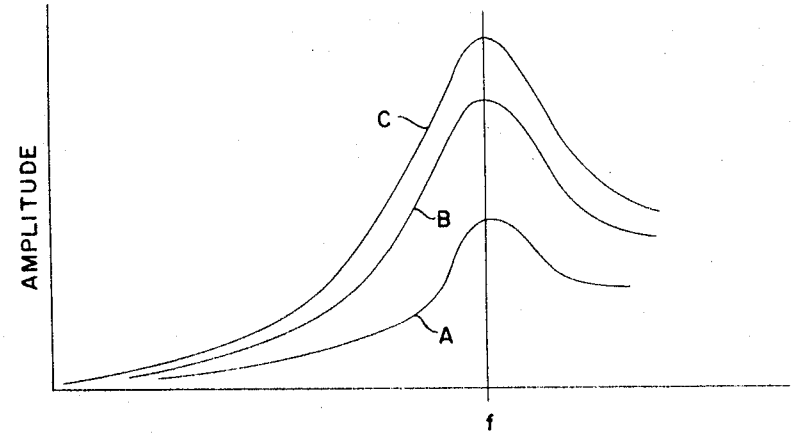


FIG. 4

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PNEUMATIC TRANSFORMER COUPLING FOR SONIC PILE DRIVER

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U.S. Cl. 175—19 6 Claims

ABSTRACT OF THE DISCLOSURE

The force exerted on a pile member by a sonic oscillator may be multiplied at a proportionately smaller displacement amplitude by coupling a pneumatic transformer between the sonic oscillator shaft and the pile to be driven. The pneumatic transformer resiliently absorbs the force of the oscillator shaft over a long stroke and transmits the power thereof to the pile at a proportionately larger force and smaller displacement amplitude.

Background of the invention

This invention relates generally to the art of resonant or sonic applications of force on a structural member.

More specifically, this invention relates to the resonant application of force on a pile member for driving the pile into or out of the earth.

When a pile is vibrated sonically, a longitudinal wave motion is mechanically induced in the pile member by physically and periodically displacing the composite molecules at one end of the pile member as by what is known in the art as a sonic generator or oscillator which is merely a rotating eccentric weight that exerts a reversing force pulse of particular magnitude and frequency along a line coaxial with the pile axis. This longitudinal wave action along the length of the pile results also in a slight lateral vibratory displacement of the pile member. This lateral vibratory action is transmitted to the surrounding earth to place it in a highly energized of "fluidized" state where it seems to literally stand back from the pile column thereby being greatly reduced as source of friction impeding the longitudinal progress of the pile. Herein resides the advantage of driving piles sonically over the conventional hammer method. The sonic method must overcome only viscous friction whereas the latter must overcome dry, sliding (coulomb) friction between the pile walls and the surrounding earth. The significance of this advantage is appreciated when it is considered that 95% or more of the force necessary to drive a pile in the conventional hammer method is required merely to overcome these frictional forces. Such forces being eliminated, the weight of the pile and the oscillator plus all the supporting power equipment, which may exceed 30,000 pounds, is usually adequate to compress and displace the earth immediately beneath most piles.

Sonic pile driving equipment of this class has demonstrated, in field tests, the ability to outdrive conventional steam hammer pile drivers by an average ratio of the order to 20 to 1, and in some cases has substantially exceeded that ratio.

From the above it is seen that the ability and effectiveness of a sonic pile driver to reduce these frictional forces is related to the capacity of the oscillator to displace incremental elements of the pile column along its length. Additionally, since the pile column is elastic and acts as a spring, such displacement is related to the force impressed on the end of the pile by the fundamental relation of:

$$F=kx$$

where:

F=impressed force
x=spring displacement
k=spring constant of the pile system.

It is therefore seen that in order to induce the displacement necessary to achieve our purposes of reducing friction it is necessary to impress the system with a proportional amount of force. This force is provided by the sonic oscillator which may be of the type described in U.S. Patents No. 3,189,106 and 3,291,227. However, machines of this type are limited by inherent design, properties of constructional materials and economic factors to the amount of force they are capable of exerting, usually not much in excess of 150,000 pounds. Such a magnitude of force is inadequate to drive certain piles under some conditions.

It would be desirable and hence is an object of this invention to amplify the force available from existing sonic pile driving oscillators.

Vibrating systems display marked increases in their ability to absorb power when operated at or near a resonant frequency. Hence, another object of this invention is to enable a sonic oscillator of a given force capability to deliver more power to a pile when it is in this power-receptive state.

A further object of this invention is to provide a swiveling pneumatic spring and transformer coupling between a pile oscillator and the pile column.

Summary of the invention

These and other objects may be achieved by inserting a pneumatic transformer between a sonic oscillator and the coupled end of a pile column. According to the invention, the rotating eccentric weights of the oscillator act directly on one end of a reciprocating oscillator shaft. The opposite end of the oscillator shaft is provided with a piston structure which constitutes the primary or driving element of the pneumatic transformer. The piston end of the oscillator shaft reciprocates within a cylinder that is secured to an end of the pile member. The cylinder constitutes the secondary or driven element of the transformer. A valving system is provided to conduct a compressible gas such as air into and out of the said cylinder in such a manner as to inject a desired quantity of gas in a compression chamber of the said cylinder preceding the compression stroke of the piston. The valve is closed as the compression stroke is continued and the quantity of gas trapped within the chamber is adiabatically compressed. Hence, the force of compression is transmitted from the oscillator shaft to the pile connected cylinder via the resilient medium of the gas. The effect of such force transmission through the pneumatic transformer is to exert a greater force on the pile over a shorter stroke distance than was put into the transformer by the oscillator shaft for reasons to be explained hereinbelow.

Brief description of the drawing

Additional details of the transformer structure, its objectives and operation may be learned from the following detailed description of the drawings wherein:

FIGURE 1 is a schematic view of a sonic pile driving machine assembly;

FIGURE 2 is a half-sectional detail of a pneumatic transformer in accordance with the invention;

FIGURE 3 is a graphic plot of three response curves of a pile excited by three respective constant force magnitudes but at varying power and frequency levels wherein power is plotted along the ordinate and frequency is plotted along the abscissa;

FIGURE 4 is a graphic plot of the amplitude, along the ordinate, of a pile under the same conditions as in FIGURE 3.

Description of preferred embodiment

The driving effectiveness of a sonic pile driver derives from the response of the surrounding soil to periodic displacement of the pile column, the accelerations imparted to the soil particles being the controlling factor. Generation of longitudinally moving compression waves within the pile column that travel from one end of the column to the other end and are reflected back in such a manner as to form a standing wave have proved to be the most effective way to maximize the accelerations. Such compressive waves are generated by periodically imposing an axially directed stress, i.e., force, on one end of the pile column by a sonic oscillator. For the most effective results, this force may be periodically applied at or very near the natural frequency of the system which may be determined analytically by those of ordinary skill in the art. Then, the system is caused to resonate, with the reflective compression waves being spaced apart along the length of the pile column in phase with the newly generated waves.

The factors of force F, distance d (displacement) and time t (frequency), in such a system, may be analyzed in terms of power P which is defined as:

$$P=\frac{Fd}{t}$$

Also, relying on the conservation of energy principle and separating the analysis of the oscillator from that of the pile we may write the following relation:

$$P_o=\frac{F_o d_o}{t_o}=\frac{F_p d_p}{t_p}=P_p$$

where:

o subscript relates to the oscillator
p subscript relates to the pile.

Analyzing each factor of the above equality, F_o, the force of the oscillator, is limited to the maximum force capacity of the machine. F_p is that force required to produce the desired displacement of the pile d_p. The displacement d_p is the maximum amplitude of the pile motion and hereafter is defined as A_p. The factor d_o is the displacement of the oscillator. It could be described as the amplitude of the oscillator but is better known as the stroke S_o of the oscillator, a variable prescribed by the design of the machine. Since this analysis applies to a single cycle, the time factor t is the time required for one cycle at the resonant frequency f of the system, which is same for both the oscillator and the pile, i.e., $t=1/f$. Rewriting the equality we now have:

$$P_o=F_o S_o f_o=F_p A_p f_p=P_p$$

since $f_o=f_p$

$$F_o S_o=F_p A_p$$

Recalling that the problem to be solved arises from the fact that the oscillator force and the pile amplitude have restrictive limitations, the oscillator stroke S_o becomes the independent variable most amenable to manipulation for balancing the equality.

Digressing for the moment, consider a sonic pile driving system according to the present state of the art where the oscillator is rigidly coupled to the pile. Such is the condition represented by curve A in FIGURES 3 and 4. FIGURE 3 is a plot of the power consumption of a pile along the ordinate relative to the induced pile frequency f plotted along the abscissa at three respective constant force levels. FIGURE 4 plots the amplitude along the ordinate of the same pile under the same conditions imposed in the FIGURE 3 graph. When the pile and the oscillator are rigidly coupled together, the oscillator can achieve no more amplitude (stroke) than will be accepted under the prevailing force conditions by the pile. Hence the power of the system is limited to the low peak level indicated by curve A in FIGURE 3.

If, however, the oscillator could be coupled to the pile with a resilient connection to allow the oscillator a stroke that is independent of the pile displacement at the same force and frequency delivery rates, the power to the system may be increased thereby. The pile receives the increased power input as increased force and the periodic amplitude is accordingly increased as represented by curves B and C of FIGURES 3 and 4.

It may now be seen that more power may be transmitted to a driven pile member to increase the vibratory amplitude and consequent acceleration thereof, thereby decreasing the driving friction, by allowing a differential between the excursion distance of the oscillator and the displacement distance of the pile. The essence of the present invention therefore is the provision of such a coupling between the oscillator and the pile. Such a coupling transforms low force and long stroke (of the oscillator) to high force and short amplitude (in the pile) much in the same manner as an electrical transformer converts a low voltage, high current to a high voltage, low current. It might appear that such a result would defeat the primary objective of acquiring a greater amplitude in the pile to reduce driving friction. However, it turns out that the oscillator has a relatively broad range of stroke variation and although the amplitude of the pile must be proportionately less than the stroke of the oscillator, the latter may be increased to such a degree as to maintain normal pile amplitude or even to increase it. Furthermore, the relationship between force and amplitude is not linear in the resonant frequency range. "$F=kx$" no longer applies, but rather the amplitude increases by a logrithmetic function of the force. Hence, it is possible to get a much greater amplitude in the pile than the linear inverse relationship between stroke of the oscillator and amplitude of the pile implied by the electrical transformer analogy.

Turning now to the apparatus and structure by which the foregoing analytical conclusions are applied, reference is had to FIGURE 1 showing diagrammatically a typical driving system of the prior art essentially as described in U.S. Patent No. 3,189,106, and also showing diagrammatically the present invention, its function and position in the system. The basic components of such a system are an oscillator **10** with one or more eccentrically revolving weights **13** driven by engines or motors **21** through drive shafts **18** and **19** and gears not shown. The rotating weights **13** react on an oscillator shaft **23** to reciprocate a primary transformer piston **30** inside a hollow secondary piston **35**. The secondary piston **35** is rigidly secured at its lower end to a pile string **15** by a clamp **43**. The outer periphery of the secondary piston **35** is formed to constitute a reciprocating air spring piston within a vibration cushioning air spring cylinder **50**. The volumetric space between the ends of the air spring cylinder **50** is filled with compressible fluid such as air whereby the weight of the oscillator **10** and engines **21** is supported above the pile string **15** by the resilient air cushion between the upper surfaces of the secondary piston **35** and the upper end of the cylinder **50** when the pile **15** is being driven downwardly. Conversely, when the pile string **15** is being extracted or driven upwardly, tension is exerted in the cable **17** to load the lower surface of the secondary piston **35** by the lower end of the cylinder **50** via the pressurized air therebetween. Fundamentally, the air cushion within the cylinder **50** serves to vibrationally isolate the engines **21** and the internal gearing portion of the oscillator **10** from the resonant vibrations of the pile string **15**.

Most of the foregoing is disclosed in the prior art and is recited here only to make clear the position and environment of the present invention which is the pneumatic transformer broadly comprising the primary trans-

former piston 30 oscillating within a compressible fluid chamber in the secondary piston 35 to function as a spring of controllable stiffness between the oscillator shaft 23 and the pile 15.

Referring now to FIGURE 2 and the preferred embodiment of the invention, the oscillator shaft 23, which is rotatively coupled to the rotating eccentric weights 13 as shown in FIGURE 1, is provided on the lower end thereof with a primary transformer unit 30 comprising two axially aligned pistons 31 and 32. A spacer ring 33 is secured to both primary pistons 31 and 32 to provide axial spacing therebetween and to facilitate assembly of the primary piston unit. The pistons 31 and 32 and the spacer 33 may be secured to the oscillator shaft 23 by means of bolts, not shown, or other conventional fastener means. A bearing sleeve 34 may also be secured to the primary transformer unit 30 between adjacent ends of the oscillator shaft 23 and the upper primary piston 31.

The opposing or secondary component 35 of the transformer unit is comprised of a cylindrical piston body 36, the interior wall of which is shaped by radially inwardly extending, axially tapering projection 37. Upper and lower piston faces 38 and 39, respectively, are secured to the piston body 36 at their outer peripheries in a manner to close off at top and bottom upper and lower transformer chambers 44 and 45 respectively formed between the faces of projection 37 and the interior surfaces of the piston faces 38 and 39. To the inner periphery of the upper piston face 38 is secured a guide sleeve 40. A sealing sleeve 41 is sandwiched between the inner periphery of the lower piston face 39 and a sleeve bearing 42. The inner periphery of the piston face 39, the sealing sleeve 41, the bearing 42 and the pile coupling 43 are secured together by conventional fastener means, not shown. The axial spacing between the upper and lower faces of the tapering secondary unit projection 37, and the piston faces 38 and 39 forming the transformer cylinders 44 and 45 is sufficient to allow a full axial stroke of the oscillator shaft 23 as dictated by the stroke capacity of the sonic generator rotating eccentric weight mechanism, not shown.

The whole transformer assembly, comprising the primary transformer unit 30 in assembly with the secondary transformer unit 35, is sealingly and axially slidably enclosed by an outer cylinder, i.e., spring housing unit 50. Spring housing unit 50 is comprised of a cylinder wall 51, the inner surface of which slidably receives the outer peripheral surface of the secondary transformer unit 35. A gas-tight chamber is formed within the confines of the bore of the cylinder wall 51 by end walls 52 and 53. For convenience of fabrication, end spacers 54 and 55 are secured between the end walls 52 and 53 and the axially opposite ends of the cylinder wall 51. The cylinder wall 51, the end spacers 54 and 55 and the end walls 52 and 53 are secured together by conventional fastener means, not shown, to form a unit assembly for the spring housing unit 50. The upper end of the unit 50 is also secured to the lower end of the oscillator housing 24. Belleville type spring 56 provides a resilient connection between the integrated transformer-air spring assembly and the outer protective housing 25. Belleville spring 57 provides pre-load to the sealing ring 49 between the protective housing 25 and the lower air spring cylinder end wall 53.

The fit between the inner bore of the end wall 52 and upper guide sleeve 40 is such as to provide a gas-tight air spring chamber 58 between opposing surfaces of the end wall 52 and the upper secondary piston face 38 of the pneumatic transformer. Similarly, a lower air spring chamber 59 is formed between opposing faces of the lower end wall 53 and the lower secondary piston face 39 by the sealing fit between sealing sleeve 41 and the annular groove 60 in said lower end wall 53.

As described in the technical analysis of this invention above, it is necessary to provide a resilient, force-transmitting coupling between the oscillator shaft 23 and the pile 15. This function is served by pressurized gas, air, for example, in the transformer cylinders 44 and 45. Depending on the length and size of the pile and the earth conditions into which the pile is driven, the transformer coupling should have a particular spring rate. This may be illustrated by the fact that if the spring rate is too low the oscillator shaft and primary piston unit 30 will reciprocate at full stroke and optimum frequency without transmitting sufficient force to the pile to overcome the damping force of the system. If the spring rate is too high, the primary piston unit 30 and the pile 15 will effectively be coupled rigidly together and no transformer advantage may be gained thereby.

Since the driving conditions will vary even while driving a single pile, provision must be made for varying the spring rate of the transformer. The spring of the transformer coupling, being of the pneumatic type, results from the compression of the air contained in the transformer cylinders by the reciprocative displacement of the primary pistons 31 and 32 relative to the secondary transformer unit 35. The spring rate, therefore, is defined by the ratio of air pressures in a given transformer cylinder chamber on one side of a respective primary piston head at extreme positions of the primary piston stroke. In a closed compression chamber in which there is a constant weight of gas throughout the compression cycle, which is the instant case, the pressure ratio and hence, the spring rate, is also relative to the absolute weight of air present in the chamber. It may therefore be seen that the pressure ratio of a compression cycle in which the initial presure is atmospheric will be less than that of a pressure ratio having an initial pressure of 1000 p.s.i., for example, for the same volumetric displacement ratio. The explanation of this phenomena resides fundamentally in the fact that a greater weight of air is present in a given chamber volume at the higher pressure than at the lower pressure. Hence the spring rate of the transformer may be varied to suit changing conditions by changing the pressure in each chamber of the respective transformer cylinders at a particular point in the compression cycle.

To vary the pressure in respective chambers of transformer cylinders 44 and 45, air supply conduits 60, 61 and 62 are provided in the secondary transformer unit 35. Pressure regulated air is supplied to central conduit 60 through a transformer air supply line 63 which passes through the cylinder wall 51. Communication is continuously maintained between the supply line 63 and the central conduit 60 notwithstanding any relative axial or rotational displacement between the two conduits by an annular chamber 64 between the outer periphery of the secondary transformer unit 35 and the inner surface of the spring cylinder wall 51. The upper and lower limits of the annular chamber 64 are delineated by sealing rings 65 and 66 fitted to the piston body 36.

The point in the compression cycle at which supply air is admitted to the respective chambers of transformer cylinder 44 and 45 is determined by the position a sealing ring, 67, for example, fitted to the primary transformer unit 30, has with respect to a longitudinal inlet slot 68 cut in an adjacent portion of the secondary transformer unit 35. For the particular control point selected for description, when primary unit 30 moves down relative to the secondary unit 35 the upper edge of the sealing ring 67 passes over the slot 68 to allow communication between the conduit 61 and the upper chamber of transformer cylinder 44 via an annular supply chamber 69 and the slot 68. Flow of supply air begins as the primary piston 31 and the respective chamber volume approach their maximum limits. The same operational principle applies for the control of supply air from conduit 60 to the lower chamber of cylinder 44 and both chambers of cylinder 45 from conduits 60 and 62.

Due to the necessity of reducing the weight of air in the transformer cylinders as well as increasing it, exhaust

conduits **70** and **71** are provided in the secondary unit **35** which communicate with flexible exhaust lines **72** and **73** via annular chambers **76** and **77**. The control of air exhaust from the transformer cylinders **44** and **45** is performed by the sealing rings **78** and **79** fitted to primary pistons **31** and **32** sliding over exhaust ports **80** and **81**. With reference to primary piston **31** and the upper chamber of transformer cylinder **44**, as the piston **31** moves down relative to the secondary unit **35** and approaches the lower extreme position of its stroke, the upper sealing edge of the sealing ring **78** uncovers the exhaust port **80** relative to the upper chamber of cylinder **44**. It will be observed that both the inlet port **69** and the exhaust port **80** are open at the same time for a short cyclic interval. The precise timing of the air control valves should allow the exhaust port **80** to open momentarily sooner than the inlet port **69** for the purpose of facilitating a partial scavenging of the chamber on each cycle of the primary unit. This scavenging and consequent radial air flow across the transformer chamber is necessary to cool the piston **31** and the the surrounding secondary unit **35**.

Since the weight of exhausted air through the ports **80** and the like to atmosphere, for example, is relatively constant irrespective of the prevailing pressure within the transformer cylinder, it is possible to control the pressure in the transformer chamber by merely admitting fresh air through inlet port **69** at a greater or lesser rate than it is exhausted.

One object of this invention being to magnify the force exerted against the pile **15**, it follows that to do so also magnifies the force on all that is integrally connected with the pile. For this reason, the transformer secondary unit **35** is constructed as a piston to "float" between air spring chambers **58** and **59**. In this manner the oscillator housing **24** and other sonic generator structure is insulated from the higher order shaking forces generated within the secondary unit **35** and pile **15**. Pressure controlled air is admitted to the spring chambers **58** and **59** via supply lines **82** and **83** and conduits **84** and **85** in the secondary unit **35**. Air may be exhausted from the chambers **58** and **59** when the supported load thereon is diminished and residual air pressure expands one of the respective spring chambers and pushes the secondary unit **35** past a central position opening a conduit **84** or **85** to communication with a respective one of the exhaust lines **86** or **87**. The position of sealing rings **88** and **89** relative to supply and exhaust lines **82** and **86** controls the direction of air flow relative to the spring chamber **58**. Sealing rings **90** and **91** perform the same air flow control function relative to spring chamber **59**. In this manner, the air pressures in spring chambers **58** and **59** is continually adjusted to keep the secondary unit **35** generally centered within the spring housing unit **50**.

In addition to resiliently supporting the weight of the sonic driver **10** on the pile **15**, a function performed primarily by the air spring of chamber **58**, the bias load on the pile **15** may be reversed in order to extract a pile. In this case, the upward load exerted on the drive **10** by pulling on the suspension cable **17** with the winch **16** is resiliently transmitted to the pile **15** by the pressurized air in spring chamber **59**. Hence, the bias load on the pile **15** necessary to urge it either in or out of the ground is resiliently insulated from the shaking forces generated within the pile by the primary unit **30** irrespective of which direction the pile is being driven.

To provide a self-aligning support between the piling **15** and the engine supporting platform **22**, the spherical bearing **56** is provided between the spring housing unit **50** and the outer protective housing **25** to which the engine platforms are rigidly secured.

It should also be observed that all units comprising the transformer coupling, support spring and pile **15** are circularly concentric about the axis **26**. Consequently, the pile **15** and its associate secondary unit **35** are free to rotate about the axis **26** independently of the oscillator and housing structure, an unobvious and desirable facet of the machine.

In operation, the pile **15**, in assembly with the sonic driver **10**, is situated over the desired location on the ground with the lower end of the pile in engagement with the earth. Part or all of the weight of the sonic driver assembly including the engines **21** is allowed to come to rest on the pile **15** via the air spring chamber **58**. Power is then applied to the primary unit **30** via the engines **21**, the rotating oscillator eccentrics **13**, and the oscillator shaft **23**, thereby causing the primary pistons **31** and **32** to reciprocate within the transformer cylinders **44** and **45**. Pressurized air is admitted to the respective chambers of cylinders **44** and **45** via inlet conduits **63**, **60**, **61** and **62**. When the volume of a respective transformer cylinder chamber is in the maximum range a pressure level is established by the balance of air flows in and out of the chamber. As the volume of the chamber is diminished by further movement of the respective primary piston, the inlet and outlet control ports, **69** and **80**, for example, are closed and the air trapped within the chamber is compressed adiabatically to a degree determined by the stroke of the primary unit **30**. The force of air pressurization is transmitted to the secondary transformer unit **35** and finally to the pile **15**. The desired power to the pile **15** may be established by adjusting the speed of the engines to a value resulting in the optimum reciprocation frequency of the oscillator shaft **23** at maximum stroke. As the pressure ratio with the transformer chambers is increased by admitting more air thereto, the force of compression is transmitted to a secondary unit **35** and finally to the pile **15**. Hence, the oscillator and primary unit **30** is allowed to reciprocate at a stroke amplitude independent of that of the pile **15** to deliver a power value that would exceed the stress limitations of the oscillator if it delivered this same power value at the stroke amplitude required by the pile.

Although there has been disclosed only one preferred embodiment of the present invention, it is obvious to those of ordinary skill in the art to provide other valve and piston arrangements to achieve the same objectives. For example, one may provide a single primary piston element to transfer the shaking forces from the oscillator shaft **23** to the pile **15**. Also, the weight bias on the pile may be of such magnitude as to require two or more air spring suspension pistons and chambers. In other possible embodiments of this invention different means or arrangements may be used to conduct the flow of air in or out of the transformer and/or spring cylinders.

It will therefore be understood that various omissions and substitutions in the form of details of the devices illustrated and their operation may be made by those skilled in the art without departing from the spirit of the disclosure. Consequently, it is intended that the scope of this invention be limited only as indicated by the scope of the following claims.

I claim as my invention:

1. A pile driver apparatus for driving or extracting piles comprising:

an elastic wave generator;

a pile member;

housing means rigidly connected to the upper end of said pile member, said housing means having first piston chamber means therein;

first piston means slidably mounted in said first piston chamber means and operably secured to said wave generator for movement therewith;

said first piston means being operatively positioned at all times in said first piston chamber means intermediate the ends thereof and dividing said first piston chamber means into first and second variable volume means;

first fluid conduit means communicating a source of fluid pressure with said first and second variable volume means;

second fluid conduit means communicating said first and second variable volume means with the space outside thereof;

first flow control means in said first conduit means;

second flow control means in said second conduit means;

said first and second flow control means substantially blocking fluid flow through said first and second conduit means when said first piston means is in a neutral position within said first piston chamber means;

said first and second flow control means allowing fluid communication through said first and second conduit means with said first variable volume means when said first piston means is in a first position away from said neutral position, said fluid communication between said conduit means and said second variable volume means remaining blocked;

said first and second flow control means allowing fluid communication through said first and second conduit means with said second variable volume means when said first piston means is in a second position away from said neutral position, said fluid communication between said conduit means and said first variable volume means remaining blocked; and

said first and second positions of said first piston means being in axially opposite direction from said neutral position.

2. Apparatus as described by claim 1 wherein said second fluid conduit means comprises aperture means in the wall of said first piston chamber means and said second flow control means comprises radially biased piston ring means circumferentially positioned around the periphery of said first piston means, said piston ring means being of sufficient width to substantially block fluid communication between said aperture means and either of said variable volume means when said first piston means is in said neutral position.

3. Apparatus as described by claim 1 wherein fluid pressure in said variable volume means biases said first piston means to said neutral position.

4. Apparatus as described by claim 3 wherein said first piston means comprises a shaft extending through a bore in said housing means and operably secured to said elastic wave generator, said first flow control means comprising cooperative seal and conduit means on said shaft and in said bore.

5. Apparatus as described by claim 4 wherein said second fluid conduit means comprises aperture means in the wall of said first piston chamber means and said second flow control means comprises radially biased piston ring means circumferentially positioned around the periphery of said first piston means, said piston ring means being of sufficient width to block fluid communication between said aperture means and either of said variable volume means when said first piston means is in said neutral position.

6. Apparatus as described by claim 1 additionally comprising:

platform means;

prime mover means mounted on said platform means for driving said elastic wave generator;

second piston chamber means forming a portion of said platform means; and

second piston means formed outwardly on said housing means and slidably mounted within said second piston chamber means and dividing said second piston chamber means into third and fourth variable volume means, said third and fourth variable volume means containing compressible fluid means whereby said prime mover and platform means are supported by said second piston means but substantially vibrationally isolated therefrom.

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U.S. Cl. X.R.

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