United States Patent

Bodine

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[45] **Aug. 15, 1972**

[54] SONIC DRILLING DEVICE

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[52] **U.S. Cl.** **175/56,** 173/162

[51] **Int. Cl.** **E21c 3/08**

[58] **Field of Search** 175/55, 56; 173/162, 139, 49

[56] **References Cited**

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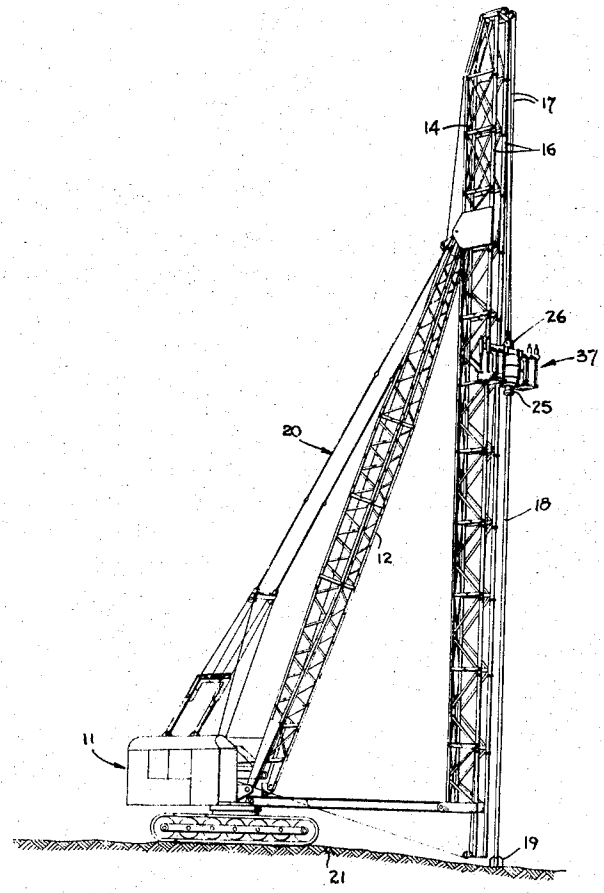
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[57] **ABSTRACT**

A sonic drive unit including an orbiting mass oscillator for generating vibratory energy which is driven through a torsionally stiff rotary drive shaft by an engine contained within the unit is supported for vertical motion. The drive unit has an elastically vibratory column extending vertically downward from the bottom thereof, the column having a drill bit as its end for drilling into earthen material. The drive unit includes an air spring structure which provides vibration isolation of the vibratory energy of the supper end of said column from the support and from the drive engine; and which air spring also affords self-centering, with variations in downward loading, that automatically achieves accurate control of the drill bit bias pressure during drilling. Sonic vibratory energy is transferred from the oscillator to the column and drill bit to implement the drilling operation as the drive unit, by virtue of its weight force, biases the drill against the earthen material being drilled.

5 Claims, 5 Drawing Figures



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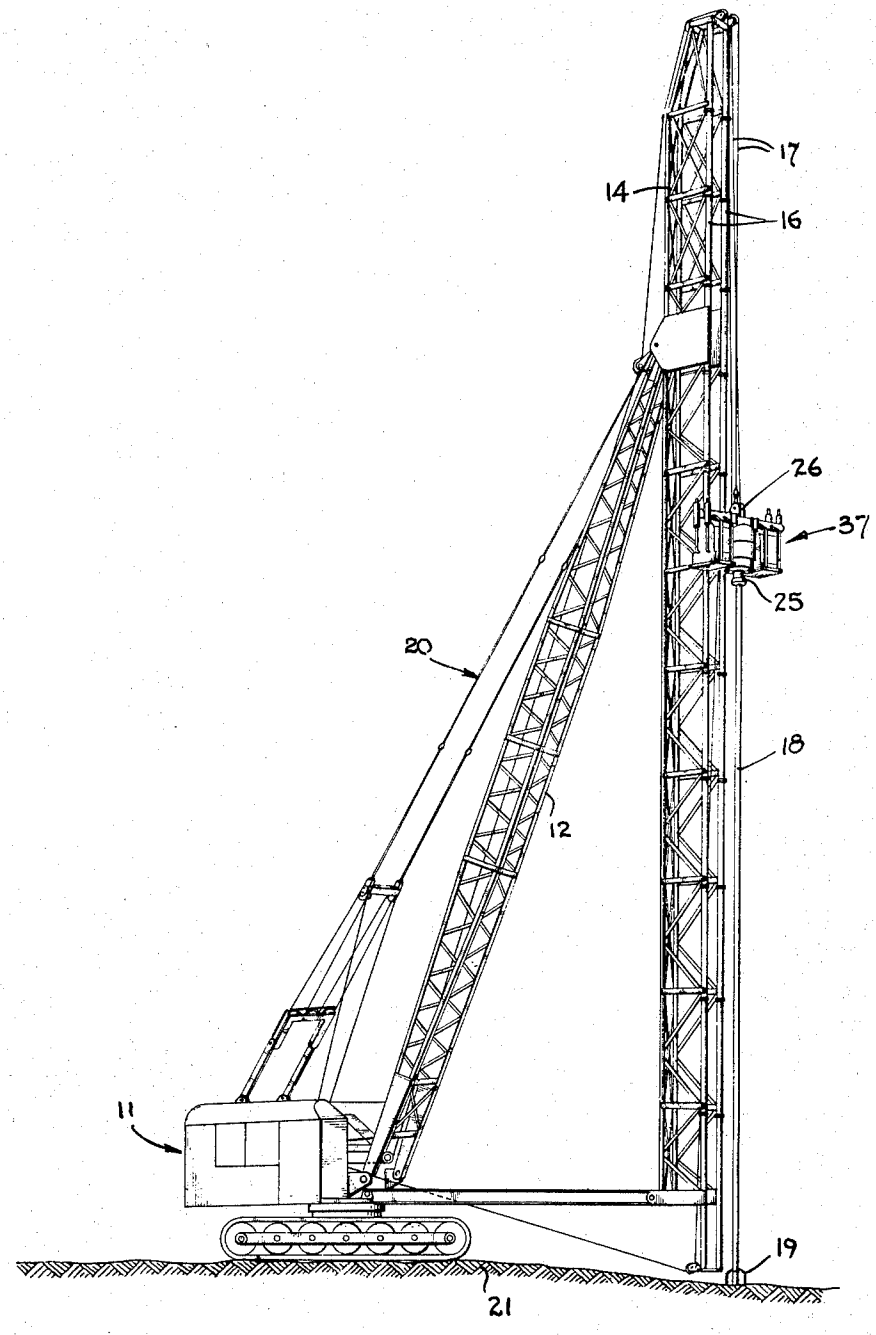


Fig. 1

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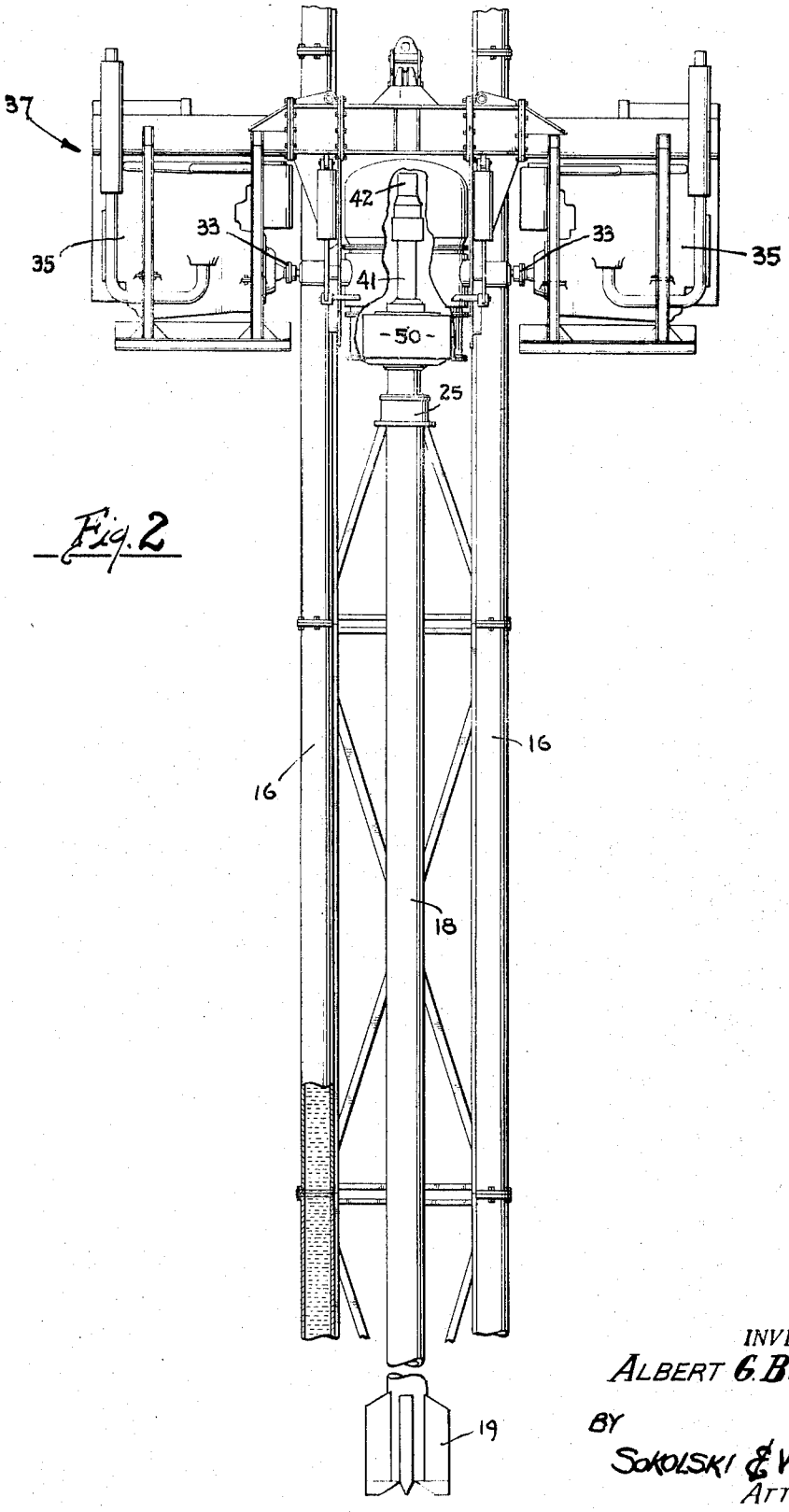


Fig. 2

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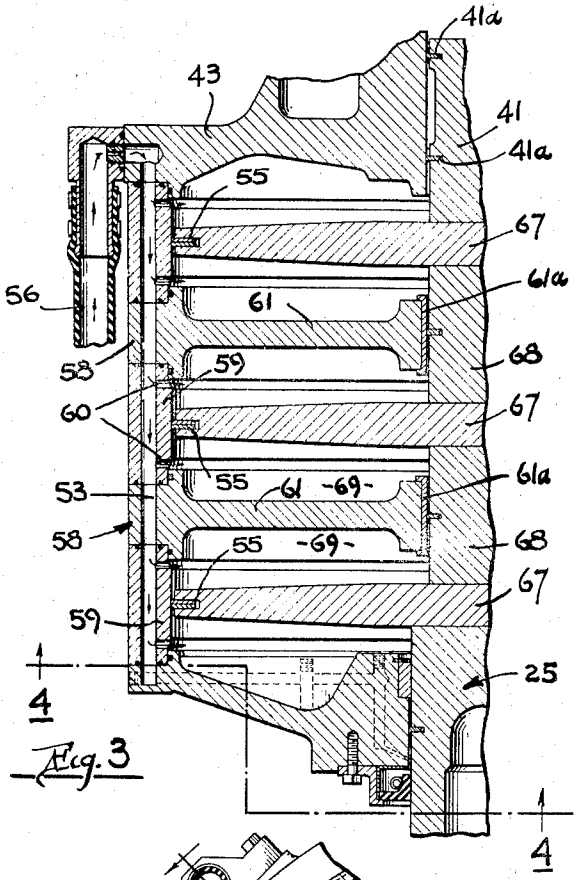


Fig. 3

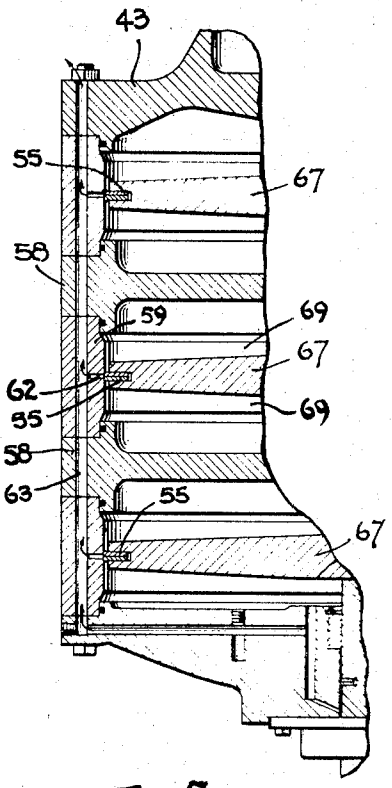


Fig. 5

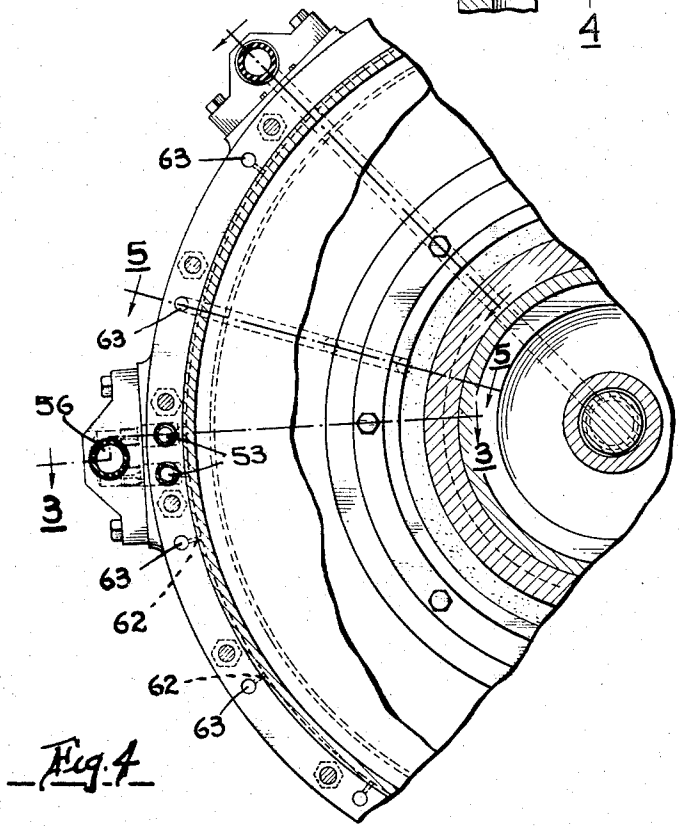


Fig. 4

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SONIC DRILLING DEVICE

This invention relates to the drilling of earthen material, and more particularly to such drilling wherein sonic vibratory energy is utilized.

In my U.S. Pat. No. 3,189,106, a sonic pile driver is described which utilizes a sonic driver having a self-contained engine drive and an orbiting mass oscillator for generating sonic vibratory energy. This driver is supported for vertical motion along a pair of legs or rails which are part of "leads" extending vertically from a vehicle boom. This pile driver has several special features which distinguish it, these including an air spring vibration isolator in the drive unit, and an integral drive for the oscillator utilizing positive gear drive and a torsionally rigid drive shaft from the engine.

The present invention is involved with the modification of the device described in the aforementioned patent for use as a drill. It has been found that by virtue of the features afforded by the basic isolator and the torsionally rigid drive structure of my aforementioned patent, that unique and unexpected results are obtained where this structure is modified for use in conjunction with a drill, making for significant improvements in operation as compared with prior art drilling devices. Thus, it has been found that the air piston arrangement which has a self-centering feature gives accurate control of drill bit bias pressure against the bottom of the hole during drilling to optimize cyclic fatigue force in the earthen material being drilled. Further, the employment of an integral engine drive with direct positive gear drive having a torsionally rigid drive shaft makes the engine and drive combination function as a stabilizing flywheel enabling the oscillator to lock to an optimum resonant frequency. This is uniquely effective in drilling hard rock where the shock impact tends to upset the frequency. Still further, the track-like members in the "leads" provided for guiding the drive unit in the structure of the invention, in some forms, maintains the vertical positioning of the drive mechanism, thus minimizing the generation of unwanted lateral vibration.

It is therefore the principal object of this invention to provide an improved sonic drilling device capable of self-centering the drive mechanism to accurately control cutting bias.

It is another object of this invention to provide an improved sonic drilling device utilizing a drive unit which is vertically guided on a track mechanism so as to minimize the generation of lateral vibrations.

It is still another object of this invention to provide an improved sonic drilling device utilizing a drive unit in which the oscillator and prime mover are integrally combined and coupled together through a torsionally rigid drive shaft so as to maintain the frequency of operation of the oscillator with changes in the load.

Other objects of this invention will become apparent as the description proceeds in connection with the accompanying drawings, of which:

FIG. 1 is a side elevational view illustrating one embodiment of the device of the invention,

FIG. 2 is a side elevational view illustrating the drive unit and associated structure of the embodiment of FIG. 1,

FIG. 3 is a cross sectional view illustrating the air piston mechanism of the embodiment of FIG. 1, taken along the plane indicated by 3—3 in FIG. 4;

FIG. 4 is a cross sectional view taken along the plane indicated by 4—4 in FIG. 3, and

FIG. 5 is a cross sectional view taken along the plane indicated by 5—5 in FIG. 4.

It has been found most helpful in analyzing the device of this invention to analogize the acoustically vibrating circuit utilized to an equivalent electrical circuit. This sort of approach to analysis is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonics" by Hueter and Bolt, published in 1955 by John Wiley and Sons. In making such an analogy, force F is equated with electrical voltage E, velocity of vibration u is equated with electrical current i, mechanical compliance C_m is equated with electrical capacitance C_e mass M is equated with electrical inductance L, mechanical mechanical resistance (friction) R_m is equated with electrical resistance R and mechanical impedance Z_m is equated with electrical impedance Z_e.

Thus, it can be shown that if a member is elastically vibrated by means of an acoustical sinusoidal force $F_0 \sin\omega t$ (ω being equal to 2 π times the frequency of vibration), that

$$Z_m = R_m + j(\omega M - 1/\omega C_m) = F_o \sin\omega t/tu$$

Where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance Z_m is equal to the mechanical resistance R_m, the reactive components ωM and $1/\omega C_m$ cancelling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, power factor is unity, and energy is more efficiently delivered to a load to which the resonant system may be coupled.

It is important to note the significance of the attainment of high acoustical "Q" in the resonant system being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of power. As for an equivalent electrical circuit, the "Q" of an acoustically vibrating system is defined as the sharpness of resonance thereof and is indicative of the ratio of the energy stored in each vibration cycle to the energy used in each such cycle. "Q" is mathematically equated to the ratio between ωM and R_m. Thus, the effective "Q" of the vibrating system can be maximized to make for highly efficient, high-amplitude vibration by minimizing the effect of friction in the system and/or maximizing the effect of mass in such system.

In considering the significance of the parameters described in connection with equation (1), it should be kept in mind that the total effective resistance, mass, and compliance in the acoustically vibrating system are represented in the equation and that these parameters may be distributed throughout the system rather than being lumped in any one component or portion thereof.

It is also to be noted that orbiting-mass oscillators are utilized in the implementation of the invention that automatically adjust their output frequency and phase to maintain resonance with changes in the characteristics of the load. Thus, in the face of changes in the effective mass and compliance presented by the load with changes in the conditions of the work material as it is sonically excited, the system automatically is maintained in optimum resonant operation by virtue of the "lock-in" characteristic of applicant's unique orbiting mass oscillators. Furthermore in this connection the or-

biting mass oscillator automatically changes not only its frequency but its phase angle and therefore its power factor with changes in the resistive impedance load, to assure optimum efficiency of operation at all times. The vibrational output from such orbiting-mass oscillators also tends to be constrained by the resonator to be generated along a controlled predetermined coherent path to provide maximum output along a desired axis.

Briefly described, one form of the device of the invention comprises a drive unit which rides along and is guided by a vertical track member formed in "leads" which are vertically suspended from a vehicle boom. The drive unit includes a sonic oscillator which is driven by an engine drive which is coupled to the oscillator through a torsionally rigid drive shaft so as to provide close feedback from the oscillator to the engine, whereby the oscillator frequency tends to remain constant, particularly with cyclic changes in the torque load thereon. The output of the oscillator is coupled to a column which has a drill bit at the opposite end thereof. The drive unit includes an air spring which tends to self-center the drive shaft and bit with changes in load during the drilling operation and thus automatically controls the bias applied to the drill. The oscillator is preferably operated at a frequency such as to cause resonant elastic vibration of the column and drill bit.

Referring now to FIG. 1, an embodiment of the device of the invention is illustrated. Vehicle **11** has a boom **12** which extends therefrom, from which "leads" **14** in the form of a box frame beam structure are suspended. The leads have a pair of tubular front legs **16** which form tracks along which sonic drive unit **37** rides. Sonic drive unit **37** is suspended from the lead structure and its vertical position controlled by means of cable **17** and block and tackle **26**, cable gear **20** being utilized to raise and lower boom **12**. Column **18**, which is fabricated of an elastic material such as steel, has a drill bit **19** at one end thereof and is coupled at the other end thereof to sonic drive unit **37** by means of coupler **25**.

In operation, the boom and leads are positioned so as to bring drill **19** against the surface of the earthen material **21** to be drilled, as shown in FIG. 1. The drill **19** is biased against the earthen material by the weight of the sonic drive unit and the column, the cable **17** being permitted to play out as the drill moves deeper into the ground.

Drive unit **37**, as to be explained in connection with FIG. **2**, comprises an orbiting mass oscillator for generating sonic energy, this oscillator being driven by an engine drive. The oscillator is preferably driven at a frequency such as to set up resonant elastic vibrations along the longitudinal axis of column **18** which as noted in the discussion at the beginning of this specification provides high-level sonic energy at the drill bit which efficiently implements the drilling action.

Turning now to FIG. 2, the drive unit of the device of the invention is illustrated. This structure will be but briefly described herein, the detailed description thereof in my Patent No. **3,189,106** being incorporated by reference. Orbiting mass oscillator **42** is supported on support column **41** directly attached to the central portion of air spring unit **50** which in turn is coupled to column **18** by means of coupler **25**. The drive shafts of internal combustion engines **35** are coupled through associated drive couplings **33** to appropriate gear trains (not shown) which in turn are coupled to the drive shafts of oscillator **42**, as fully explained in my aforementioned patent. The coupling between the engines and the oscillator is a torsionally rigid one whereby the engine and drive mechanism functions as a stabilizing flywheel on the oscillator which tends to hold the oscillator frequency to a predesired frequency for optimum resonant operation of the drill shaft and drill.

As to be explained more fully in connection with FIGS. **3–5**, air spring **50** provides a self-adjusting spring coupling between support column **41** (as well as the oscillator **42** and column **18**, directly coupled thereto) and the frame of the drive unit which responds to variations in drill bias. The air spring also serves to provide vibration isolation between the oscillator and the members which form part of the vibration system and the remaining structure so as to minimize the dissipation of the vibrational energy.

Referring now to FIGS. **3–5**, the self-centering air spring of the device of the invention is illustrated. Housing **58** has a plurality of partition walls **61** formed therein, the partition walls having bushings **61a** with O-rings therein which form a pressure seal with the walls of centrally positioned washers structure **68**. Washers units **68** are connected between pistons **67**, the assembly of washers and pistons being bolted on the top end to column **41** on which the oscillator rests and on the bottom end to the top portion of hydraulic coupler **25**. The housing also has a plurality of spaced cylindrical portions **59** therein against which the ends of pistons **67** abut, a pressure seal being formed between the walls of cylindrical portions **59** and pistons **67** by means of O-rings **55**. Pressurized air is provided to hose **56**, this air being channelled through channel **53** formed between the end walls of separators **61** and the walls of the housing. Pressurized air is passed from channel **53** through apertures **60** to the spaces **69** between pistons **67** and separators **61**. It is to be noted at this point that the load of the entire drive unit, except for the oscillator, the support columns and the members attached thereto, is borne by the air spring housing **58**, this load being transferred to the housing through cover plate **43**. Column **41** has a certain amount of vertical freedom of motion relative to plate **43**, O-rings **41a** being provided at the interface between these two members to provide an air seal therebetween.

Referring now particularly to FIGS. **4** and **5**, apertures **62** are provided in cylindrical portions **59**, these apertures communicating with vertical channels **63** formed in the housing wall. With the pistons centered as indicated in FIG. **5**, apertures **62** are closed at their inner ends. However, in the event that the bias on the bit should increase such as to move the drive shaft and along with it the pistons upwardly relative to the housing, the inner ends of channels **62** will become uncovered, providing communication between the cavities **69** and channel **63**, thereby permitting air to escape from the cavities underneath the pistons providing a pressure differential between the upper and lower portions of the pistons. The greater pressure on the upper portion of the pistons will provide an increased bias force on the pistons in a downward direction, thereby

tending to restore the drill to its original position. In this manner, bias force is applied to the bit automatically with increases in the loading thereon. It also can be seen that if the downward loading on the housing 58 should exceed a predetermined value, the housing will be moved downwardly relative to the piston, establishing an air pressure differential of the same type just described tending to restore the column and drill bit to their original positions. The air spring also provides vibrational isolation between the oscillator and its associated vibration system and the remainder of the drive unit, thus minimizing the dissipation of vibrational energy in the surrounding components.

It thus can be seen that the device of the invention provides an improved sonic drilling device in which accurate control drill bias pressure against earthen material being drilled is automatically provided. Further, vertical guidance of the drill drive shaft is afforded to minimize lateral vibration of the shaft. Also, torsionally rigid coupling is provided between the prime mover and the oscillator tending to maintain the frequency of operation of the oscillator to an optimum desired value with changes in the load.

I claim:

1. In a sonic drill for boring into earthen material,

an elongated elastic column member,

a cutter bit attached to the lower end of said column, said cutter bit having a greater diameter than that of said column so as to permit passage of cuttings alongside the shaft, and

a sonic drive unit connected to the other end of said column, said sonic drive unit including a housing, an orbiting mass oscillator supported in said housing, oscillator coupling means for rigidly coupling said oscillator to said column, prime mover means for rotatably driving said oscillator at a frequency such as to set up resonant elastic vibrations of said shaft, and air spring means for providing resilient coupling between said oscillator and said drive unit housing, said air spring means being adapted to provide a restoring force which tends to automatically maintain the relative vertical positioning between said oscillator support means and said housing with variations in the loading on these two components.

2. The device of claim 1 wherein said air spring means comprises a plurality of pistons and means for providing pressurized air to the opposite sides of said pistons, vertical relative motion occurring between said pistons and said drive unit housing, and orifice means formed in said housing for permitting air to escape from one side of said pistons to create a pressure differential to restore the pistons and housing to their original relative positions.

3. The device of claim 1 and additionally including means for vertically guiding and positioning said drive unit so as to minimize lateral movement of said column.

4. The device of claim 1 and further including means for torsionally rigidly coupling said prime mover to said oscillator.

5. The device of claim 3 and additionally including means for torsionally rigidly coupling said prime mover to said oscillator.

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