United States Patent

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Continuation of application Ser. No. 531,950, Mar. 4, 1966, now abandoned.

[54] **CONTINUOUS EXCAVATING AND CONVEYOR MECHANISM EMPLOYING SONIC ENERGY**
8 Claims, 23 Drawing Figs.

[52] **U.S. Cl.** ..... **37/1,** 37/58, 37/80 R, 172/40, 299/14, 198/70, 198/74, 302/17, 302/64
[51] **Int. Cl.** **E02f 3/88,** E02f 3/62, E21c 37/20
[50] **Field of Search** ..... 299/14; 175/55; 172/40; 37/DIG. 18, 61, 80 R, 19, 58, 1; 15/379; 302/17, 64

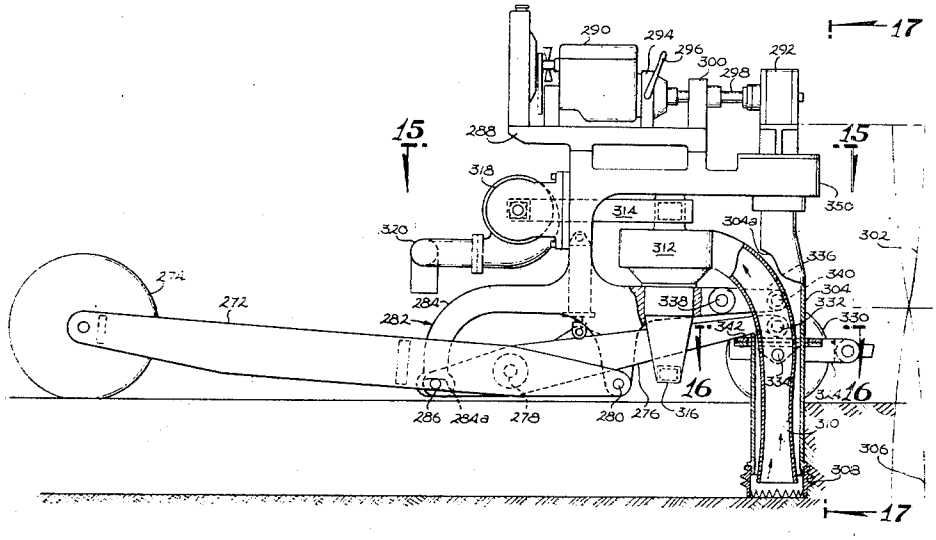
[56] **References Cited**

UNITED STATES PATENTS

130,807	8/1872	Johnson	37/19 X
491,843	2/1893	Kauser	37/61
1,340,445	5/1920	Huelsdonk	37/58
2,706,450	4/1955	Bodine, Jr.	103/1
2,902,937	9/1959	Bodine, Jr.	103/76
2,953,095	9/1960	Bodine	103/1
2,959,805	11/1960	Bodine, Jr.	15/379
3,124,076	3/1964	Bodine, Jr.	103/43
3,232,669	2/1966	Bodine, Jr.	299/37
3,255,699	6/1966	Bodine, Jr.	103/1
3,256,695	6/1966	Bodine, Jr.	172/40 X
3,461,969	8/1969	Bodine, Jr.	172/40 X

Primary Examiner—Robert E. Pulfrey
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ABSTRACT: A combination excavator and conveyor which employs high-power sonic energy to loosen and fluidize the earthen material which is to be removed from the excavating area. Gyrating or orbital-mass sonic oscillators impart resonant standing waves to the earth cutting portion of the excavator as well as to the conveyor which carries the excavated material to a discharge location. Self-propelled and towed versions are shown. Also illustrated is an integral excavating-conveying device in which the toothed end of a sonically excited conduit is used to "nibble" the earthen surface and thereafter fluidize and propel the loosened material through the sonically vibrated conduit to a discharge location.



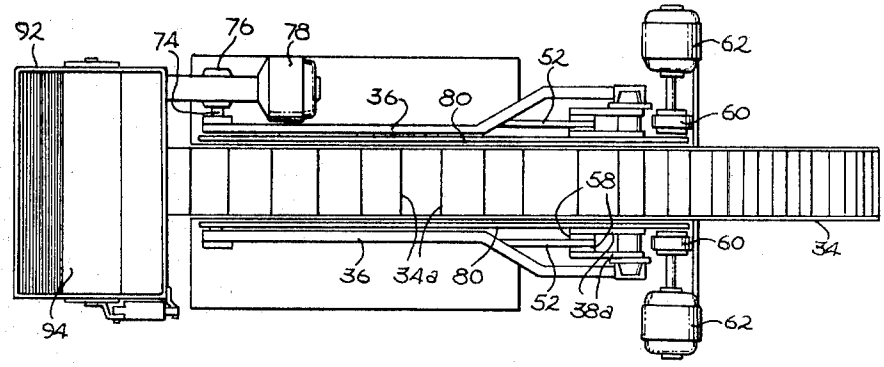


FIG. 2

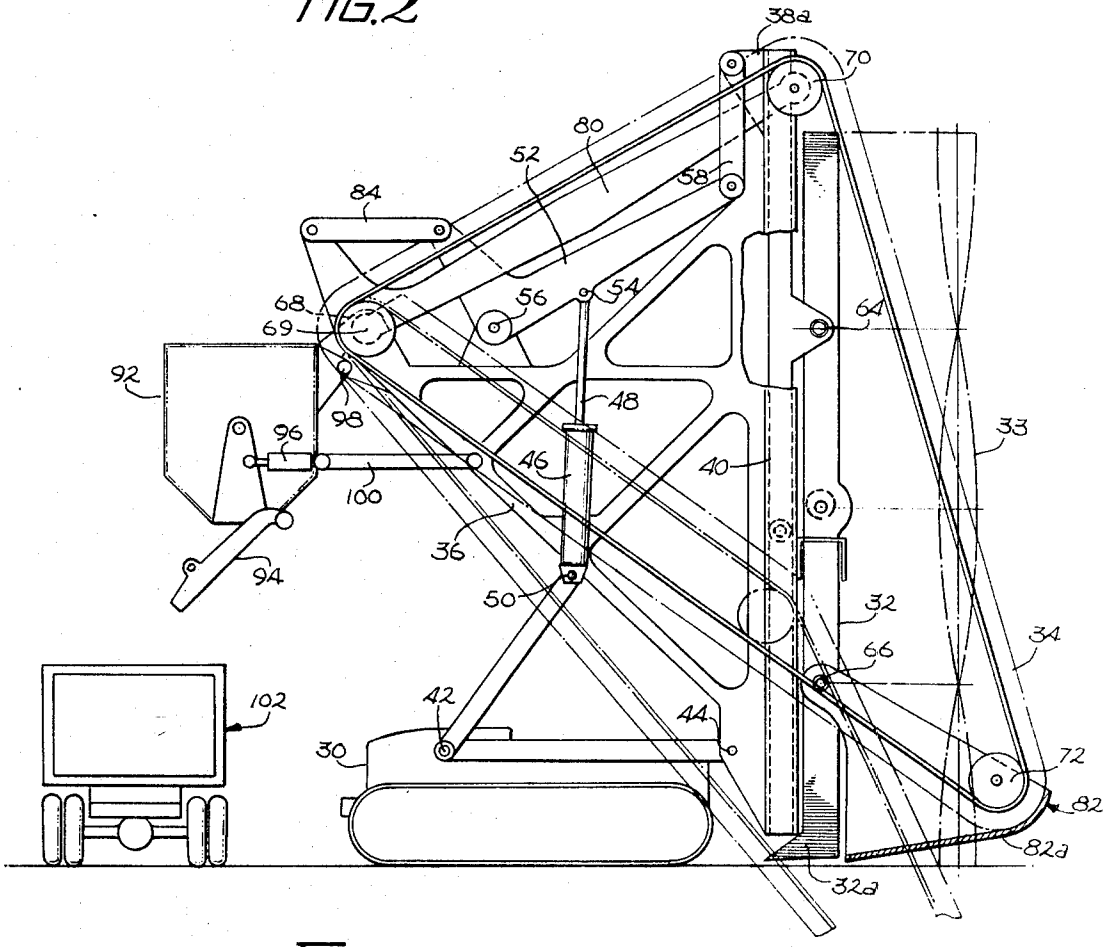


FIG. 1

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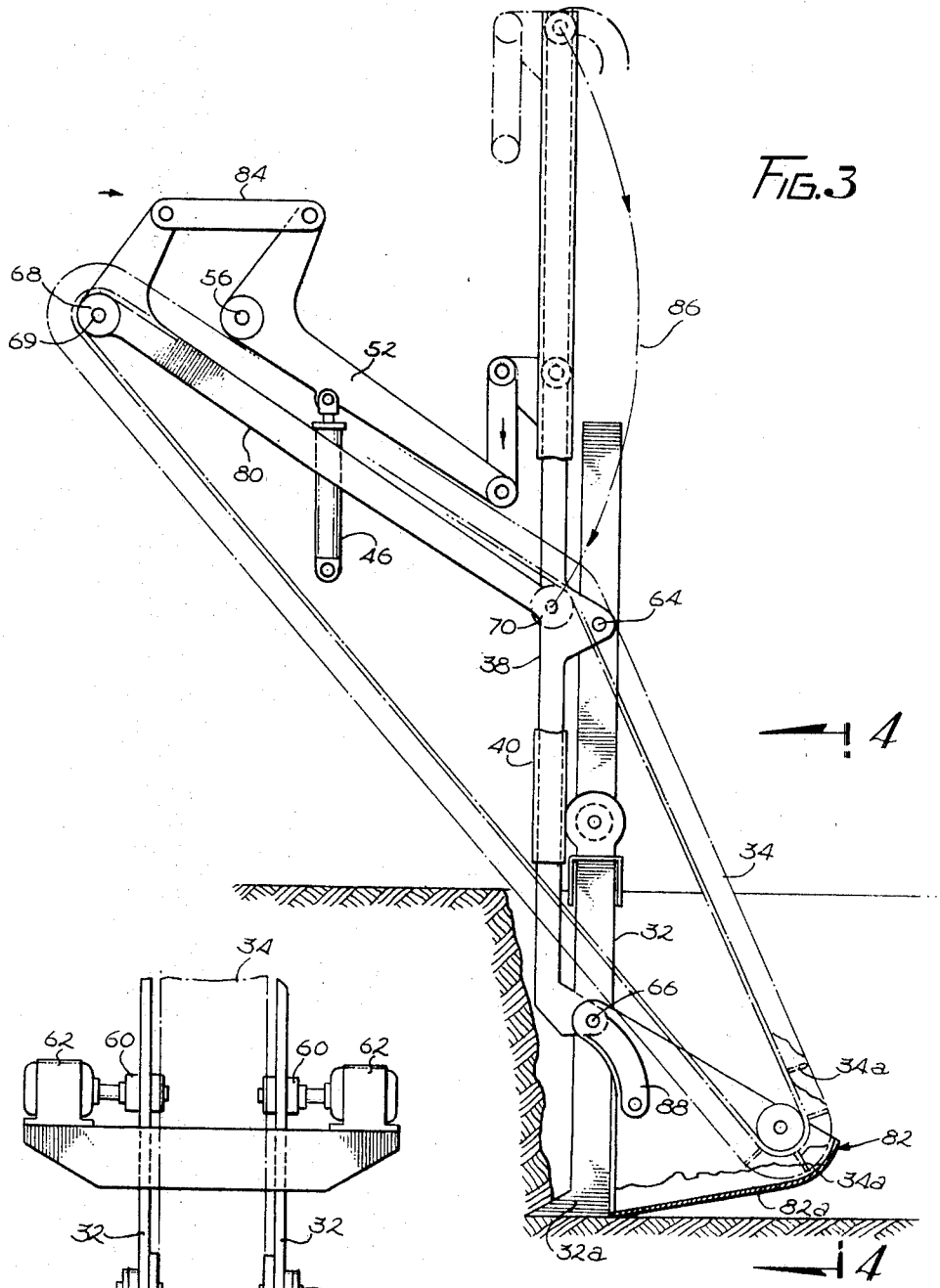


FIG. 3

FIG. 4

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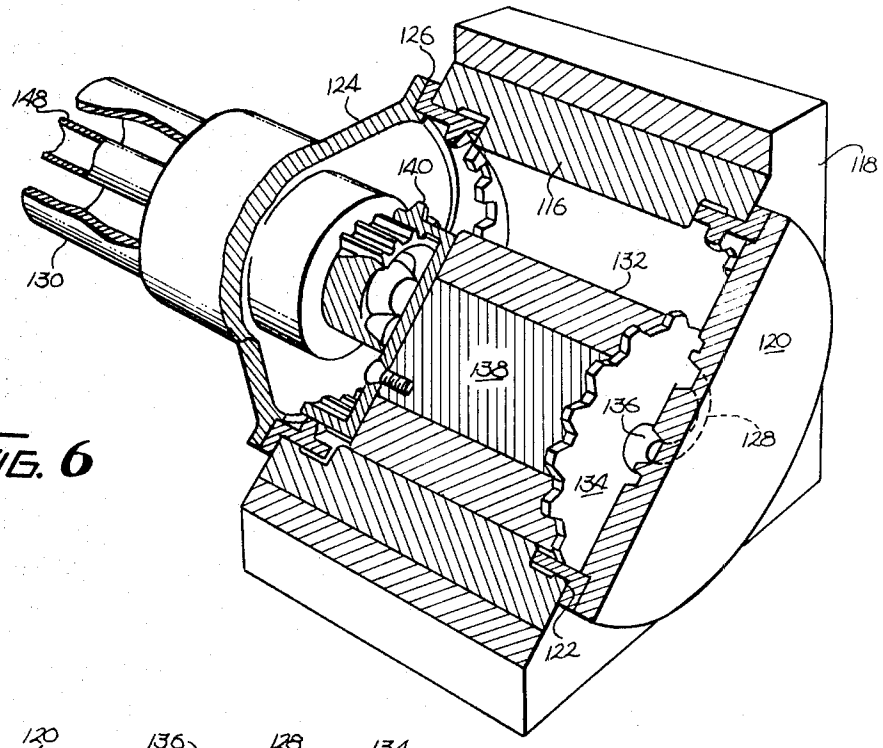


FIG. 6

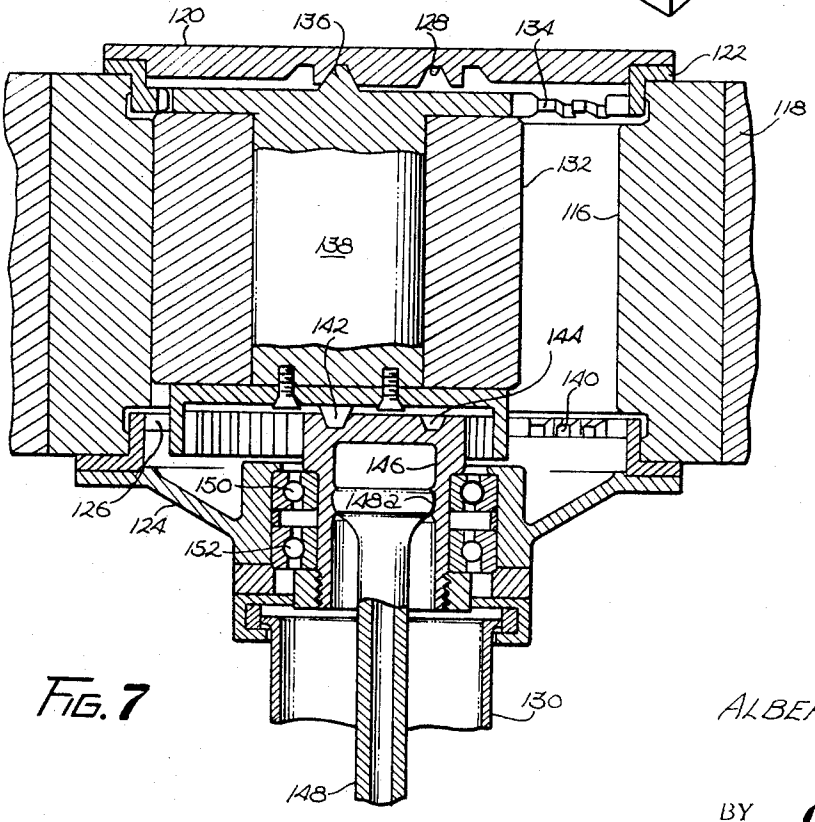


FIG. 7

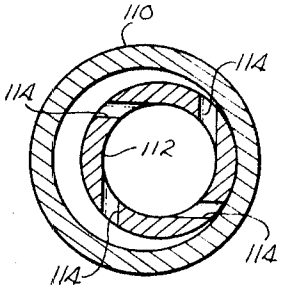


FIG. 5

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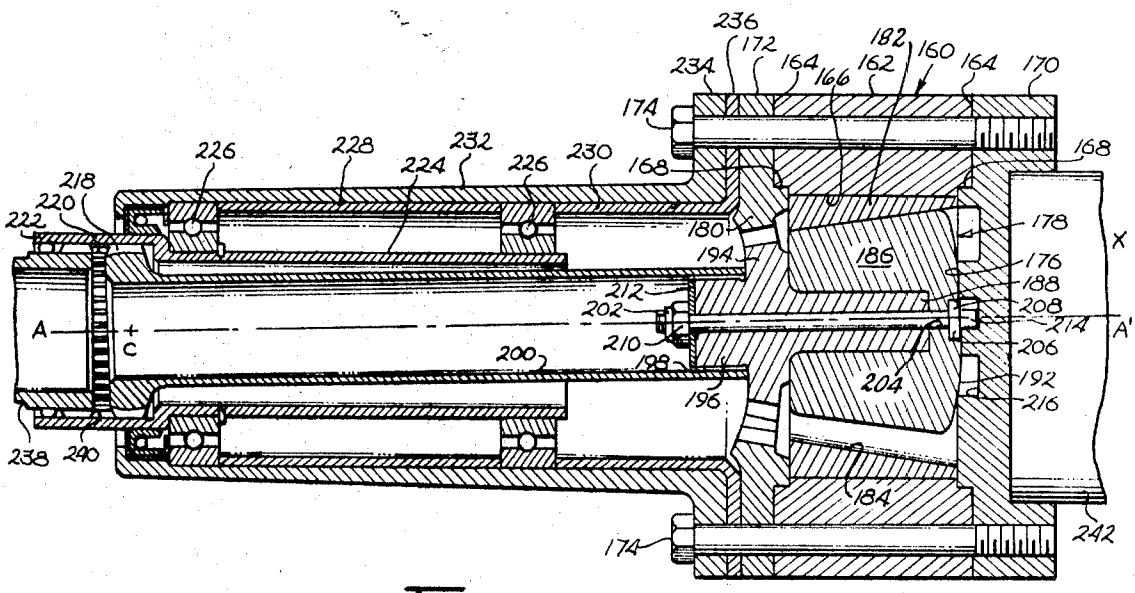


FIG. 8

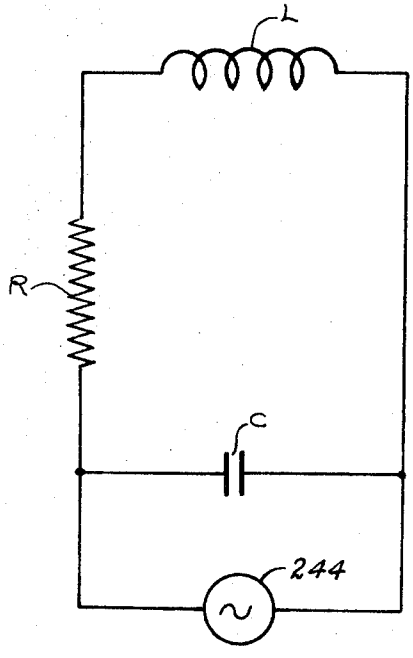


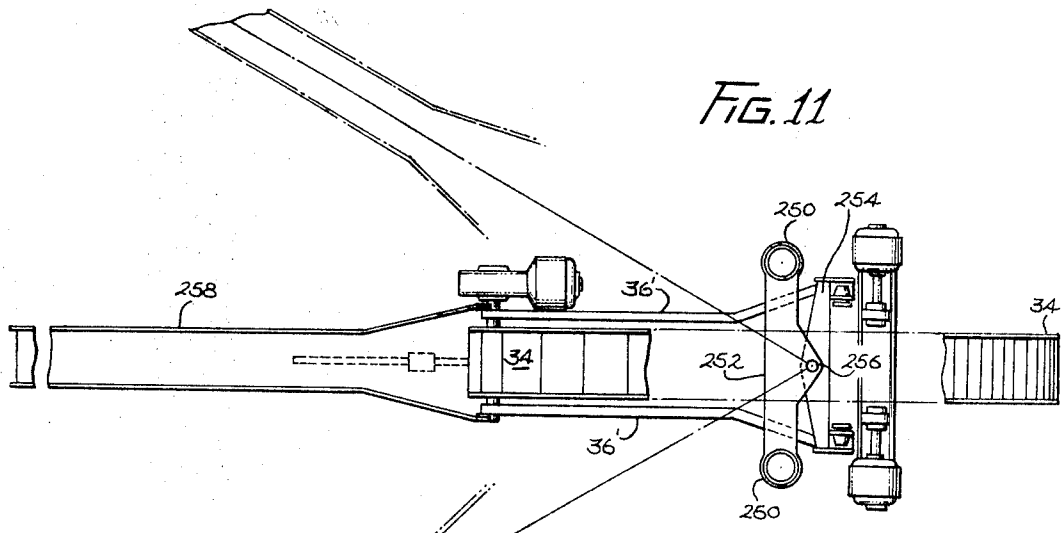
FIG. 9

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FIG. 11



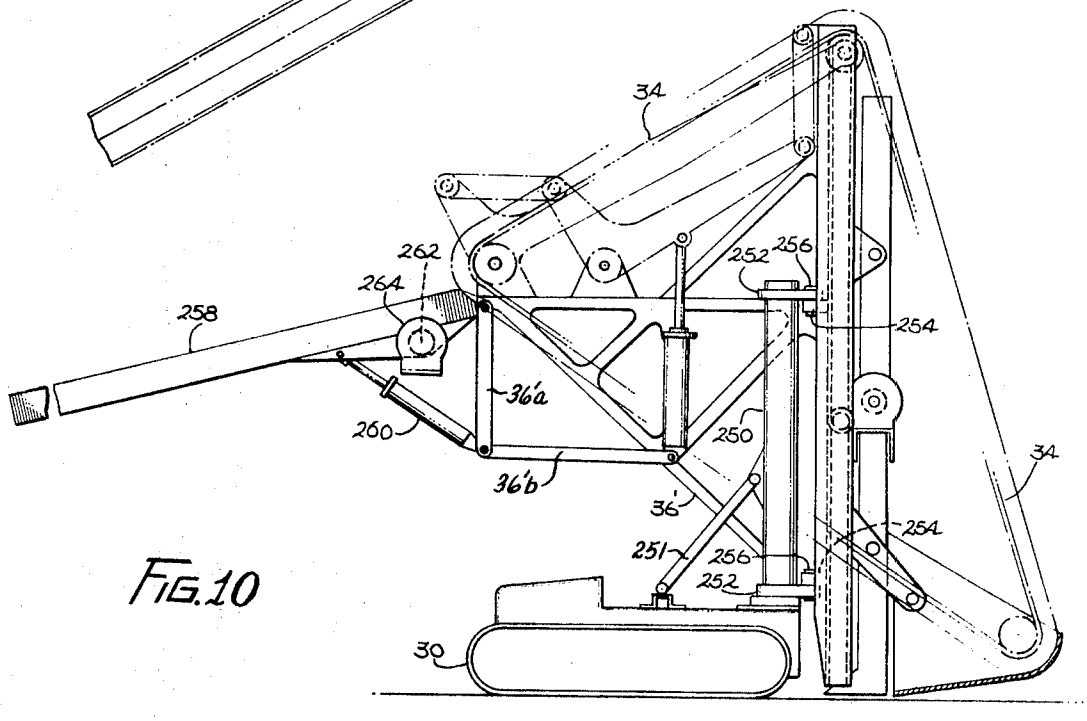


FIG. 10

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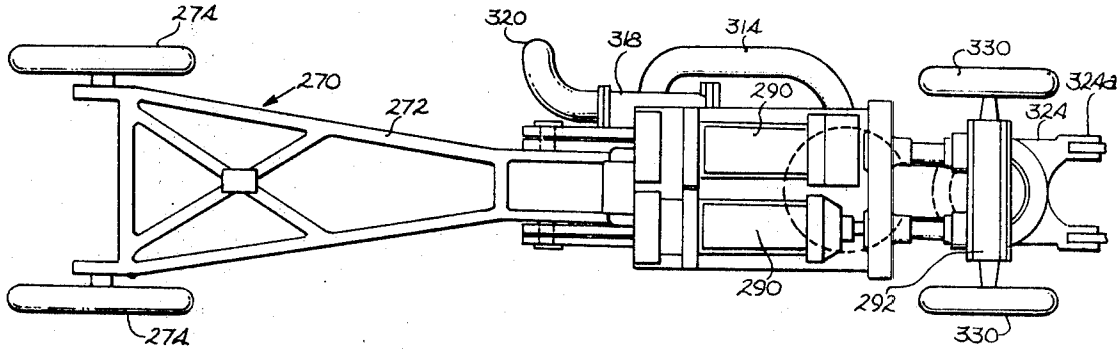


FIG. 13

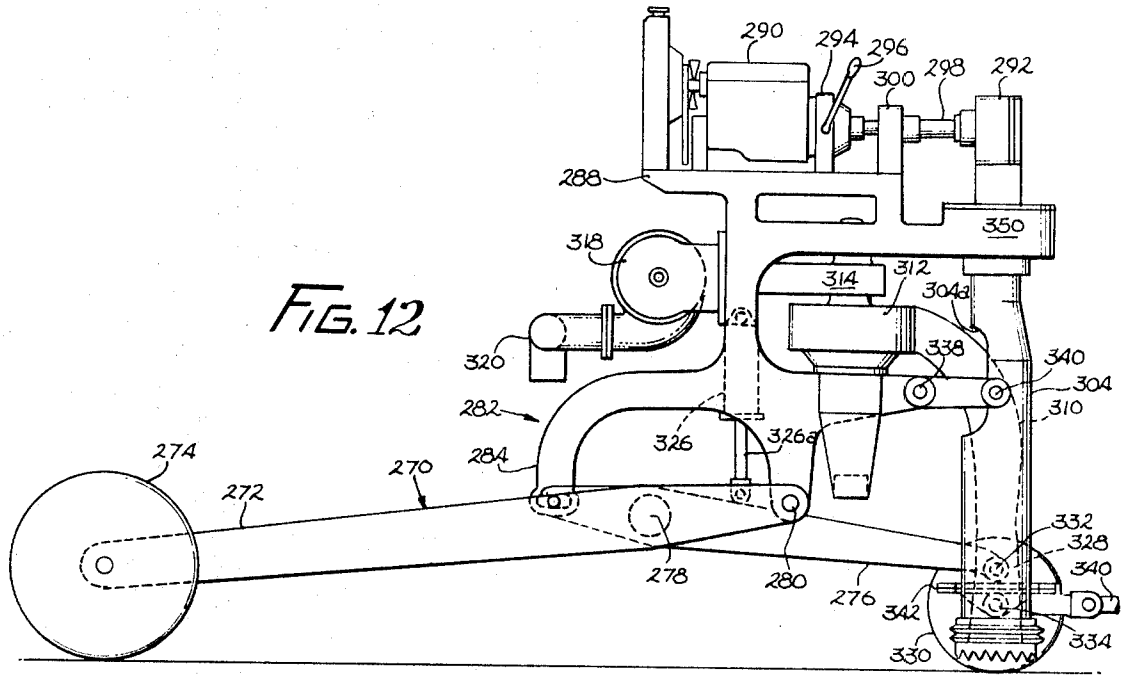


FIG. 12

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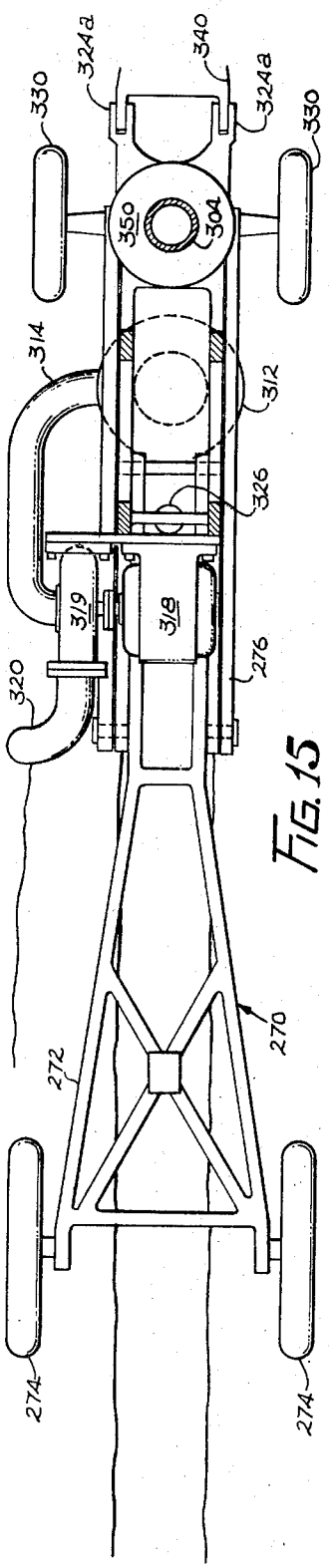


FIG. 15

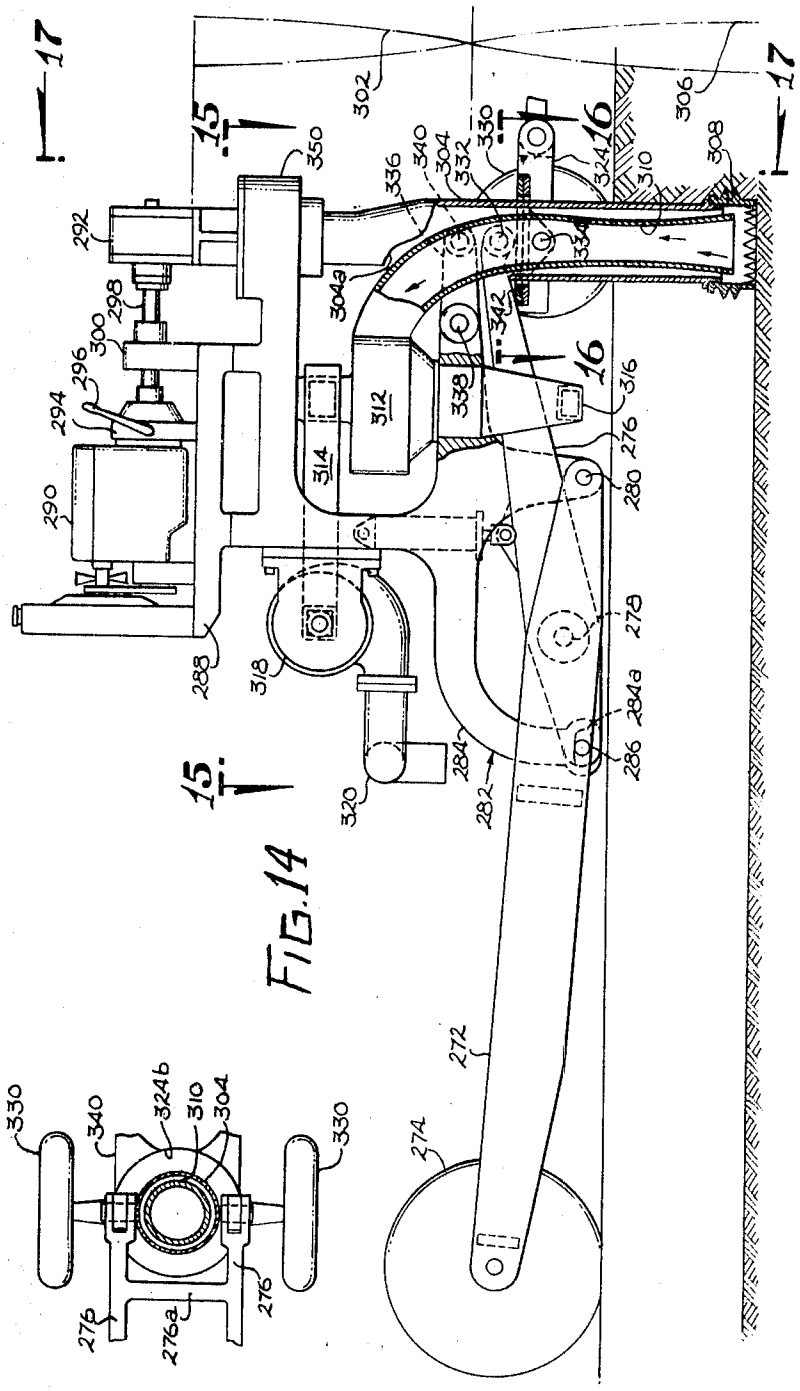


FIG. 14

FIG. 16

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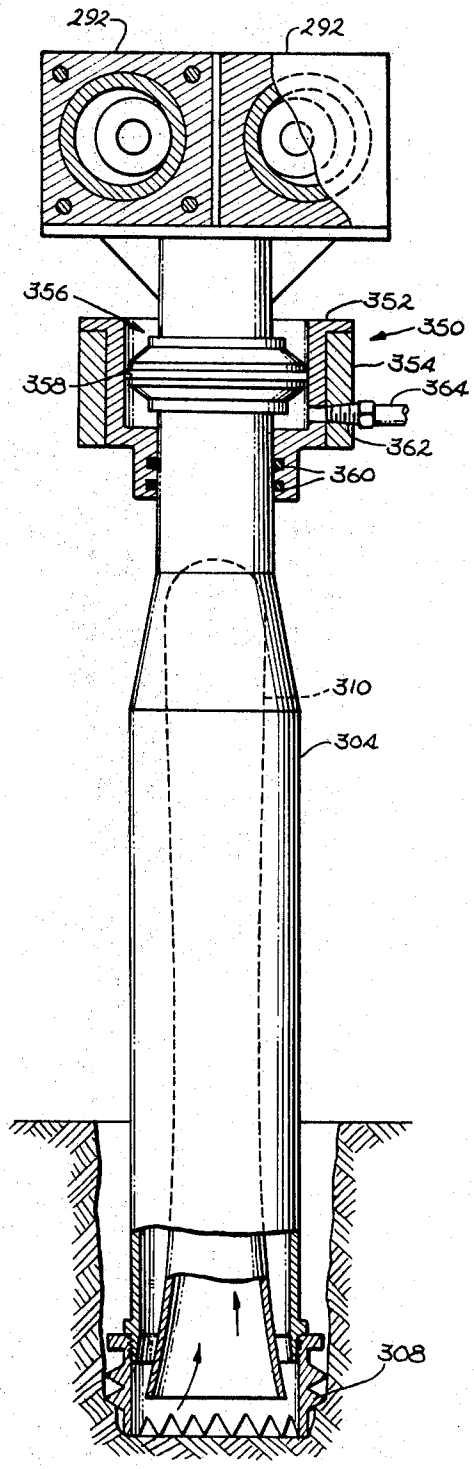
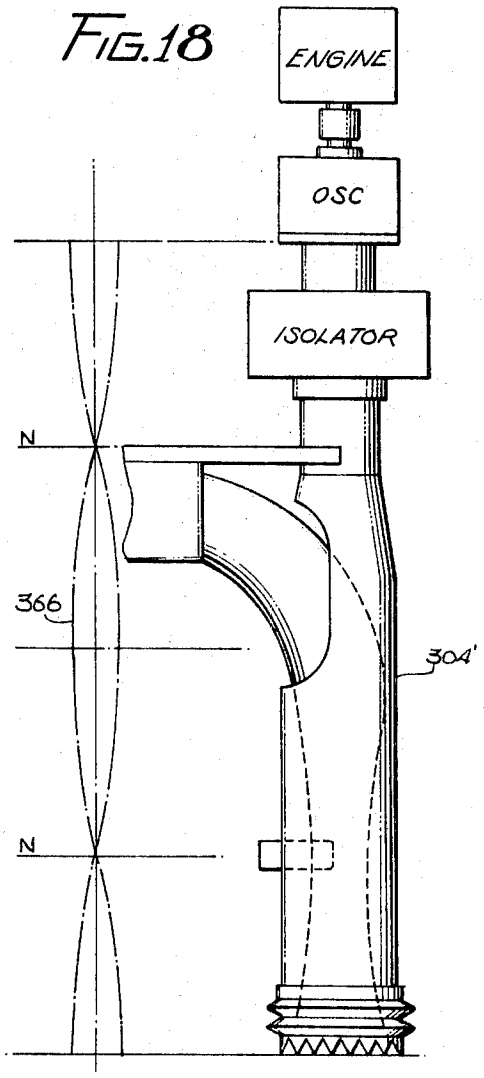


FIG 17

FIG. 18



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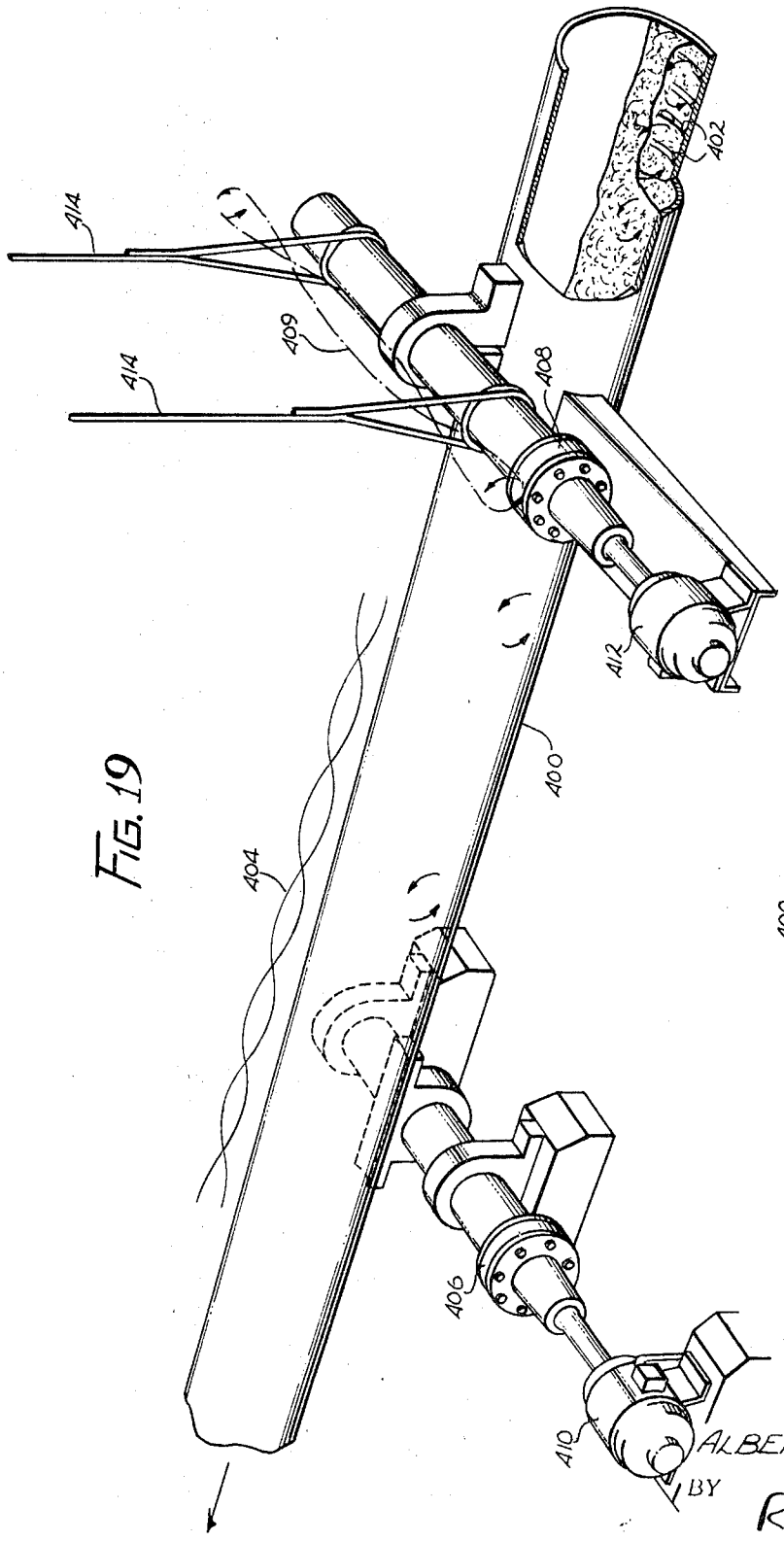


FIG. 19

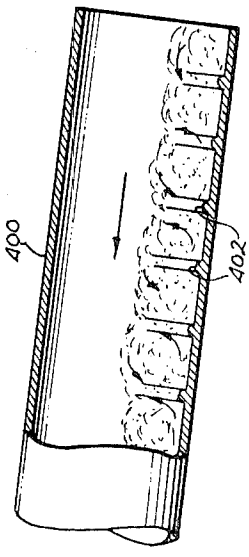


FIG. 20

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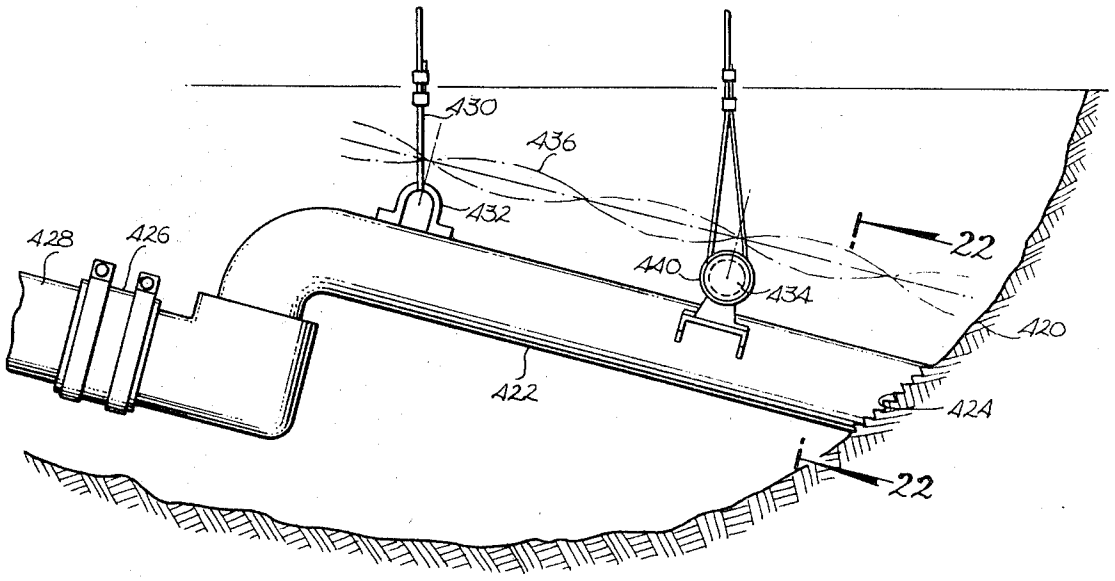


FIG. 21

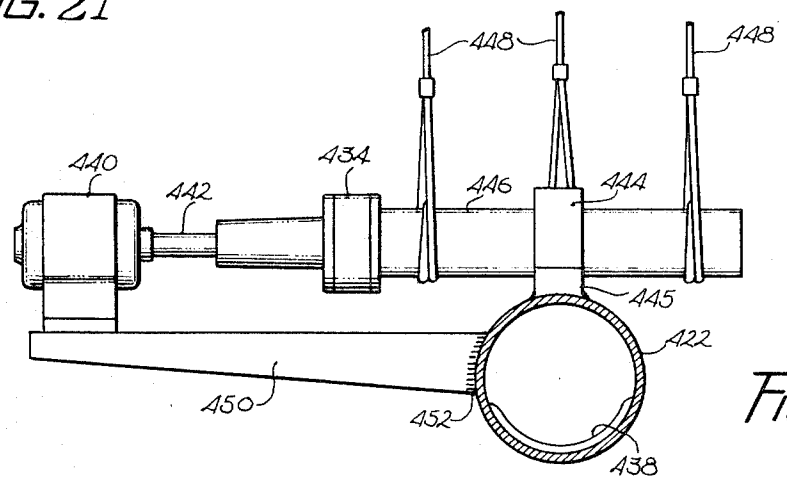


FIG. 22

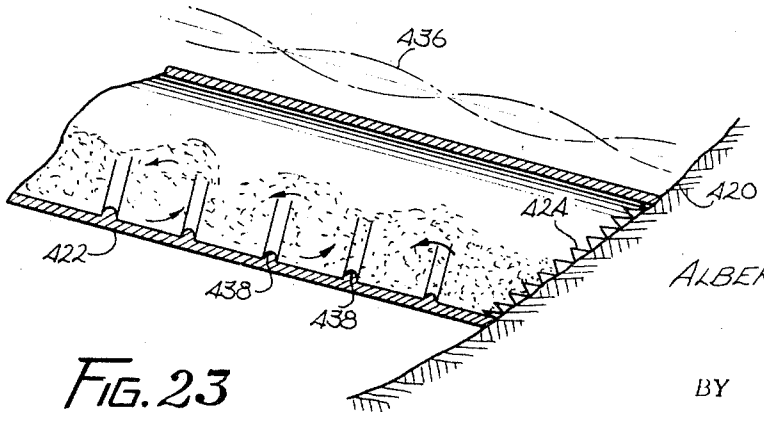


FIG. 23

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CONTINUOUS EXCAVATING AND CONVEYOR MECHANISM EMPLOYING SONIC ENERGY

This application is a continuation of application Ser. No. 531,950, filed Mar. 4, 1966, now abandoned.

This invention relates to excavating and conveyor mechanisms and, more particularly, to an improved excavating and conveyor mechanism employing sonic principles for loosening and fluidizing earthen material that is being removed from an excavating area. The conveyor mechanism embodying the invention is also adapted to operate in conjunction with dredging apparatus, which is based on the application of one or more sonic principles, such as the apparatus disclosed in copending application Ser. No. 413,495, filed Nov. 24, 1964, now U.S. Pat. No. 3,307,278.

Inasmuch as the art relating to processing equipment and methods is not coextensive with the art relating to acoustical engineering, and may be outside the experience of those skilled in the former, and to aid in a full understanding of the invention, some general discussion and definitions are deemed to be useful. As used throughout this specification, "sonic vibration" means elastic vibrations, i.e., cyclic elastic deformations, which travel through a medium with a characteristic velocity of propagation. If the vibrations travel longitudinally or create a longitudinal wave pattern in a medium or structure having uniformly distributed constants of elasticity and mass, the vibrations are analogous to those of sound wave transmission. Regardless of the frequency of such elastic vibrations, the same mathematical formulas apply to them as to the study of sound wave transmission.

In some elastic vibratory systems, the essential features of mass may appear as a localized influence, referred to hereinafter as a "lumped constant." A lumped constant in an elastically deformable medium provides an effect variously referred to as elasticity, modulus of elasticity, stiffness, stiffness modulus, or compliance (the reciprocal of stiffness modulus). These constants, when functioning in an elastically vibratory system, have cooperating and mutually influencing effects much like those of equivalent factors in alternating current electrical systems. In fact, in both distributed and lumped constant systems, mass is mathematically equivalent to inductance; elastic compliance is mathematically equivalent to capacitance; and friction or other pure energy dissipation is mathematically equivalent to resistance.

As was mentioned hereinbefore, because of these equivalents, the elastic vibratory systems of the apparatus of the present invention with their mass stiffness and energy consumption, and their sonic energy transmission properties, can be viewed as equivalent electrical circuits, where the functions can be expressed, considered, changed, and quantitatively analyzed by using well proven electrical formulas.

It is important to recognize that the transmission of sonic energy into the interface or work area between two parts to be moved against one another requires the aforementioned elastic vibration phenomena in order to attain the benefits of the present invention. There have been other proposals involving exclusively simple bodily vibration of some parts; however, these simple bodily vibrations do not result in the benefits of sonic or elastically vibratory action such as are inherent in the present invention.

Since sonic or elastic vibration results in the mass and elastic compliance elements of the system taking on these special properties akin to the parameters of inductance and capacitance in alternating current phenomena, vastly improved performance is attained in the mechanical art. The concept of acoustic impedance becomes of paramount importance in understanding such improved performance. Here, impedance is the ratio of cyclic force or pressure acting in the media to resulting cyclic velocity of motion, just like the ratio of voltage to current in electrical circuits. In this sonic adaptation, impedance is also equal to the medium density times the speed of propagation of the elastic vibration. In this invention, impedance is important to the accomplishment of desired

ends, such as where there is an interface. A sonic vibration transmitted across an interface between two media or two structures can experience some reflection, depending upon the differences of impedance of the media. This can cause large relative motion, if desired, at the interface. Impedance is also important to consider if optimized energization of a system is desired. If the impedances are adjusted to be somewhat matched, energy transmission is made very effective.

Sonic energy of fairly high frequencies can have energy effects on molecular or crystalline systems. Also, these fairly high frequencies can result in very high periodic acceleration values, typically of the order of hundreds or thousands of times the acceleration of gravity. This is because, from a mathematical point of view, acceleration varies with the square of frequency. Accordingly, by taking advantage of this square function, very high forces can be produced by the sonic system of the present invention.

The present invention applies the foregoing sonic principles to an excavating and conveyor mechanism for loosening and fluidizing earthen material to vastly improve its ease of removal from an area to be excavated. A longitudinal standing wave is set up in the excavating portion of the mechanism to loosen material to be removed. The loosened material is transferred automatically under the influence of sonic energy to the conveyor portion of the mechanism, which may also have standing waves set up therein to propel or aid in propelling the loosened material to its point of discharge.

In one embodiment of the invention, the conveyor portion may comprise an endless belt having flights thereon, which belt is arranged to be positioned in conjunction with the excavation portion, so that the action of the latter causes loosened material to be scooped or funneled onto the flights of the conveyor belt. The conveyor itself plays no part in the heavy work of digging or fragmentation, and hence may be a relatively light-duty carrier. It is pointed out that such an arrangement provides fast digging action and continuous flow of loosened material.

In other embodiments of the invention, the conveyor portion may comprise a conduit such as an open trough or a closed pipe. When a conduit is used, a continuous sonic wave is maintained in the conduit, to cause fluidization of material flowing through the conduit. The material being conveyed may be dry or semidry and no liquid is required to cause the material to flow through the conduit.

It is believed that, in the case of a conduit, the conduit system itself completely satisfies the requirements of capacitance and inductance that are required for the operation of a sonic circuit. Therefore, since the material being moved does not function in a major way as a reactive impedance, it is possible for the material to function primarily as a resistive impedance. Thus, the individual grains of the material vibrate in random directions with various amplitudes of vibration, vibrate relative to each other, and become very mobile. The result is that the material attains great fluidity, which prevents sticking or piling up of the material as it flows through the conduit. In addition, by certain orientations of the sonic vibrations, it is possible to cause the conduit to pump the material along, and even to propel it along an uphill grade.

It is particularly pointed out that sonic energy is used to fluidize earthen material from the instant that it is removed from the ground and on through the conduit system to its discharge point. The sonic energy delivered by the excavating portion of the apparatus causes fluidization of the material in the earth, so that it is easily picked up and introduced into the conduit system. Introduction of the material into the conduit can be aided by locating a lip or blade section of the sonically-activated excavating portion of the apparatus so that it tends to cause the material to flow into the conduit.

In another embodiment of the invention, a flow of air is introduced into the conduit so as to further aid the introduction of fluidized material into the conduit and its flow through the conduit. Such a system is arranged so that the flowing material

is delivered to a separating stage such as a centrifugal separator or "cyclone" pump. In that stage, the dirt is thrown out of the air stream so that it can be discharged at the delivery point and the air is discharged free of dust. Generally, the airstream is passed through a filter, and it may be desirable to apply sonic energy to the filter so that any dust collected thereby is continually dropped off into the dirt-discharge region of the mechanism.

An important feature of the mechanism herein disclosed is that it moves fine particles very quickly away from the region of earth contact. This reduces absorption of sonic energy by these fine particles in the region of excavation, where their cushioning effect could absorb a considerable amount of the energy needed for the excavation action. Thus, the quick removal and flowing away of such fine material greatly reduces the consumption of sonic energy. This feature, which is unique to the present invention, is not present in prior known earth-moving devices, where fine material is carried along with coarse material as a large body, which is conducted or forced into a hopper or bowl-type structure or is pushed aside by a bulldozer blade. Thus, the excavating portion of the mechanism is constantly operating only in the tough, coarse material that remains after the fine material is removed. The excavating portion is able to apply its maximum fatigue and fracturing effect on the larger hard lumps which remain in the excavation region.

Further features and advantages of the invention will become apparent from the following description of several embodiments thereof, taken in conjunction with the accompanying drawings in which:

FIG. 1 is an elevational view of one embodiment of the invention showing the mechanism in its retracted or nonexcavating position;

FIG. 2 is a plan view of the embodiment shown in FIG. 1;

FIG. 3 is an elevational view of a portion of the mechanism shown in FIG. 1 in its extended or excavating position;

FIG. 4 is a partial end view of the mechanism of FIG. 3 taken on the line 4–4 of FIG. 3;

FIG. 5 is a cross-sectional view of a mass oscillator that may be used in the practice of the invention;

FIG. 6 is a perspective view, partially broken away, of another form of oscillator that may be used in the practice of the invention;

FIG. 7 is a longitudinal cross-sectional view of the oscillator shown in FIG. 6;

FIG. 8 is a cross-sectional view of another form of mass oscillator;

FIG. 9 is a diagram of an equivalent electrical circuit analogous to the vibratory system shown in FIGS. 1—4;

FIG. 10 is an elevational view of a modified form of the apparatus shown in FIG. 1;

FIG. 11 is a plan view of the mechanism shown in FIG. 10;

FIG. 12 is an elevational view of another embodiment of the invention employing a different type of conveyor than that shown in FIGS. 1—4 and showing the mechanism in its retracted position;

FIG. 13 is a plan view of the modification shown in FIG. 12;

FIG. 14 is an elevational view of the mechanism shown in FIG. 12, but showing the mechanism in its extended position;

FIG. 15 is a sectional view taken on the line 15–15 of FIG. 14;

FIG. 16 is a sectional view taken on the line 16–16 of FIG. 14;

FIG. 17 is an end view, partially in section, taken on the line 17–17 of FIG. 14;

FIG. 18 is a diagrammatic view showing a different standing wave pattern that can be set up in the excavating portion of the mechanism shown in FIGS. 12—17;

FIG. 19 is a perspective view, partially broken away, of another embodiment of the conveyor portion of a mechanism embodying the invention;

FIG. 20 is an enlarged sectional view of a portion of the conveyor shown in FIG. 19;

FIG. 21 is an elevational view of another modification of the mechanism embodying the invention;

FIG. 22 is a sectional view taken on the line 22–22 of FIG. 21; and

FIG. 23 is a longitudinal sectional, fragmentary view of the mechanism shown in FIG. 21.

FIGS. 1, 2, 3 and 4 illustrate one embodiment of an excavating and conveyor mechanism embodying the invention, with FIGS. 1 and 2 showing the mechanism in a retracted or non-digging position, and FIGS. 3 and 4 showing the mechanism in an extended or digging position.

The mechanism of the invention is shown in FIG. 1 as being mounted on a self-powered tractor 30 or other similar device. Although certain conventional elements have been omitted for ease in understanding the drawings, it is to be understood that the vehicle 30 contains not only its own motive power, but also contains means for generating hydraulic power and electrical power to actuate the excavating and conveying mechanism of the invention.

The apparatus of the invention comprises a pair of sonic resonating bars 32, only one of which is shown in FIGS. 1 and 3, and an endless conveyor belt 34 arranged to follow a generally triangular path. The entire mechanism is supported by a generally triangularly shaped frame structure 36 which is mounted on the vehicle 30. The resonating bars 32 and the conveyor belt 34 are adapted to be raised and lowered with respect to the frame structure, as will be hereinafter described in detail. The frame structure 36 comprises two similar halves, and the resonating bars 32 and the conveyor belt 34, along with their associated supporting parts, are mounted between the two halves of the frame structure 36.

It is pointed out that the two similar halves of the frame structure 36, and the various actuating mechanisms and lever arms to be hereinafter described, are in general provided in pairs, one of each pair being mounted adjacent each part of the frame structure 36. Although the mechanism embodying the invention will be described hereinafter as incorporating two resonating bars 32, it is apparent that any number of resonating bars may be employed, depending upon the desired width of a cut of earth to be taken by the mechanism.

Each of the sonic resonating bars 32 is supported at its nodal points by a guide bar 38. Each of the guide bars 38 is supported within a channel member 40 having an open side adjacent the resonating bars 32. Each channel member 40 also has an open side opposite the resonating bar 32 so that the guide bar 38 may be moved up and down within the channel member 40. The channel members 40 are secured to the frame structure 36 as by being welded thereto. In turn, the frame structure 36 is fixedly mounted on the vehicle as shown at 42 and 44.

Vertical movement of the guide bars 38 and resonating bars 32 is controlled by actuation of a pair of hydraulic cylinders 46, each having a movable piston rod 48. Each hydraulic cylinder 46 is pivotally secured to the frame structure 36, as at 50, and the outer ends of the piston rods 48 are similarly secured to one arm of each of a pair of bellcranks 52, as at 54. The fulcrum of each bellcrank 52 is pivotally mounted on the frame structure 34, as at 56.

The arm of each bellcrank 52 to which a piston rod 48 is secured is pivotally attached at its outer end to a link 58. The end of each link 58 that is not attached to a bellcrank 52 is pivotally secured between a pair of lips 38*a* extending outwardly from each guide bar 38 at its upper end.

Each sonic resonating bar 32 is provided at its lower end with a cutter toe 32*a* in the shape of a pointed laterally extending projection. Each of the resonating bars 32 also carries in its midsection a sonic vibration oscillator or generator 60, each vibration generator 60 being powered by an electric motor 62. Each vibration generator 60 sets up a lateral standing wave in its associated resonating bar 32, each of which is secured to the guide bar 38 at its nodal points 64 and 66. In order to lower each resonating bars 32 so that its toe 32*a* engages earth to be excavated, hydraulic pressure is removed

from the associated hydraulic cylinder 46 so that the piston rod 48 moves downwardly. This causes the bellcranks 52 to rotate in a clockwise direction about the pivot points 56, thus causing the links 58 to move downwardly. As the links 58 move downwardly, they lower the guide bars 38 and the resonating bars 32, as shown in FIG. 3. As previously mentioned, very high periodic acceleration values result from the setting up of lateral standing waves in the resonating bars 32. These high forces produced by the sonic system of the invention result in the toes 32*a* of the resonating bars 32 fluidizing the earthen material, including rock, with which they come in contact. Thus, earthen material is rapidly and efficiently loosened from its surroundings and converted into a fluid state, whereby it may easily be picked up and transported by a conveyor.

The conveyor portion of the mechanism of the invention is an integral part thereof, and is linked to and interacts with the excavation portion of the mechanism, as will be hereinafter described. The conveyor belt 34 is supported by three pulleys 68, 70 and 72 arranged in generally triangular form. The pulley 68 is rotatably mounted between the two halves of the frame structure 36, and is connected by means of a shaft 74 and a conventional gear box 76 to a motor 78 for driving the conveyor belt 34. The pulley 70 is rotatably mounted between the ends of two bellcranks 80, which are pivotally mounted on the same axis 69 as is the pulley 68. The third pulley 72 is rotatably mounted between the two sides of a scoop 82, which is secured to the resonating bars 32 at their nodal points 66. The scoop 82 serves as a dual function of affording a tie between the resonating bars 32 and the bottom turn of the conveyor belt 34 around the pulley 72, and providing, by means of an inclined floor 82*a*, a path over which fluidized and sonically energized earthen material passes in going from the areas of intensive fluidization created by the resonating bars 32 to the conveyor belt 34.

The conveyor belt 34 is provided with a plurality of lands 34*a* which are in close proximity to the curved floor 82*a* of the scoop 82 and pick up the fluidized material between the lands as the conveyor belt 34 advances.

Coordination of two movement of the resonating bars 32 and their guide bars 38 and the conveyor portion of the mechanism is accomplished by means of the bellcranks 52, the bellcranks 80 and links 84 that link together the two short sharp arms of the bellcranks 52 and 80. As the bellcranks 52 rotate in a clockwise direction to lower the resonating bars 32 into the earth, they cause the bellcranks 80 to rotate about the axis 69 to simultaneously lower the conveyor portion of the mechanism into the earth in synchronism with the movement of the resonating bars 32. Thus, the pulley 70 follows a fanlike arcuate path as indicated by the arrows 86 in FIG. 3. The scoop 82 is also secured to the resonating bars 32 at their nodal point 66 by means of arms 88 that prevent rotational movement of the scoop about the point 66. Thus, movement of the resonating bars 32 and positions of the conveyor belt 34 are synchronized so that the scoop 82 is always adjacent the rear end of the toe 32*a* of each resonating bar 32.

As previously mentioned, the pulley 68 over which the conveyor belt 34 passes is fixed in position relative to the frame structure 36. Thus, it provides a convenient place for discharge of earthen material transported by the conveyor belt. As shown in FIGS. 1 and 2, in one embodiment of the invention, the earthen materials may be discharged into a conventional bottom-drop hopper 92. The hopper 92 is provided with a drop-bottom 94 which is opened and closed by means of a hydraulic cylinder 96. The hopper 92 is secured to the frame structure 36 as at 98, and is maintained in position by an arm 100 secured at one end to the hopper 92 and at the other end to the frame structure 36. The advantage of using a hopper is that one complete hopper load can be discharged into a waiting dump truck 102 without tieup resulting from maneuvering successive damp trucks into position beneath the hopper.

There are shown in FIGS. 5—7 two examples of sonic oscillators which may be employed in the apparatus of FIGS. 1—4. The operating principle of a gyratory type sonic oscillator is shown in FIG. 5 and comprises, in part, an outer cylinder 110 and a smaller diameter inner cylinder 112. The inner cylinder 112 is provided with a plurality of jet orifices or turbine nozzles 114. By applying fluid under pressure to the interior of the cylinder 112 and withdrawing it from the interior of the cylinder 110, the (outer) cylinder 110, which acts as an orbiting mass, will be caused to follow an epicyclic or gyratory path as it moves about the exterior surface of the (inner) cylinder 112. This will generate a substantially sine wave vibration which will be imparted to the structure supporting the outer cylinder 110.

There is shown in FIGS. 6 and 7 an alternative construction of a sonic oscillator of the orbiting mass type in which rotary kinetic energy, rather than hydraulic fluid pressure, is employed to drive the eccentric mass.

As shown, the orbiting mass oscillator comprises an outer cylinder 116 which may be press-fitted into, or otherwise supported by, a frame 118 or other structure to which sonic energy is to be imparted. The cylinder 116 is closed at one end by a plate 120 and a gear ring 122 and at the other end by a frustoconical shell 124 and a gear ring 126. The plate 120 is provided with a circularly grooved track 128. A stationary tube 130 is secured to the shell 124 and extends therefrom. The orbiting mass comprises a cylindrical weight 132 coaxially mounted on a gear member 134 for rotation therewith. A boss 136 extends from the gear member 134, and mates with or engages the circular track 128 in the plate 120. The teeth of the gear member 134 mesh with the teeth of the gear ring 122. The opposite end of a stem 138, which runs through the cylindrical weight 132, is secured to a gear wheel 140, the peripheral gear teeth of which mesh with the interior gear teeth of the gear ring 126. The gear wheel 140 is provided with a frustoconical boss 142, which travels in a mating circular groove 144 in a drive member 146. A drive shaft 148 is driven from a rotary prime mover (not shown). A splined end 148*a* of the drive shaft 148 engages an interior mating spline of the drive member 146, which is rotatably supported by conventional ball bearings 150 and 152. Rotary motion is imparted to the drive member 146 which in turn causes the gear wheel 140 to rotate by toothed engagement therewith. This in turn will impart motion to the cylindrical weight 132 or orbiting mass causing it to revolve and follow an orbital path about the interior surface of the outer cylinder 116.

A valuable feature of the sonic circuit of the present invention is the provision of an extra elastic compliance reactance so that the inherent mass or inertia of various necessary bodies in the system does not cause the system to depart so far from resonance that a large proportion of the driving force is dissipated in vibrating this mass. For example, in any practical construction, the mechanical oscillator or vibration generator will require a body or supporting structure for carrying the cyclic force generating means. This supporting structure, even when minimal, will have some finite mass or inertia. This inertia could be a force-wasting detriment, acting as a blocking impedance, using up part of the periodic force output just to accelerate and decelerate the supporting structure. However, by use of elastically vibratory structure in the system, the effect of this mass, or the mass reactance resulting therefrom, is counteracted at the frequency for resonance and, when a resonant acoustic circuit is thus used, with adequate capacitance (elastic compliance reactance), these blocking impedances are tuned out, at resonance, and the periodic force generating means can thus deliver its full impulse to the "work" which is a resistive component of the impedance.

FIG. 8 shows a modified vibration generator that may be used in practicing the invention. The generator embodies a frame or body part 160, which has a cylindrical portion 162, formed with parallel end faces 164 and a central bore 166. Wider bores 168 are formed at the ends of the bore 166. End plates 170 and 172 mate with the end faces 164, and are

fastened thereto by means of machine screws 174. The end plate 170 projects into the adjacent counterbore 168, and is formed with a radius about a center point C located on the longitudinal axis A-A' of the generator. This surface forms a bearing for the opposed convex end surface of an inertia rotor, to be hereinafter described. The inertia rotor is shown generally by the numeral 178.

The opposite end plate 172 also has a portion projecting inwardly into the adjacent counterbore 168, and is formed on its inner side with a stationary bevel ring gear 180.

Tightly mounted inside the bore 166 is a hardened race ring or bearing 182, having a tapered bore forming a conical bearing surface 184, the projected taper of which has its apex at C.

The conical inertia rotor 178 is comprised of a truncated conical roller 186 rotatably mounted on a bearing sleeve 188, the sides of which, projected, converge to the aforementioned center point C. The conical roller 186 is of a smaller central angle than the tapered or conical bearing surface 184, as shown in the drawing, so as to be capable of travel in an orbital path as it rolls around the tapered bearing surface 184. The large end of the conical roller 186 has a convex bearing surface 192, centered about point C, which bears against the concave bearing surface 176.

The bearing sleeve 188, on which the conical roller 186 is rotatably mounted, projects axially from a bevel planet gear 194 positioned adjacent the small end of the roller 186, and which meshes with the aforementioned bevel ring gear 180. The "pitch cone" of the bevel gear 194 conforms to or coincides with the cone defined by the roller 186. The angles of the bevel gears 180 and 194 also converge to the center point C. It will be understood that bevel planet gear 194 rolls around the bevel ring gear 180 in proper mesh therewith, as the conical inertia roller 186 rolls around the conical bearing face 184, with the roller 186 gaining traction on the surface 184 as the generator comes up to speed and operation stabilizes. The roller 186 turns to any necessary degree relative to the gear 194 as the generator initially comes up to running speed, or because of minor differences in the rates of rotation of the gear 194 and the roller 186 produced by slippage between the ring gear 180 and conical bearing surface 184.

Projecting axially from the bevel gear 194 is an axial extension 196, which is provided with a splined connection 198 to a conically gyratory tubular drive shaft 200.

The roller 186 is held in assembly with the gear 194 by means of a spindle 202, which extends axially through tubular bearing sleeve 188 and freely through a bore 204 in the large end portion of the roller 186, the bore 204 being counterbored, as at 206, to receive an annular flange 208 on the spindle 202. The opposite end portion of the spindle 202 is threaded to receive a locknut 210, which engages a washer 212 positioned adjacent the extremity of the tubular gear extension 196, the washer 212, as here shown, engaging the ends of the splines in the drive shaft 200. Sufficient play is provided to prevent binding of the roller 186 on the spindle 202 or on the tubular bearing 188.

Projecting axially from the spindle 202, outside of the flange 208 is a guide pin 214 which projects into an annular groove 216 formed in the arcuate end face 176 of the end plate 170, concentric with axis A-A'. In a manner analogous to the embodiment shown in FIGS. 5—7, the roller 186 is thereby positioned closely adjacent to, or in substantial rolling contact with, the conical raceway 184, and the gear 194 is at the same time maintained in proper mesh with the gear 180. When the vibration generator is up to speed, centrifugal force urges the roller 186 radially outward against the conical bearing surface 184, and relieves the pressure of the pin 214 on the adjacent sidewall of the groove 216. At such times, the roller 186 has been able to gain substantially nonskid traction with the bearing surface 184, and the gear 194 rolls in proper mesh with the gear 180, the roller 186 and the gear 194 thus describing orbital paths about the bearing surface 184 and the gear 180, respectively. During this action, a small relative rotation or creep is permitted between the roller 186 and the gear 194, so as to relive the gear teeth of strain that might occur if the roller 186 were fixed thereto and were to tend to roll on its raceway at a speed slightly different from that of the gear 194.

The driven extremity of the tubular drive shaft 200 is formed with arcuate splines 218, which engage internal splines 220 in a coupling sleeve 222, thus affording a universal joint. The coupling sleeve 222 has a tubular extension 224, of reduced diameter, which is supported by conventional bearings 226 mounted between spacers 228 and 230 without a housing tube 232. The latter is flanged, as at 234, for engagement by the assembly screws 174, and the spacer 230 is similarly flanged, as at 236, for a corresponding purpose.

The coupling sleeve 222 may be driven in any suitable manner. As here shown, a tubular drive shaft 238, understood to extend from any suitable prime mover, preferably incorporating a variable speed drive, not shown, has splines 240 drivingly engaging the splines 220 in the sleeve 222.

It will be understood from the foregoing description how the conical inertia rotor 186 and the gear 194 follow an orbital path about the conical raceway 184 and the bevel gear 180 when the tubular drive shaft 200 is provided, in effect, with a universal joint action at the point of the splined connection 218,220, such that the shaft 200 gyrates through a conical angle as the roller 186 and the gear 194 traverse their orbital paths.

The centrifugal force exerted by the inertia roller 186 on the bearing member 182 is transmitted to a supporting member or bar 242, which is press-fitted into a correspondingly-shaped recess in the end plate 170. Used singly, such a generator as disclosed in FIG. 8 exerts a gyratory force of vibration on the member 242. Used in pairs, with synchronized and phased drive, a linear alternating force may be generated and applied to a load.

FIG. 9 diagrammatically illustrates an electrical circuit that is equivalent to the mechanical resonant arrangement on which the present invention is based. As shown, an alternating current signal generator 244, which is equivalent to one of the sonic oscillators or vibration generators previously described, provides signals to a conventional tank circuit. A capacitor C is connected across the signal generator 244, and a resistance R and an inductive impedance L are connected in series across the signal generator 244. As previously mentioned, the capacitor C represents the elastic compliance of the vibratory system, the inductance L represents the mass of the system, and the resistance R represents the energy dissipation of the system used in loosening and fluidizing earth.

As is well known, when the frequency of the output signal of the generator 244 is properly adjusted, the R-L-C- tank circuit will go into resonance. This is the equivalent of setting up a longitudinal standing wave in one of the resonating bars 32, as shown at 33 in FIG. 1. As previously mentioned, each bar 32 is supported at nodal points by a guide bar 38, and has an antinode at its lower or earth-engaging end, which vibrates at the frequency of the vibration or sonic generator acting on the resonating bar.

FIGS. 10 and 11 illustrate a modified form of the invention which is very similar to that form shown in FIGS. 1 through 4, except that a chute is provided to discharge earthen material transported by the conveyor belt rather than a hopper as shown in the first embodiment. Furthermore, the excavating and conveyor mechanism is adapted to be rotated about a vertical axis so that earthen material may be dispersed over a wide area by the aforementioned chute. It is understood that the various power generating means mentioned in connection with the embodiment shown in FIGS. 1—4 are also provided in the embodiment shown in FIGS. 10 and 11. In the latter embodiment, certain parts which are shown in FIGS. 1 and 2 have been omitted for the sake of clarity. The provision of such parts will be readily understood by one skilled in the art. As shown in FIGS. 10 and 11, the mechanism of the invention is mounted on a pair of posts 250 secured to the vehicle 30 on opposite sides thereof. The posts 250 are supported vertically by links 251 between them and the vehicle 30. The two posts

250 are connected together at their tops and bottoms by horizontally extending members 252. The two opposing halves of the frame structure 36' are secured to opposite ends of horizontally extending arms 254 located adjacent the members 252 and pivotally connected thereto, as at points 256, which define a vertical axis. The entire mechanism may be pivoted about the pivot points 256 by power actuated means (not shown), if desired.

Instead of a hopper as shown in previous embodiments, the embodiment shown in FIGS. 10 and 11 is provided with a chute 258, which is swingable between the positions shown in broken lines in FIG. 11 as the mechanism pivots about the points 256. The chute 258 is mounted on the two halves of the frame structure 36' in a position to receive earthen material at its upper end discharged from the conveyor belt 34. The chute 258 may be raised and lowered by means of a hydraulic cylinder 260 mounted between the chute and vertically and horizontally extending arms 36'*a* and 36'*b*, respectively, secured to the frame structure 36'.

Earthen material flowing down the chute 258 is maintained in a fluidized state by means of a vibration generator 262 which is driven by a motor 264 and sets up either a lateral or a longitudinal standing wave along the chute 258. Thus, earthen material in a fluidized state flows continuously and evenly down the chute.

Of course, the excavating and conveyor portions of the mechanism of the invention are supported and actuated in the same manner as in the embodiment illustrated in FIGS. 1—4. Therefore, that portion of the mechanism shown in FIGS. 10 and 11 will not be described. Briefly, however, it is to be understood that the embodiment of the invention shown in FIGS. 10 and 11 is provided with resonating bars having cutting toes, which resonating bars are supported in guide bars as shown in FIGS. 1—4. The resonating bars, and the associated conveyor portion of the mechanism, are linked together in the same manner as previously shown and described, and are raised and lowered together between retracted and excavating positions. It is again noted that the principle difference between the embodiment shown in FIGS. 1—4 and that shown in FIGS. 10 and 11 is in the pivotal mounting, whereby fluidized material may be discharged from the chute 258 over a wide area, which may be quite useful in a cut-and-fill operation.

FIGS. 12—16 illustrate another embodiment of the invention which embodies a different type of conveyor than that previously shown, and which is carried by a towed vehicle, indicated generally by the numeral 270. The vehicle 270 comprises a conventional frame structure 272 on which are conventionally mounted a pair of rear wheels 274. The excavator and conveying mechanism is carried by a pair of levers 276, which are pivotally connected to opposite sides of the frame structure 272, as at 278. It is noted that the pivotal points 278 are not at the end of the frame structure 272 but are intermediate the wheels 274 and the end of the frame structure. The levers 276 are connected together by cross bars 276*a* (FIG. 16).

Pivotally connected to the end of the frame structure 272, as at 280, is a supporting structure, indicated generally by the numeral 282, which carries the excavating and conveyor mechanism. The supporting structure 282 is provided with two depending arms 284 which are pivotally connected to the levers 276, as at 286. The arms 284 are slotted as at 284*a* to allow some horizontal movement of the arms.

The supporting structure 282 is provided with a flat top portion 288, which supports two internal combustion engines 290 which drive two vibration generators 292 of the types illustrated in FIGS. 5—8 and described in the aforesaid application Ser. No. 413,495. As previously pointed out, two generators are used with synchronized drive to provide a linear alternating force to the resonating tubes and cutter heads to be hereinafter described. Power from the engines 290 is transmitted to the vibration generators 292 through conventional clutches 294 having actuating handles 296. The engines 290 are connected from the clutches 294 to the vibration generators 292 through drive shafts 298 suitably mounted in conventional bearings 300. It is to be understood, as previously noted, that any number of vibration generators and cutters may be employed depending upon the width of cut desired, and the invention is in no way limited to any particular number of generators and resonating tubes.

The vibration generators 292 set up a standing wave, as shown by the curve 302 in FIG. 14, in a resonating tube 304 having an antinode 306 at a cutter head 308, which is threaded onto the bottom of the resonating tube 304. The cutter head is toothed to enable air to enter through the cutter head even when it is held tightly against the earth. The resonating tube 304 has a Venturi tube 310 mounted within it and substantially coaxial therewith. The Venturi tube 310 extends through a lateral opening 304*a* in the side of the resonating tube 304 and into an inlet of a "cyclone" separator 312, which serves to separate fluidized earthen material from the fluid air in which it is carried. Air is admitted between resonating tube 304 and the Venturi tube 310 through the opening 304*a*, as well as through the cutter head 308. As is well known by those skilled in the art, a cyclone separator acts much in the same manner as a centrifuge. In other words, heavier material drawn into the separator is discharged through one exit while lighter material is discharged through another exit. In the present case, the heavier material, that is, fluidized earth, is discharged into an exit pipe 316, and lighter material (air) is discharged onto the earth through an exit nozzle 314. A filter may also be used, if desired, to insure that earthen material is not discharged through the nozzle 314.

The pipe 314 is connected to the entrance opening of conventional pump 318, secured to the structure 282, whose discharge pipe 320 discharges the air.

The tubes 304 and 310 are raised and lowered by means of the levers 276 previously mentioned, which are pivotally secured to the supporting structure 282 at 286. The levers 276, which form part of the structure for supporting and raising and lowering the excavating and conveyor mechanism, are actuated by an hydraulic cylinder 326, one end of which is secured to the supporting structure 282 and the other end of which is pivotally secured to a crossbar 276*a* connecting the levers 276. The hydraulic cylinder 326 has a piston rod 326*a* which, when extended, causes the mechanism to assume the position shown in FIG. 12. As the piston rod 326*a* is extended, it causes the levers 276 to rotate clockwise about the points 278, which causes the points 278 to move upwardly along with the entire mechanism carried by the supporting structure 282. Conversely, as the hydraulic cylinder 326 is deenergized, as shown in FIG. 14, the pivot point 278 moves downwardly and the resonating tube 304 with its associated cutter head 308 and Venturi tube 310 move downwardly into engagement with the earth.

The right end of the mechanism is supported by a horizontal platelike member 324 having two oppositely disposed vertical arms 328. The levers 276 are respectively pivotally connected to the arms 328, as are a pair of wheels 330. The levers are connected at points 332, and the wheels are connected at points 334. The frame structure 282 is also pivotally connected to the resonating tube 304 by means of links 336, connected between points 338 and 340.

The platelike member 324 is provided with a pair of lugs 324*a* that may be secured to a towing vehicle, a portion of which is shown at 340. The member 324 also has an aperture 324*b* through which the resonating tube 304 extends. One or more rings of elastic material 342 surround the resonating tube 304 where it passes through the aperture 324*b* so that the tube 304 will not be damaged by contact with the member 324 as the tube vibrates or the vibrations be damped.

As the hydraulic cylinder 326 is actuated and its piston rod 326*a* is extended, the right ends of the levers 276 exert pressure, through the member 324 and the wheels 330, against the earth and cause the supporting structure 282 to rise, thus raising the excavating and conveying mechanism mounted thereon. Conversely, when the cylinder 326 is deenergized,

the levers 276 move in a counterclockwise direction and cause the supporting structure 282 to be lowered and the mechanism of the invention to engage the earth, as shown in FIGS. 14 and 15.

It is pointed out that the resonating tube 304 is supported at a node, which corresponds to the pivot point 340, so that the longitudinal standing wave 302 set up therein is not damped by the mounting means.

Inasmuch as the resonant frequency of the tube 304 changes as it is driven into the ground, the tube is isolated from the supporting structure by a vibration isolating mechanism 350 which is shown in detail in FIG. 17. The isolating mechanism 350 comprises a cup-shaped member 352 which encircles the resonating tube 304. The member 352 is contained within a collar 354, which forms a portion of the supporting structure 282. The resonating tube 304 has press-fitted thereon a ringlike member 356 having a circular resilient washer 358 or the like which engages the inner surface of the cup-shaped member 352. The member 352 is also provided with a pair of grooves into which are fitted O-rings 360 that encircle and engage the resonating tube 304. A fitting 362 is provided whereby air may be injected from a line 364 into the interior of the cup-shaped member 352 between the washer 358 and the O-rings 360.

When any plane cross section in a long, thin rod is displaced longitudinally relative to adjacent planes, elastic restoring forces caused by either compression or tension in the rod tend to restore the plane to its normal position. These forces result in the propogation of longitudinal waves along the axis of the rod. The interference of two such waves traveling in opposite directions sets up a pattern of standing waves in the rod having certain discrete frequencies. The magnitude of these natural frequencies depends upon the length and material of the rod and upon the particular constraints existing at the two ends of the rod. Nodal positions having no longitudinal displacements are spaced at intervals along the length of the rod as determined by the fundamental frequency. Whenever a given rod is vibrating longitudinally, one of its natural modes may be supported or clamped at a nodal position without interferring with its particular mode of vibration. Since only a few modes of vibration, or in some cases only one, will have a nodal position at a given location, a judicious choice of support position is necessary to reduce unwanted modes of vibration. However, it is not practical to support the rod at a nodal position since the natural frequency of the rod continuously changes as the rod is driven into the earth. The frequency of the sonic driver would have to be continuously changed as is required to maintain the rod vibrating at its natural frequency. Since the rod cannot practically be supported at a nodal point, it is convenient to support it at one end.

In the embodiment of the invention shown in FIG. 14, there are two antinodes and one node as shown by the curve 302. In some instances, it may be desirable to drive the resonating bar so that it has more than one nodal point along its length. Such an arrangement is illustrated diagrammatically in FIG. 18 where the curve 366 illustrates two nodes and two antinodes in the standing wave set up in the tube 304'. This arrangement also permits the resonating tube 304' to be supported at more than one point without decreasing its resonant properties.

FIGS. 19 and 20 illustrate a conveyor mechanism that may be utilized in the mechanism of the invention. The mechanism there illustrated comprises, in effect, a "sonic pump" which may be used to propel fluidized material along a horizontal path or up a grade. Alternatively, the conveyor may be utilized to fluidize material so that the material will flow by simple gravity where the material is relatively light and the flow path is down grade.

The conveyor comprises a conduit such as a trough or pipe 400 having a plurality of ridges 402 on its inner lower surface. Standing waves, such as are illustrated by the curve 404 are set up along the length of the conduit 400 by means of vibration generators 406 and 408. The generators 406, 408 may be of the type described in U.S. Pat. No. 2,960,314 that generate standing waves transversely with respect to the conduit 400, as shown by the curve 409. Of course, the invention is not limited to the use of any particular number of vibration generators and the two generators 406 and 408 are shown only as being exemplary. The generator 406 is driven by a motor 410 and is mounted in conventional mountings underneath the conduit 400 to transmit oscillatory motion to the conduit through its under side. The vibration generator 408, which is driven by a motor 412, is mounted on the top side of the conduit 400 and both it and the conduit may be supported by a pair of cables 414.

If it is desired to propel the material through the conduit 400 from right to left, as seen in FIGS. 19 and 20, the vibration generators 406 and 408 are rotated in a direction so as to cause a counterclockwise turbulent motion of the material to be propelled within the conduit. The ridges 402 on the inside surface of the conduit 400 aid in establishing the gyratory motion of the particles within the conduit. Of course, if the direction of rotation of the generators 406 and 408 is reversed, the direction of flow of fluidized earthen material within the conduit will also be reversed.

FIGS. 21—23 illustrate another embodiment of the invention in which the excavating and conveying portions of the mechanism are combined in one unit serving a dual purpose. The embodiment shown in those figures is particularly adapted for "nibbling" at a slanted surface, such as is shown in FIGS. 21 and 23 at 420. As shown, the embodiment comprises a resonating tube 422 provided with cutter teeth on its earth-engaging open end. The other end of the resonating tube 422 is conventionally secured by means of a connecting hose 426 to a conduit that may be in turn connected to a conveyor of the type shown in FIGS. 1—4 or to that shown in FIGS. 19 and 20.

The resonating tube 422 is supported by a cable 430 which engages a U-shaped bracket 432 conventionally secured to the tube 422 as by welding. Vibration is imparted to the resonating tube 422 by a vibration generator 434 of the type previously described with reference to FIGS. 19 and 20 and described in U.S. Pat. No. 2,960,314. Longitudinal standing waves, as illustrated by the curve 436, serve the dual purpose of fluidizing the earth which the cutter teeth 424 engage and propelling the fluidized material upwardly through the resonating tube 422. As in the embodiment described with reference to FIGS. 19 and 20, the resonating tube 422 is provided with ridges 438 on its inner lower surface.

The vibration generator 434 is driven by a motor 440 to which it is connected by a shaft 442. The vibration generator imparts vibration to the tube 422 through a mounting 444, as described in the last mentioned U.S. patent which may be welded to the tube 422 as at 445. As noted in that patent, the vibration generator includes a tube 446, with the motor 440, generator 434, the mounting 444, and the tube 446 being suspended from cables 448. The motor 440 is also secured to the resonating tube 422 by means of a bracket 450 which is welded, or otherwise secured, to the tube 422 as at 452. The motor 440 is conventionally mounted on the bracket 450 at the end opposite to that where the bracket is secured to the tube 422.

The conveyor portion of the embodiment shown in FIGS. 21—23 operates in the same manner as shown in FIGS. 19 and 20. That is, it operates as a sonic pump which propels fluidized material along its length because of the gyratory motion set up therein by the action of the vibration generator 434 cooperating with the ridges 438 provided within the resonating tube 422. Thus, material may be propelled up a slope through the tube 422 and into the conduit 428 for delivery to another conveyor or to an outlet.

What I claim is:

1. An earth excavating and conveyor mechanism comprising:

cutter means adapted to engage substantially dry earth to be fluidized and excavated;

elastic resonator means acoustically coupled to said cutter means at an antinode of said resonator means;

sonic oscillator means acoustically coupled to said elastic resonator means whereby an alternating force is imparted to said resonator means and to said cutter means for loosening earth engaged by said cutter means;

means for admitting ambient air through said cutter means to aid fluidization of the earth loosened by said cutter means;

a tubular conduit for conveying earth, positioned adjacent said cutter means and continuously operated during operation of said oscillator means; and

means for maintaining said loosened earth in a fluidized state while said loosened earth is continuously moving to said conveying means.

2. The mechanism defined by claim 1, further including continuously operated means for delivering a continuous flow of fluidized earth from said cutter means to said conveying means.

3. The mechanism defined by claim 1, wherein said elastic resonator means comprises a tube.

4. The mechanism defined by claim 1, wherein said elastic resonator means comprises a first tube, and said conveying means comprises Venturi tube positioned inside said first tube and connected to a cyclone pump.

5. An earth excavating and conveyor mechanism adapted to be mounted on a vehicle and comprising:

a frame structure secured to said vehicle;

elastic resonator means supported from said frame structure;

cutter means acoustically coupled to said resonator means and adapted to engage substantially dry earth to be fluidized and excavated;

sonic oscillator means acoustically coupled to said resonator means whereby a resonant standing wave is imparted thereto and to said cutter means for loosening earth engaged by said cutter means;

means for admitting ambient air through said cutter means and thus cause fluidization of the earth loosened by said cutter means;

a tubular conduit for conveying earth positioned adjacent said cutter means and continuously operated during operation of said oscillator means;

means connected to said frame structure and to said resonator means for moving said resonator means upwardly and downwardly in synchronism with respect to said vehicle; and

continuously operated means for maintaining said loosened earth in a fluidized state while said loosened earth is continuously moving through said conveying means.

6. The mechanism defined by claim 5, further including continuously operated means for delivering a continuous flow of fluidized earth from said cutter means to said conveying means.

7. The mechanism defined by claim 5, wherein said elastic resonator means comprises a rigid tube, the elasticity of which is sufficient to permit a sonic standing wave to be propagated therein.

8. An earth excavating and conveyor mechanism comprising:

cylindrical cutter means having an open end adapted to engage substantially dry earth to be fluidized and excavated;

elastic resonator means acoustically coupled to said cutter means at an antinode of said resonator means;

sonic oscillator means acoustically coupled to said elastic resonator means whereby an alternating force is imparted to said resonator means and to said cutter means for loosening earth engaged by said cutter means;

means for admitting ambient air through said cutter means to aid fluidization of the earth loosened by said cutter means;

earth conveying means comprising a rigid tubular conduit positioned adjacent said cutter means; and

continuously operated means for maintaining said loosened earth in a fluidized state while said loosened earth is continuously moving from said cutter means to said conveying means.