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METHOD AND APPARATUS FOR SONIC JARRING WITH FLUID DRIVE

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FIG. 1

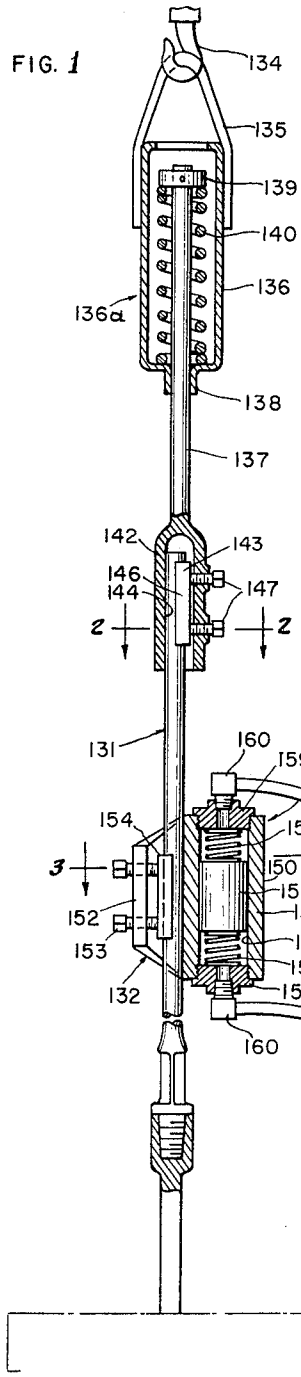


FIG. 2

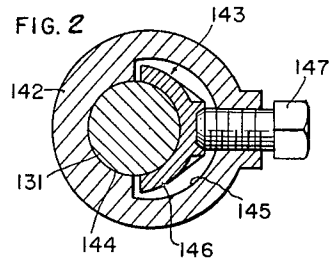
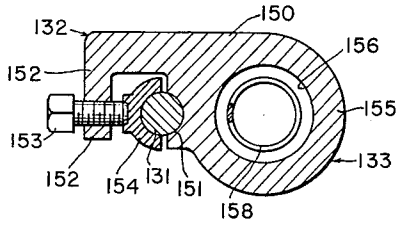


FIG. 3



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FIG. 4

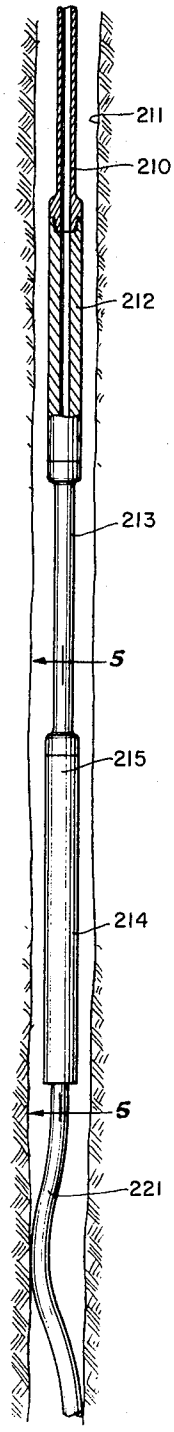


FIG. 5

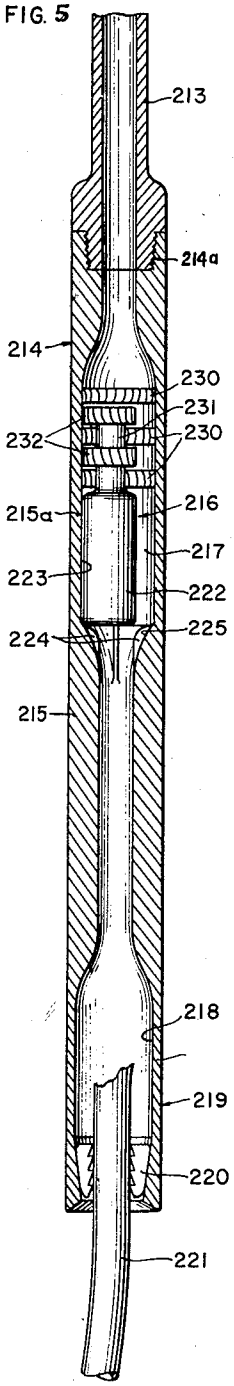


FIG. 6

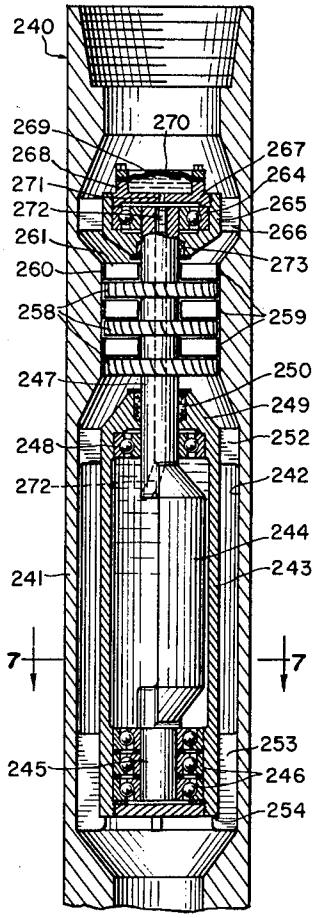
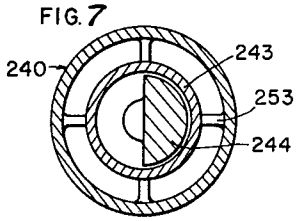


FIG. 7



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United States Patent Office

3,168,140

Patented Feb. 2, 1965

3,168,140

METHOD AND APPARATUS FOR SONIC JARRING WITH FLUID DRIVE

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Original application Feb. 20, 1956, Ser. No. 566,628, now Patent No. 2,972,380, dated Feb. 21, 1961. Divided and this application Dec. 22, 1960, Ser. No. 77,670
3 Claims. (Cl. 166—46)

This invention relates generally to methods and apparatus for loosening and/or pulling or removing elongated objects stuck or frozen by static friction in other objects, for example, pipe such as liners, casing, drill pipe, sucker rods and pump plungers, or other objects or "fish" which have become stuck by static friction in oil wells. It relates, in a still broader aspect, to longitudinal movement of elognated members in a surrounding medium, and accordingly, is applicable not only to removal of stuck members, as pipe fast in a well bore, but to driving frictionally bound members downwardly in the well, and, in another application, to driving of piles into the earth.

One primary object of the invention is the provision of improved methods and apparatus for loosening and/or moving frictionally stuck or bound members by transmitting acoustic waves therethrough under conditions of standing wave resonance, utilizing novel apparatus and procedures by which very tightly bound members may be readily broken loose and removed, or driven deeper.

This application is a division of my parent application, Serial No. 566,628, filed February 20, 1956, now Patent No. 2,972,380, entitled Acoustic Method for Moving Objects Held Tight Within a Surrounding Medium.

The invention provides for setting up in the elongated stuck object a resonant acoustic longitudinal standing wave of high amplitude, thereby causing a cyclic force in a longitudinal direction to be exerted by the object in the cement, or other surrounding holding medium, at the stuck point, as well as a cyclic elastic contraction and expansion of the object at the stuck point, which is at a velocity node of the standing wave. Impedance mismatch and phase differences between the object and the surrounding media in which the same is frozen prevent the surrounding media from contracting and expanding either in step with or to the same degree as that which the stuck region of the object may readily undergo under proper drive. Frictional resistance losses in any media also results in failure to transmit the alternate expansion and contraction from the stuck object to the media without material loss of amplitude. The lesser amplitude of the periodic contraction and expansion of the surrounding media means that the stuck object is clear of the media for a time during each contraction half cycle. Moreover, phase difference between the expansion and contraction cycles of the stuck object and the surrounding media means that the object is undergoing contraction during at least a part of the time that the surrounding media is undergoing its expansion half-cycle, with resulting still greater momentary clearance. In effect, the surrounding media "stand back" while the stuck object periodically contracts. Such action rapidly loosens the stuck or frozen object, and it may then be elevated by pulling upwardly on it. It is often desirable to pull upwardly on the object while it is undergoing its cyclic motion relative to the surrounding media, with the result that it moves upwardly by small increments as successive momentary clearances occur. In other cases, it is found preferable to permit the object, or a large longitudinal fraction thereof, to stand in compression, with the result that the object moves downward as it is loosened. After complete loosening, it

may be readily elevated. A feature of the invention is the control of the tension and/or compression in the casing to accomplish most advantageous performance in any given case.

In order to achieve the above described loosening action, I have found it necessary to transmit relatively powerful acoustic waves down the frozen rods, pipe, fish, etc., to the site where the object is stuck in the cement, or other holding medium, whereby to develop cyclic forces working against and overcoming the holding strength of the cement or other holding medium on the stuck object, and to accomplish this, certain novel relationships between the source of the acoustic waves, the stuck object, and any supporting means for the equipment, have been found to be of prime importance. In this connection, I utilize the concept of mechanical impedance, which, in this case, signifies the ratio of total cyclic peak force to displacement velocity at any given point in the acoustic wave system. The stuck region of the object is a region of high impedance, being at a velocity node of the standing wave system, while the upper end of the object is a region of lower impedance, being at a velocity antinode of the standing wave system. The acoustic wave source may be a very powerful mechanical vibrator. Now, I have found that it is of utmost importance, if the necessary substantial power for tightly stuck jobs is to flow from the wave generator into the object in which the standing wave is to be developed, that the coupling between the generator and the object have an acoustic impedance which is of at least as high an order of magnitude as that of the upper end portion of the object at the coupling point. This impedance requirement may be met by use of a firm or rigid coupling means, for example serrated wedge slips, or mechanical clutch jaws, acting directly between the generator case or frame and the object. A low impedance coupling i.e., of lower order than that of the upper end of the object, involving, for instance, a flexible element, such as a common suspension cable, or the like, lacks the ability to transmit the high cyclic force that is available from the necessary high power generator, and apply it to the pipe. Thus a high impedance coupling, i.e., one of an impedance magnitude of an order comparable to that of the upper end portion of the object at the point where the coupling is to be made thereto, is an absolute requisite, and is satisfied by any mechanical coupling device of sufficiently high impedance. I sometimes prefer for this purpose a coupling device comprising well known serrated wedge slips rigidly connected with the generator and engaged directly with the object.

Also any supporting or suspension means for the acoustic wave generator must, I have found, have a relatively low mechanical impedance, and may be a flexible cable, desirably including a spring vibration-isolator, or other relatively compliant element, so as to prevent material transmission of vibratory power through such supporting or suspension means.

Still further, I have found it highly important to employ an acoustic wave generator which is operable at a resonant frequency of the stuck object, and one whose output impedance is comparable to the impedance of the object at the point of coupling thereto.

An important incident of the setting up of the described resonant acoustic standing wave in the pipe or other member to be loosened is an energy storage property inherent in resonant systems of the character in question. A large quantity of acoustic energy is periodically delivered to the vibrating pipe or rod string, stored therein, and periodically released therefrom so as to deliver large cyclic forces to the stuck point. The resonant pipe or rod string thus inherently functions as a large energy storage reservoir, giving the system a

high Q factor, i.e., large flywheel effect, comparable to the tank circuit of an electric oscillator, and assuring large energy delivery and corresponding force application to the stuck region of the object to be loosened.

A particular form of my invention specifically covered in this divisional application embodies a fluid-driven mechanical wave generator or oscillator for setting up the sonic wave action in the elongated stuck object. My fluid drive system inherently possesses a certain degree of softness, flexibility or "mushiness" in its transmision characteristics that is unfortunately lacking in purely mechanical drives, which tend toward roughness in operation. The fluid driven oscillator is thus better able to run smoothly at the resonant frequency.

Particularly when the oscillator is in a down-hole location, a fluid transmission column from ground surface to oscillator is of unique advantage. Such a long fluid column permits the down-hole oscillator to lock-in at various resonant frequencies with increased facility, in view of the "yield" or "give" in the fluid column. The oscillator is, in other words, because of the soft or flexible fluid link, fairly independent of flow irregularities of the fluid pump (usually a conventional piston mud pump) at the ground surface. As a matter of fact, assuming such a mud pump, and the use of drilling mud as a fluid drive medium, the alternating or reciprocating mud flow near the pump becomes substantially continuous flow at the down-hole oscillator. In addition, the fluid column affords a large energy storage reservoir, which tends toward stabilizing the operation of the oscillator, supplying always just the energy required for uniform oscillator operation.

An object of the invention is accordingly the provision of a fluid driven sonic jar.

The invention will be further understood from the following detailed description of a number of related illustrative embodiments, reference for this purpose being had to the accompanying drawings, in which:

FIG. 1 is a view, partly in elevation and partly in vertical medial section, showing an illustrative form of the invention adapted for loosening a string of well pumping sucker rods;

FIGS. 2 and 3 are sections on lines **2—2** and **3—3**, respectively, FIG. 1.

FIG. 4 is an elevation of another embodiment of the invention;

FIG. 5 is a section taken on line **5—5** of FIG. 4;

FIG. 6 is a vertical medial section showing a modifica- of FIG. 5; and

FIG. 7 is a section on line **7—7** of FIG. 6.

FIGS. 1–3 illustrate an embodiment of the invention designed for the purpose of loosening an elongated elastic object or column, in this case an oil well sucker rod string and or pump plunger frozen in a well by sand or other conditions. The upper end portion of the sucker rod string **129**, above well-head **130**, known usually as the polished rod, is indicated at **131**, and clamped thereto as by means of clamp **132**, is an acoustic wave generator or oscillator **133**. It will be understood that the sucker rod string **129** and deep well oil pump below the well head may be of any conventional type. Numeral **134** designates a hook understood to be suspended by conventional derrick tackle, by which it may be raised and lowered, and this hook engages a bail **135** carrying the casing **136** of a low impediance spring isolator **136*a***. A suspension rod **137** is reciprocable through an opening in the bottom of casing **136** and has at its upper end a head **139** supported on the upper end of coil spring **140** whose lower end is supported on the lower end of casing **138**. The lower end of rod **137** carries a socket **142** which receives the upper extremity of rod **131**, and this socket is equipped with a clamp **143** adapted to clamp rod **131** rigidly within the socket. As here shown, the socket may have a half round bore **144** adapted to snugly receive the upper extremity of the polished rod **131**, and with an enlarged half round bore **145** adapted to accommodate arcuate clamp member **146** which engages the rod and clamps it by means of screws **147**.

The vibration generator **133** includes a housing **150** formed with a half round seat **151** (FIG. 3) adapted to engage the rod **131**, and with a projecting arm **152** in which is mounted clamp screws **153** adapted to engage arcuate clamping member **154** engaging the rod **131** and clamping it tightly to its seat **151**.

The generator housing **150** has a vertical fluid cylinder **155** formed with a bore **156** in which is fitted a linearly reciprocating piston **157** positioned between coil compression centering springs **158** bearing against caps **159** screwed into opposite ends of bore **156**. The caps **159** are bored and threaded to receive air hose fittings **160** which are connected by air hoses **161** to opposite ends of air cylinder **162**. A piston **163** in cylinder **162** is reciprocated by connecting rod **164** driven from eccentric **165** on a shaft **166**, which may be powered by and suitable prime mover, not shown, for instance, an internal combustion engine.

On each stroke of piston **163**, air under pressure for moving piston **157** is delivered to the space in cylinder **156** at one end of piston **157** and removed from the space at the other end thereof. On the opposite stroke of piston **163**, the reverse takes place. Accordingly, piston **157** is caused to oscillate linearly within cylinder **156** between springs **158**, which alternately elongate and contract to accommodate the action, and act to retard and stop the piston at the ends of the stroke.

The described linear oscillation of piston **157**, whose mass acts on the end caps **159** of the cylinder through springs **158**, results in alternating vertical reactive forces being exerted against the generator housing, and therefore on the sucker rod string to which it is rigidly clamped. The upper end portion of the sucker rod string is thereby vertically oscillated, and longitudinal acoustic waves are accordingly set up in the sucker rod string, and transmitted to the site where the string or pump plunger is frozen within the well. The suspension means as described comprises a low impedance support, the spring isolator preventing transmission of vibration energy to the hook and derrick tackle above. A biasing force or tension can be exerted in the sucker rod string, assuring efficient transmission of power from the generator to the rod string.

The acoustic waves, transmitted down the rod string as described above from the oscillator to the point where the rod string or pump plunger is stuck in the well, are reflected from the stuck (stationary) point and reflected back up the rod string. In terms of impedance the point where the rod string or plunger is stuck is a point of high mechanical impedance, and the cyclic stresses in the string or plunger are at maximum amplitude in that region, longitudinal motion or displacement being minimized, or approaching zero. The prime mover driving the air piston **163** is then operated at a speed which, through the fluid drive system, reciprocates piston **157** of oscillator **133** at a frequency establishing in the rod string between the stuck point and said oscillator, a resonant acoustic standing wave of an odd number of quarter wavelengths, such as represented in FIG. 4 of my aforementioned Patent No. 2,972,380. The operator readily recognizes that he has set the prime mover to drive the system at this condition of resonance by obvious and well-known physical manifestations of resonance, including large increases in amplitude of vibration with small variations in frequency, as in all vibratory systems operating at or approaching resonance.

It should be understood that when a resonant longitudinal standing wave is established in a column, which is stuck or immobilized against longitudinal motion at a given point, a velocity node of the standing wave must necessarily occur at the stuck or immobilized point, and that a cyclic longitudinally-directed force will be exerted in the column, at the node, against the immobilizing medium. It should be understood that forces at a node at

a free point in a column are opposed and dynamically balanced. When, however, a given column is held fast at an arbitrary point, the resonant standing wave set up in the column will have a node at the fast point, and, in general, the cyclic forces in the column on the acoustically free side of the fast point will not be dynamically balanced by like forces on the other side thereof, but will be exerted against and opposed by the immobilizing medium. Additionally, as mentioned heretofore, the elastic column, in which a longitudinal standing wave is sustained, alternately elastically dilates and contracts at the velocity antinode in step with alternating compressive and tension phases of the wave in the column. This follows from a phenomenon generally referred to as Poisson's Ratio, and consists in a radial dilation or contraction of an elastic column in response to compression or tension exerted in the column.

Returning to a consideration of FIGS. 1–3, the longitudinally-directed cyclic forces thus exerted by the rod string or pump plunger on the holding medium act to overcome the holding strength of the medium. The alternating dilations and contractions of the spring act also to overcome the holding strength of the medium. In connection with the latter effect, i.e., alternating dilation and contraction of the string, owing to impedance mismatch between the string and the medium in which it is frozen, frictional losses between the members, and cyclic phase displacements, the cyclic contractions of the string are not followed up by like contractions of the medium in which the string has become frozen, and the bond is quickly broken.

A unique advantage in the system of FIGS. 1–3 is the softness or flexibility of oscillator drive afforded by the described fluid drive means, contributing toward ability of the oscillator to run smoothly and evenly at the resonant standing wave frequency desired to be established in the stuck column or rod string.

In FIGS. 4 and 5 is shown another embodiment of the invention, in this case characterized by a gyratory type of down-hole vibration generator or oscillator in a tool suspended in the well from a string of drill pipe and operated by down-hole turbine means motivated by fluid pumped down the drill string from the ground surface. Drilling mud fluid can be used, or crude oil, if available, or water. Numeral **210** designates the lower end portion of a hollow drill stem suspended in well bore **211**, and to the lower end of drill stem **210** is coupled the upper end of a section of heavy drill collar **212**. Coupled to the lower end of the latter is a relatively slender and flexible pipe section **213**, and pipe section **213** suspends the vibratory tool **214** by means of a coupling indicated at **214***a*. The tool **214** comprises a mandrel or hollow body **215** containing a turbine driven vibration generator **216**.

The body or mandrel **215** is of good elastic material, such as steel, and relatively thick-walled excepting for an intermediate section **215***a*, wherein is formed an enlarged cavity **217** for accommodation of generator **216**, and a lower end section **215***b* which is formed with the socket **218** of an overshot grappling tool **219**. The latter is conventionally shown with tapered extremity containing wedge slips **220** adapted to rigidly secure a fish **221**.

The generator **216** comprises a cylindrical inertia roller **222** adapted to roll around a cylindric raceway **223** formed inside body section **215***a*. The lower end of roller **222** is vertically supported by the curved shoulders of ribs **224** formed inside body **214** at the lower end of the generator cavity **217**, the interior walls of section **215***a* joining the thick-walled section below by a tapered surface **225** so as to provide adequate clearance for downward liquid flow from the chamber **217**.

Tightly mounted in the upper part of chamber **217**, above roller **222**, are a plurality of vertically spaced turbine stators **230**, and between these, on an axial stem **231** extending upwardly from roller **222**, are tightly mounted a plurality of turbine rotors **232**. Fluid pumped down through drill stem **210**, inertia collar **212**, flexible pipe **213** and into the upper end of body **215**, is set into rotation in passing stators **230**, and imparts rotation to rotors **232** and therefore to inertia roller **222**. The roller accordingly rolls about raceway **223**. It is of interest to note that, since the diameter of roller **222** is less than the diameter of its raceway **223** but is greater than the radius of the raceway, it will rotate on its axis at a lesser number of revolutions per second than its number of trips per second around the periphery of the raceway. Any slip between the surfaces of the roller and the raceway will affect this difference. It is the number of trips per second around the periphery of the raceway that determines the frequency of the generator.

The operation of the acoustic wave generator is as follows: The roller **222** rolling around the raceway **223** exerts on the body **215** a centrifugal force, and it will be seen that this force, rotating about the longitudinal axis of the body **215**, elastically bends the surrounding portion of the body, moving it around in a gyratory path. The body **215** does not bodily rotate, but has a gyratory action which, upon analysis, will be seen to be the resultant of two perpendicular transverse linear harmonic vibrations in quadrature. A generator of this type is described more particularly in my Patent No. 2,960,314. As described in said patent, the elastic gyratory deformation of the portion of the body **215** surrounding the inertia roller **222** is propagated by corresponding elastic waves traveling longitudinally along the body **215**. These are transmitted to and along the fish **221** to the site where the latter is stuck in the well, where the wave is reflected back; and also, in the opposite direction, into and along the flexible pipe to the point of junction of the latter with the end of the heavy inertia collar **212**, where the wave is reflected back. Under such conditions, standing wave resonance is automatically developed along the body **215**, the fish down to the stuck point, and the flexible pipe **213** up to the inertia collar **212**, with a velocity antinode (region of maximum deformation amplitude) at the site of the generator, and velocity nodes at the point where the fish is stuck in the well, and at the junction of flexible pipe **213** with collar **212**. The turbine driven roller is constrained by back reaction from this resonant system to roll around its raceway at the resonant frequency. The fluid drive system particularly accommodates this resonant frequency operation notwithstanding fluctuations in fluid pump operation. There may be additional nodes and antinodes in the system under certain conditions, but those described above are characteristic of the system.

The described resonant standing wave developed in the system with a velocity node at the side where the fish is stuck in the well, tends rapidly to loosen the fish. The gyratory wave action described, while propagated longitudinally of the tool string, takes place in a transverse plane. At the location where the fish is frozen in the well, where a velocity node of the wave occurs, the elastic stress magnitude is maximized, and gyratory motion minimized. Under these conditions, the fish is powerfully "worked," and rapidly broken free of whatever has been holding it fast.

In FIGS. 6 and 7 is shown a modification of the system of FIGS. 4 and 5, being similar to that of FIGS. 4 and 5 excepting for employment of a modified type of gyratory acoustic wave generator. The tool **240** of FIGS. 6 and 7 may be considered a substitution for the tool **214** of FIGS. 4 and 5, and it will be understood that the device of FIG. 6 may be suspended from a drill string similar to that shown in FIG. 4, and may be equipped with an inertia collar and a flexible pipe section similar to the elements **212** and **213** of FIG. 4, the upper end of the tool **240** being understood to be coupled to the lower end of a flexible pipe such as **213**. Further, the lower end portion of the tool **240** may be formed with a grappling tool, similar in all respects to that provided at the lower end of the tool **214** of FIGS. 4 and 5.

With the understanding stated in the preceding paragraph, the tool **240** comprises a hollow body **241**, generally similar to the body **214** of FIG. 5, the lower portion of which is omitted from FIG. 6. The bore through the hollow body **241** has an enlarged cavity **242** in which is contained, at an annular spacing from the corresponding thin wall section of the body, a cylindrical case **243** for an unbalanced or eccentric rotor **244**. This rotor has at the bottom a shaft **245** mounted in suitable bearings **246** placed in the lower end of casing **243**, the lower end of the latter being closed by a threaded closure disc. Rotor **244** has extending upwardly from its upper end a shaft **247**, supported in a bearing **248** placed in the upper end of casing **243**. The casing **243** has an upper end portion **249** formed with suitable packing **250** for shaft **247**. The casing **243** is positioned within the thin wall portion of body **241** by means of ribs **252** extending inwardly from body **241** at the top, and similarly by ribs **253** at the bottom, the last mentioned ribs being also formed with shoulders at **254** for vertical support of the casing **243**.

The rotor shaft **247** carres a plurality of axially spaced turbine rotors **258**, and above each of these is a stator **259**. The stators comprise rims **260** tightly seated in the bore of the body **241**, and a multiplicity of radial vanes **261**.

The upper extremity of rotor shaft **247**, above the hydraulic turbine described in the preceding paragraph, is provided with an outboard bearing at **264**, carried within a cup **265**, and has an upwardly extending annular wall **268** forming a chamber **269** which is closed at the top by a flexible diaphragm **270**.

Cap **267** has a central aperture **271**, which communicates with a longitudinal passage **272** extending longitudinally through rotor **247** and opening at the bottom inside rotor case **243**. The cup **265** has at the bottom a suitable packing **273** forming a fluid tight seal with shaft **247**. Casing **243** is filled with oil and this oil extends upwardly through passageway **272** and aperture **271** into chamber **269**. In the operation of the apparatus, the hollow pipe string carrying the device **240** is filled with driving fluid, and the hydraulic static head of this fluid imposed on the flexible diaphragm **270** pressurizes the oil system and prevents leakage of the external driving fluid into the oil system through the various packings.

An inspection of FIG. 6 will reveal that a fluid passage has been formed downwardly through the tool **40** around the outside of the bearing cup **265** to the region of the turbine, and from the lower end of the turbine around the outside of rotor housing **243** to the downwardly extending bore below. The fluid is deflected by the stator vanes to drive the rotors of the turbine, and therefore the unbalanced inertia rotor **244**. Rotation of the latter generates a centrifugal force, the reaction of which is transmitted through the rotor shafts, the rotor casing **243**, and the supporting ribs **252** and **253** to the body **241**. Apart from the detailed action of the specific gyratory acoustic wave generator of FIG. 6, the system is the same as that of FIGS. 4 and 5, and the description need not be repeated.

The several embodiments now disclosed are representative of fluid driven oscillators in acoustically vibratory jars, and will be seen to have the advantages stated in the introductory paragraphs of this specification.

The "down-hole" oscillator embodiments of FIGS. 4–7, with their long fluid column drive means, afford a large degree of softness or flexibility of oscillator drive, which permits smooth and even oscillator operation at the resonant frquency of the system, notwithstanding irregularities of fluid pumping action at the ground surface.

The invention has now been described through illustration of a number of illustrative embodiments. It is to be understood, of course, that these are merely illustrative of various different inventive forms in which the broad invention may be embodied, and are not to be considered as exhaustive of the complete range of equivalents coming within the broad scope of the appended claims.

I claim:

1. The method of moving a column system embodying a portion held fast in the earth and a portion extending therefrom which is acoustically free and in a condition to sustain a vibration wave pattern, that comprises: acoustically coupling a fluid-drive vibrator to said acoustically free portion of said column system at a point spaced from said held portion, and fluid driving said vibrator at a frequency which produces resonance of said column system and which establishes a vibration pattern with cyclic impulse force in said column system within the region of said held portion, said resonant frequency and said vibration pattern being established independently of minor irregularities in fluid drive effort by reason of inherent fluid drive flexibility.

2. The method of moving a column system embodying a portion held fast in the earth and a portion extending therefrom which is acoustically free and in a condition to sustain a vibration wave pattern, that comprises: acoustically coupling a fluid-drive vibrator to said acoustically free portion of said column system at a point spaced from said held portion, then applying a bias force to said column system tending to free said held portion thereof from the earth, and simultaneously fluid-driving said vibrator at a frequency which produces resonance of said column system and which establishes a vibration pattern with cyclic impulse force in said column system within the region of said held portion, whereby said bias force and said cyclic impulse force act in combination to move said column system against the holding resistance of the earth.

3. The method of moving a column system embodying a portion held fast in a bore in the earth deep below ground level, and a portion extending upwardly therefrom which is acoustically free and in a condition to sustain a vibration wave pattern, that comprises: lowering into said bore and acoustically coupling to said acoustically free portion of said column system at a point thereon spaced from said held portion, a fluid-drive vibrator, and pumping fluid from the ground level down said bore to said fluid-drive vibrator at a rate to drive said vibrator at a frequency which produces resonance of said column system and which establishes in said system a vibration pattern with cyclic impulse force in said column system in the region of said held portion thereof, said resonant frequency and said vibration pattern being established independently of minor irregularities in fluid-drive effort by reason of inherent fluid-drive flexibility.

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