Oct. 13, 1964 A. G. BODINE, JR 3,152,642

ACOUSTIC METHOD AND APPARATUS FOR LOOSENING AND/OR LONGITUDINALLY MOVING STUCK OBJECTS

Filed Jan. 30, 1961 5 Sheets-Sheet 1

Fig. 1

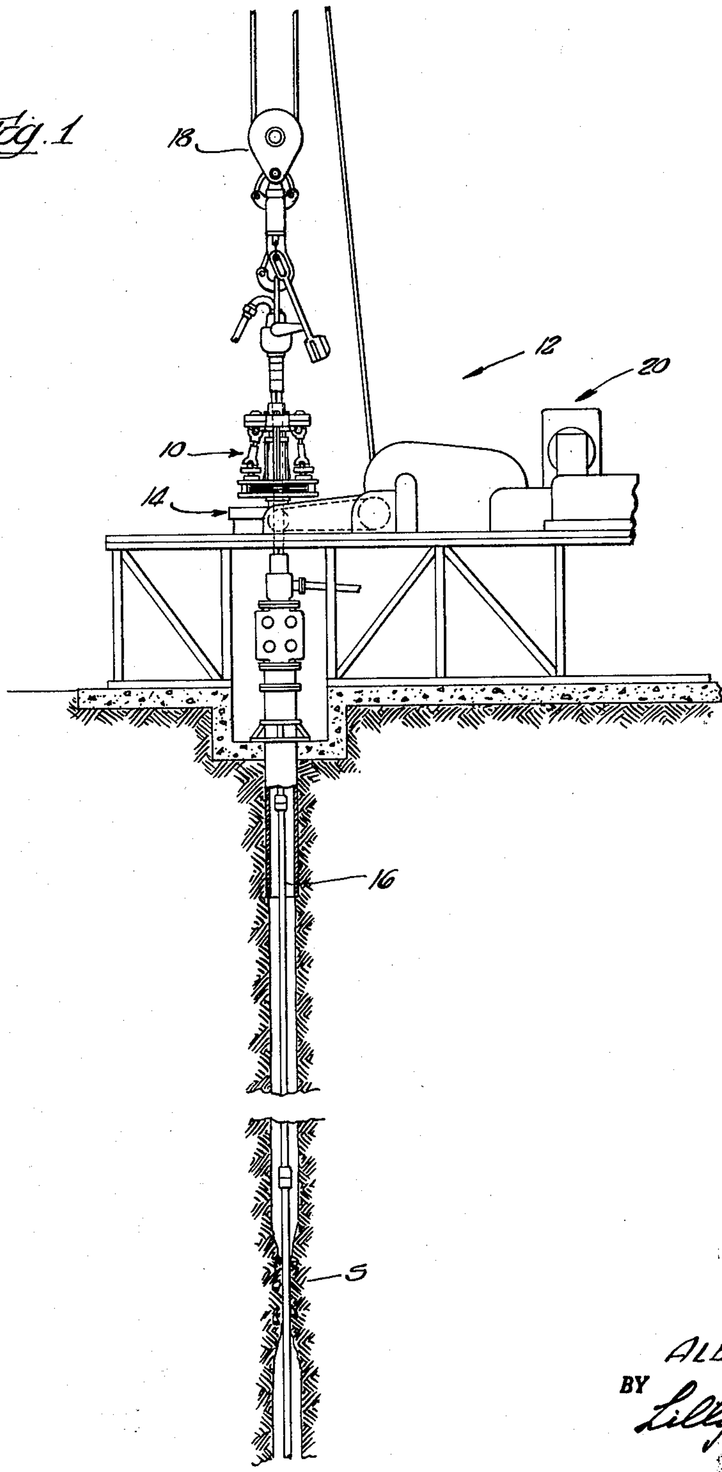

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Fig. 2

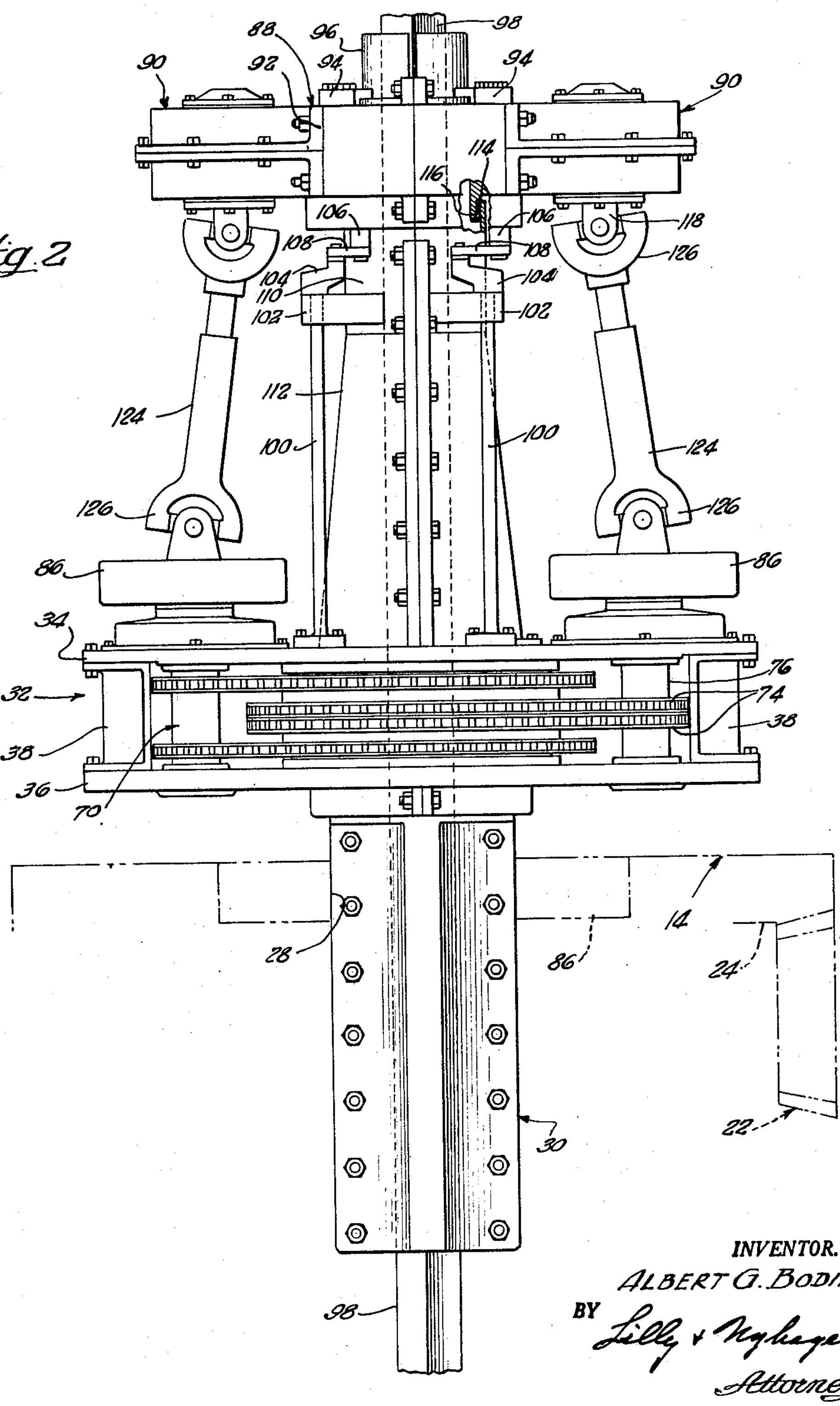

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Fig. 3

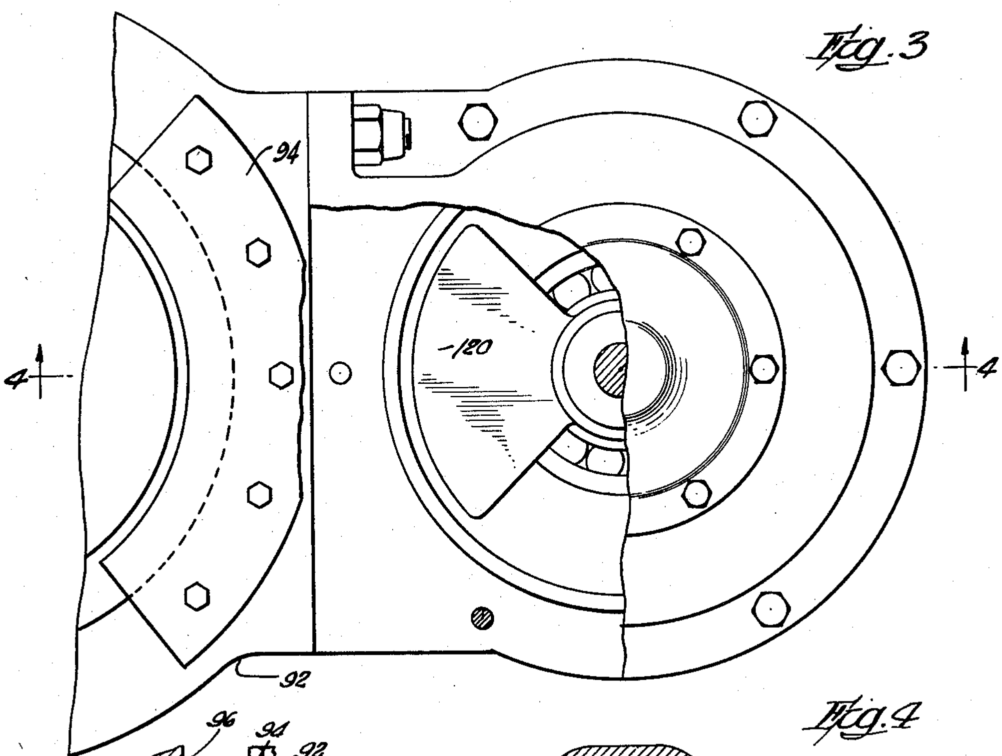
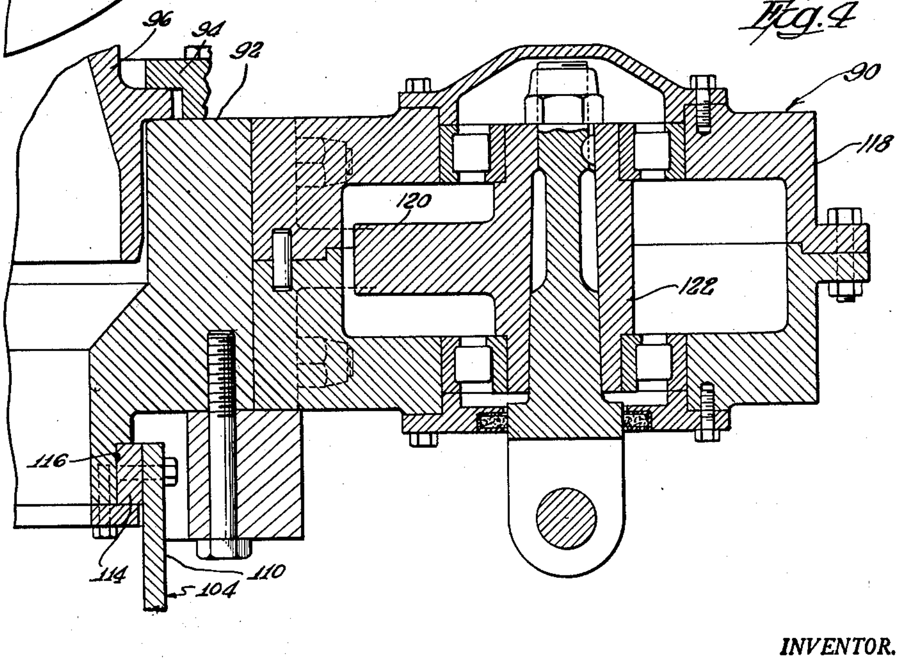


Fig. 4



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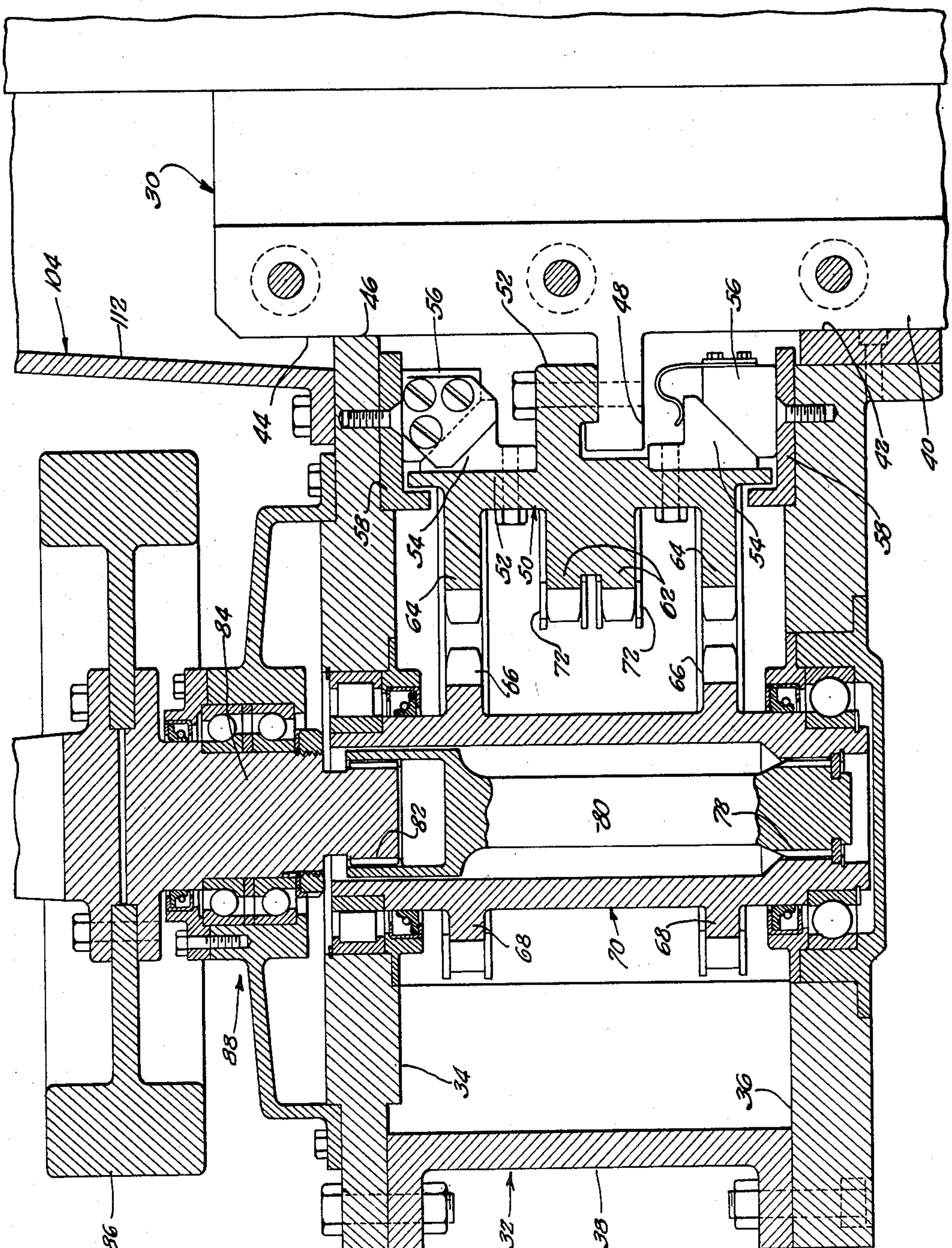

Fig. 5

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Fig. 6

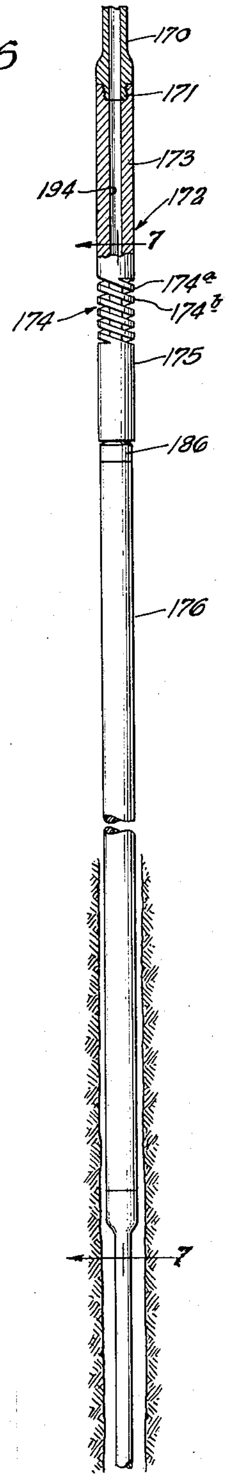
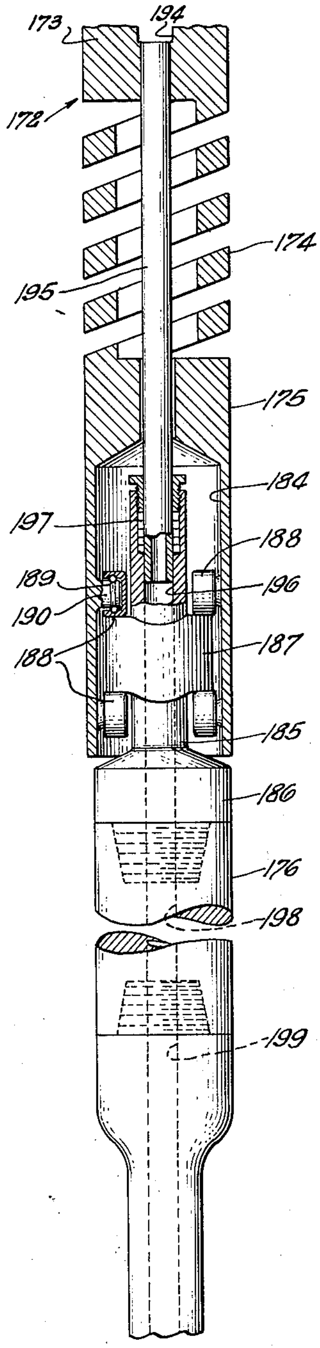


Fig. 7



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United States Patent Office

3,152,642

Patented Oct. 13, 1964

3,152,642

ACOUSTIC METHOD AND APPARATUS FOR LOOSENING AND/OR LONGITUDINALLY MOVING STUCK OBJECTS

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Filed Jan. 30, 1961, Ser. No. 85,909
6 Claims. (Cl. 166—46)

This invention relates generally to an acoustic method and apparatus for loosening and/or moving objects which are tightly held or frozen in a surrounding medium.

The present application is a continuation-in-part of my co-pending applications Serial No. 566,628 entitled Acoustic Method and Apparatus for Moving Objects Held Tight Within a Surrounding Medium and Serial No. 644,774 entitled Acoustic Method and Apparatus for Driving Piles.

Typical applications of the present invention are loosening and/or removing pipe, sucker rods, casing or drill pipe, which has become stuck or frozen in an oil well as well as maintaining a drill string loose throughout the drilling operation; and loosening and/or removing structural members, electrical conduits, plumbing, and other similar objects which are buried in the earth or embedded in concrete or masonry.

Taking for illustration a drill string stuck in a well due to cave-in of the surrounding earth formation, for example, the invention in the preferred form provides for applying a torsional oscillation or vibration to the upper end of the string of a frequency which creates a resonant standing wave of high amplitude in the string. I have found that this type of resonant operation creates large cyclic torsional forces which are exerted by the drill string on the surrounding medium at the point where the string is stuck or frozen in the medium and which are of sufficient magnitude to loosen even very tightly bound drill strings.

As indicated above, the method and apparatus of this invention are useful not only in loosening a stuck drill string, but also preventing a drill string from becoming stuck during a drilling operation, as well as loosening and/or removing other kinds of object which are buried in the earth or embedded in concrete or masonry.

One illustrative form of the present apparatus is uniquely designed for permanent installation in a well drilling rig. This form of the apparatus becomes operative during a drilling operation whenever the drill string starts to stick. Complete jamming of the drill string is thereby avoided.

A second and simplified form of the invention is installed directly in the drill string and also becomes operative whenever the drill string starts to stick.

In both illustrative forms of the invention the power of the elastic vibrations delivered to the stuck drill string is made proportional to the reaction torque developed in rotating the drill string and drill bit thereon. This is accomplished by arranging the torsional vibration mechanism in such a way that the torque for rotating the drill string is delivered to the latter through and activates the mechanism.

With this preliminary discussion in mind, a general object of the invention may be stated as being the provision of an acoustic vibration method and apparatus for loosening and/or moving objects which are stuck or bound in a surrounding medium as well as preventing complete jamming of a rotating drill string or other similar object which is subject to become stuck or bound in a surrounding medium by transmitting through the objects acoustic vibrations which create in the objects a condition of elastic standing wave resonance.

A highly important object of the invention is to provide

acoustic torsional vibration method and apparatus of the character described which are adapted for use in connection with a rotary drive mechanism, such as a rotary well drilling mechanism, for driving the object to be vibrated and in which the torsional vibrations are generated by power extracted from the rotary driving mechanism in such a way that the power of the generated torsional vibrations is proportional to the torque delivered to the driven object.

Another important object of the invention, closely associated with the foregoing object, is to provide acoustic torsional vibrating apparatus of the character described which is operatively connected between the rotary driving mechanism and driven object in such a way that the driving torque is delivered to the object through and activates the vibrating mechanism whereby the proportionality between torque and vibration power is attained automatically.

Yet another important object of the invention is to provide an acoustic torsional vibrating apparatus of the character described which automatically becomes operative to generate torsional vibrations in response to an increase in the reaction torque developed by the driven object such as a rotary drill string whereby complete jamming of the drill string or other rotating object is avoided.

A further object of the invention is to provide an acoustic torsional vibration method and apparatus which are useful not only in well drilling but also in the loosening and removal of structural members, electrical conduits, plumbing and other similar objects from the earth, concrete or masonry.

Other objects, advantages and features of the invention will become apparent as the description proceeds.

The invention will now be described in detail by reference to the attached drawings, wherein:

FIG. 1 illustrates one form of the present apparatus permanently installed in a rotary well drilling rig of conventional design;

FIG. 2 is an enlarged side elevation of the present apparatus shown in FIG. 1;

FIG. 3 is a further enlarged top plan view of the right hand half of the apparatus in FIG. 2 with parts broken away for clarity;

FIG. 4 is a section taken along line **4—4** in FIG. 3;

FIG. 5 is an enlarged vertical section through the left-hand torsional vibration generator in FIG. 2;

FIG. 6 is a side elevation partly broken away as an alternative form of the invention; and

FIG. 7 is an enlarged section taken along line **7—7** in FIG. 6.

FIGS. 1 to 5 of these drawings illustrate the form of my torsional vibration generator **10** which is installed in a conventional rotary drilling rig **12**, such as is used in oil well drilling. In FIG. 1 we see that the vibration generator **10** is located just above the rotary table **14** of the rig and is operatively connected between the drill string **16** and hoisting equipment **18**. From this it can be seen that the hoisting equipment **18** can be used to raise and lower the generator **10** and drill string **16** and thereby to control the vertical tension or compression in the drill string.

Rotary table **14** is driven in the usual way by an engine powered drive **20** through a beveled gear **22** meshing with a beveled gear **24** on the rotary table **14**.

Mounted on the rotary table **14** for rotation therewith is a master bushing **26**. This bushing has a central square opening **28** in which is slidably fitted a tang **30**. Tang **30** is thus keyed to and rotates with the rotary table but is free to move vertically in the master bushing **26**.

Tang **30** extends upwardly and axially through a drive sprocket assembly **32**. This sprocket assembly comprises upper and lower circular plates 34 and 36 which are spaced and joined by segments 38 to which the plates are bolted, as shown. Plates 34 and 36 and segments 38 together make up the housing for the sprocket assembly. Tang 30 has a round neck portion 40 journalled in a central bearing bore 42 in the lower plate 36 and an upper trunnion portion 44 journalled in a central bearing bore 46 in the upper plate 34.

Between the plates 34 and 36, tang 30 has a radial flange 48. An annular sprocket unit 50 encircles the tang between the plates 34, 36 and has an internal annular flange 52 which rests on and is bolted to the tang flange 48, as shown.

Sprocket unit 50 comprises a hub 52*a* extending to opposite sides of its flange 52. Bolted to the inside of this hub, adjacent its ends, are upper and lower beveled bearing rings or ring segments 54. Bearing ring segments 54 slidably contact upper and lower beveled bearing rings or ring segments 56 seating in and slidably turnable on hardened ring inserts 58 which are bolted to the plates 34 and 36, respectively. In the present case, the upper and lower ring members 54 and 56 are in the form of ring segments, and a spacer 57 is disposed between the ends of upper ring segments 54 and 56. This spacer is not shown in the case of the lower ring segments 54 and 56, but may be used, as above. The rings or ring segments 56 will be readily understood to consist of complete circular rings, which may be split diametrically into two halves for assembly, as in common practice. If desired, gaps may be provided at the ends, filled by spacers 57. The rings or ring segments 56 will thus not be wedged inwardly from the position illustrated because of interengagement at their ends. These bearing rings or ring segments 54 and 56 serve as axial thrust bearings supporting the tang 30 realtive to the plates 34 and 36. They turn together with the hub 50, and relatively to the plates 34 and 36 in the tang 30.

Integrally formed on the hub 52 of the sprocket unit 50 are a centrally located pair of sprockets 62 and a pair of sprockets 64 located adjacent the ends of the hub. A pair of sprocket chains 66 are trained about the sprockets 64 and a pair of sprockets 68 rigid on a stub shaft 70. A second pair of sprocket chains 72 are trained about the sprockets 62 and a pair of sprockets 74 rigid on a second stub shaft 76 located diametrically opposite the first stub shaft 70. Stub shafts 70 and 76 are rotatably supported at their ends in plates 34 and 36 by bearings as shown.

As shown in FIG. 5, stub shaft 70 is hollow and is internally keyed at 78 to a drive shaft 80 which extends axially through the stub shaft. The upper end of this drive shaft is keyed at 82 to the shaft 84 of a flywheel 86. The wheel shaft 84 is rotatably supported on the plate 34 by the bearing assembly 87. Stub shaft 76 is similarly connected to a second flywheel 86.

In FIG. 2, the numeral 88 designates the torsional vibration generator assembly of the illustrated apparatus. This assembly is comprised of two diametrically opposed torsionel vibration generators 90 soon to be described. Generator assembly 88 comprises a cylindrical mounting trunnion 92 to which is rigidly fixed, by clamps 94, a split clamp sleeve 96. This clamp sleeve is rigidly clamped to the kelly bar 98 which extends downwardly and loosely through the apparatus and beyond the lower end of the tang 30 for connection to the drill string 16.

Extending between the lower sprocket assembly and the upper generator assembly, are a plurality of torsion spring rods 100. The lower ends of these springs are bolted to the upper plate 34 of the sprocket assembly housing. The upper ends of the torsion spring pass rotatably through bearing blocks 102, the latter fixed to a pedestal 103 soon to be described, and to the upper end of rods 100 are fixed the hubs of swinging arms 104. Pivotally connected between the other ends of these arms

and bearing pin extensions 106 on the trunnion 92, are links 108.

As will shortly be seen, during operation of the illustrated apparatus, a torque is created which tends to rotate the sprocket assembly housing in one direction. The torsion spring rods 100 transmit this torque to the trunnion 92 from which it is delivered to the kelly bar 98. This places an effective bias torque on the drill string 16 while it is being torsionally vibrated by vibrator assembly 88.

We return now to the pedestal tube 103 mentioned above. This pedestal, which is a rigid metal sleeve-like structure, has an upper neck portion 110 to which the torsion spring bearing blocks 102 are secured, and a lower tapered portion 112. Rigidly joined internally to the upper end of the pedestal is a bearing bushing 114. This bushing seats in a bearing groove 116 formed in the lower end of the trunnion 92. The lower end of the pedestal is bolted to the top plate 34 of the sprocket assembly housing, as shown.

From this description, it is evident that the entire apparatus in effect hangs on the kelly bar 98 by virtue of the sole connection between the apparatus and kelly bar at the clamp 96. Further, the pedestal 103 and sprocket assembly 32 thereon hang rotatably from trunnion 92 by virtue of the bearing connection 114, 116. Accordingly, the trunnion can oscillate with respect to the pedestal and sprocket assembly.

We turn now to FIGS. 3 and 4 illustrating one of the torsional vibration generators 90. Generator 90 will be seen to comprise a housing 118 which consists of two parts bolted together and to a flat side of the trunnion 92. Within the hollow interior of the housing 118 is an eccentric weight 120 on a shaft 122 which is rotatably supported at its ends in the top and bottom walls of the housing by means of the bearings illustrated. The lower end attachment 128 of the eccentric shaft 122 extends below the generator housing 118. The other torsional vibration generator 90 is identical to that just described and is attached to the diametrically opposite side of the trunnion 92.

Each flywheel 86 is drivably connected to a generator shaft 128 by a telescopic drive line 124 and universal joint connections 126. The torsional vibrators 90 are thus driven from the stub shafts 70 and 76.

In describing the operation of the present apparatus, we assume first that the drill string 16 is stuck in the well due to a cave-in for example; the drill string and kelly bar are thus prevented from rotating. Rotation of the rotary table 14 then turns the tang 30 and the sprocket unit 50 thereon. The stub shafts 70 and 76 are driven from the sprocket unit through the sprocket chains 66, 72 and in turn, drive the shafts of the torsional vibration generators 90.

It will be seen that driving of the stub shafts 70, 76 through the sprocket chain drive produces a torque on the sprocket assembly housing 34, 36, 38 which tends to rotate the housing about the tang 30. The taut sides of the chains 62 and 72 produce a couple which is responsible for this torque. This torque is transmitted through the torsion springs 100, torsion spring arms 102 and links 108 and through trunnion and its clamp 96 to the kelly bar 98. An effective torque bias is thereby exerted on the drill string 16 during operation of the torsional vibration generator 90.

The generator shafts 122 are preferably driven in the same direction of rotation by rotation of the rotary table and are oriented so that the position of the eccentric weight 120 of the generator 90 about its axis of rotation is displaced 180° from the position of the eccentric weight 120 of the other generator about its axis. In this way, all linear components of motion of the rotating eccentric weights cancel out while the rotational or torsional components of motion of the weights are additive, but periodically reverse their directions as the weights travel inside and then outside of their supporting shafts 122. The rotating eccentric weights, therefore, generate an alternating torque which causes torsional vibration of the trunnion 92, and which is applied to the kelly bar 98 through the clamp 96. This alternating torque creates elastic torsional oscillations or vibrations that travel through the kelly bar and drill string at the speed of sound within the material of the kelly bar and drill strings to the point S at which the drill string is stuck.

Upon reaching the stuck point, the elastic torsional vibrations reflect back along the drill string.

The frequency of the torsional vibration generator 90 is adjusted by adjusting the speed of the rotary table 14, to fall within the range of resonance of the drill string 16 for acoustic torsional vibrations. This frequency is easily found since the torsional vibration of the trunnion can be observed to maximize at resonance. Under these conditions the acoustic (elastic torsional) vibrations, in waves traveling down the drill string, are in phase with and reinforced by the acoustic vibrations or waves reflected from the stuck point. Under these conditions a resonant torsional standing wave, usually of an odd number of quarter wavelengths, is established in the drill string.

I have found that this type of resonant operation creates very large cyclic torques at the stuck point so that the latter undergoes a high torsional stress cycle. This stress cycle produces alternating circumferential expansion and contraction of the drill string at the stuck point which results in rapid breaking of the bond between the drill string and surrounding medium as explained more fully in my aforementioned application Serial No. 566,628. It is clear that the drill string moves when the cyclic torsional impulse force exerted on the drill string together with the torsional bias force exerted on the drill string oppose and exceed the holding strength of, or resistance to movement exhibited by, the surrounding media under the conditions of torsional standing wave action in the drill string.

It will be noted that since the trunnion clamp 96 is tight on the kelly bar 98, the complete vibrator assembly travels up and down as a unit with the kelly bar. The vertical travel of the apparatus is, of course, limited by the length of the tank 30 which must be withdrawn from the master bushing 86 of the rotary table. In other words the tang must remain in operative driving engagement with the rotary table 14. For this reason, I prefer in some instances, to make the tank 30 almost as long as the kelly bar so that the complete assembly can be located close to the top of the kelly. This locates the assembly in an elevated position in which it does not interfere with normal drilling activity around the top of the rotary table.

It is possible, therefore to use my vibrator apparatus continuously during any prolonged drilling interval when there is a constant danger of the drill string becoming stuck in the well. In this case, trunnion clamp 96 may be loosened slightly to permit the drill string to be lowered as the drilling operation progresses, and the assembly remains on the kelly even while new sections of drill pipe are added to the drill string.

An interesting and important feature of the torsion vibrator under discussion is that during the drilling operation, the flow of torque from the rotary table 26 to the drill string is through the tang 30, sprocket chains 66, 72, stub shafts 70, 76, sprocket assembly housing 34, 36, 38, torsion springs 100, trunnion 92, and clamp 96 to the kelly bar 98 and thence to the drill string.

The vibrator is designed so that the torque required to drive the torsional vibration generators 90 from the tang 30 through the sprocket chains 66, 72, up to full power output, is preferably somewhat greater than that required to rotate the drill string 98 during a normal drilling operation. Also, the torsion springs 100 are proportioned to deflect only slightly under normal torque loads. Under these conditions, the drill string is driven through the torsional vibrator with little if any action of the torsional vibration generators 90 and little if any bias torque in the drill string. As the resistance to rotation of the drill string increases, such as might occur when the drill bit or drill string begins to stick, the resistance torque exceeds the torque required to "idle" the generators 90. The generators 90 then commence to be driven powerfully from the tang 30 through the sprocket chains 66, 72, and they generate torsional vibrations which increase in intensity and frequency as the resistance to rotation of the drill string increases. These torsional vibrations, of course, aid in maintaining the drill string free.

When the generators 90 are driven, the torque which is produced on the sprocket assembly housing 34, 36, 38, is delivered to the trunnion 92 through the torsion springs 100 and then to the kelly bar and drill string through the trunion clamp 96. A bias torque is thereby exerted on the drill string which also increases in magnitude as the resistance to rotation of the drill string increase. This bias torque of course, also aids in keeping the drill string free in the well hole.

We refer now to FIGS. 6 and 7 showing a sonic elastic vibration generator which is installed in a drill string at a point between the drill bit and the surface drive mechanism. This form of generator employs sonic principles and includes a cam mechanism which generates both longtiudinal and torsional oscillations or vibrations to be delivered to the drill string.

The primary aim of this form of the invention is to achieve a frequency of the elastic vibrations which is proportioned to the difference in the rotational speed between the upper power input end and the lower power output end of the drill string.

At 170 in FIG. 6 is indicated the lower end of a conventional drill pipe stem, understood to be suspended from the usual rotary table at the ground surface, by which it may be rotated to power the loosening operation. The lower end of the drill stem is coupled at 171 to the upper end of a driving tool 172, having a long inertia mass 173, a spring section 174, and a lower section 175 equipped with means for imparting vertical reciprocation to the parts suspended therebelow. At 176 is indicated a heavy drill collar, of a length of the order of 100 feet, to the lower end of which is coupled the remainder of the drill string.

The lower end portion 175 of the tool 172 is formed with an upwardly extending bore or socket 184, and receives a stem 185 extending upwardly from a coupling member 186 coupled, as indicated, to the upper end of collar 176. Stem 185 has rigidly mounted thereon a cam collar 187 whose upper and lower edges are contoured in the form of a sine wave. This cam collar rides between rollers 188 mounted by means of bearings 189 on stub shafts 190 projecting inwardly from the walls of member 175. Accordingly, assuming collar 176 to remain rotationally stationary, by reason of its inertia, by friction in the well bore, and by being connected to a stuck drill string below, and assuming drill stem 170 and tool 172 to be rotated by the rotary table at the ground surface, the rollers 188 bearing on the sinuous outline of cam collar 187 cause the tool portion 175 to reciprocate vertically. The upper portion 173 of the tool 172 is of considerable mass, and the spring section 174 deforms as the portion 175 reciprocates, so that the massive section 173 and the drill stem above are not subject to material vibration, particularly if the spring section is tuned for the operating frequency range. The reaction of the reciprocating tool section 175, exerted through rollers 188 on cam collar 187, imposes a vertical oscillating force on the stem 185 on which the cam collar is mounted. This force results in alternate elastic elongation and contraction of stem 185, with the result that longitudinal elastic waves are transmitted down the collar 176. The above mentioned reaction also automatically applies a periodic torque to the stem 185 and collar 176 since each roller delivers its force to the cam surface of the cam collar 187 along a line of action having a torsional component.

The apparatus of FIGS. 6 and 7 is equipped with means for circulating fluid for drilling and for this purpose the fluid is pumped down the hollow drill stem, through a circulation bore 194 in the upper section 173 of tool 172, and thence through a tube 195 pressed into the lower end of section 173 and extending down through spring 174 into the upper end of hollow stem 185. The low end of tube 195 is slidably fitted into the bore 196 of stem 185. and packing is provided at 197. The bore 196 continues down through coupling 186 to the circulation bore 198 of collar 176, the circulation liquid being discharged from the lower end of the latter into the well bore. This circulation fluid washes the area where the drill string is stuck in the well, loosens and removes packed sand, and is returned up the well bore outside the tool string, carrying sand with it, much as practiced in rotary drilling.

The spring section 174 of the tool 172 is preferably milled out from solid stock, and as here shown, comprises two helical elements 174*a* and 174*b*, as may be readily understood from an inspection of FIGS. 5 and 6.

Operation consists in establishing acoustic longitudinal and torsional wave transmission in the collar 176 and drill stem therebelow by rotating the drill stem, above, as earlier described. This acoustic wave transmission is continued down through the coupling at 177 and downwardly to the site where the drill stem is stuck in the well, setting up a standing wave, and the loosening action occurs in the general manner described in connection with the earlier embodiment. The standing wave in this case is the result of both the longtiudinal vibrations or oscillations.

Acoustic standing wave resonance is established in the collar 176 and down to the high impedance point where the drill string is frozen in the well by control of the speed of rotation of a conventional rotary table (not shown) at the ground surface, by which the drill stem is turned. The occurrence of resonance is readily observed at the ground surface by increasing torque at the rotary table as resonance is approached. Characteristic audible manifestations are also readily observed at resonance. Despite the spring isolator 174, sufficient vibratory energy is transmitted up the string for these to be easily recognized.

It will be evident upon examination of FIGS. 6 and 7 that if the drill string below the cam mechanism, 187, 188 and the drill bit (not shown) turn easily there is small torque delivered through the cam mechanism, so that the cam 187 tends to move at practically the same angular velocity as the rollers 188. However, as soon as the drill tends to drag, or any of the pipe string below the cam mechanism tends to stick, the cam 187 will tend to slow down. This slowing of the cam, with continuous torque applied from above, results in substantial relative angular velocity between the rollers 188 and the cam with the results that the rollers progress around the cam and deliver substantial impulsive longitudinal and torsional energy thereto.

From the above description it can be seen that this invention employs a rotary elastic wave oscillator or vibrator which is arranged in a rotary drive system for a drill string or other column so as to be driven by the driving mechanism of the system, all in such manner that the power of the vibrations is proportional to the resistance

to rotation of the column. Another important feature which will be noted from the description is that with my invention the elastic wave vibratory or oscillatory loosening action can be applied continuously while the main column is being rotated by the rotary drive mechanism.

The invention has now been described through illustration of certain illustrative embodiments. It is to be understood, of course, that these are merely illustrative of various different 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 loosening an elastic column which is stuck in a well at a distance down from the upper end and which is acoustically free thereabove, that includes: applying a torsional bias to said column, acoustically coupling the vibratory output member of a freely operating torsional elastic wave generator to said acoustically free portion of said column at a point spaced longitudinally of the column above the stuck point and in a manner to apply an alternating torque to the column, and operating said generator at a torsional resonant frequency of the column, and at a power output level developing a cyclic force on said column at the stuck point which exceeds and opposes the force holding said column at the stuck point.

2. The method as defined in claim 1, including also the step of exerting a tension in said column and member extending down to said stuck point, whereby the column is biased to move upwardly as loosening occurs.

3. The method as defined in claim 1, including also the step of exerting a limited tension in the column extending down to a point above said stuck point and allowing the rest of the column and member to stand in compression, whereby the column is biased to move downwardly as loosening occurs.

4. The method as defined in claim 1, including also the step of causing substantially the entirety of the column to stand in compression, whereby the column is biased to move downwardly as loosening occurs.

5. In a system for loosening a pipe and the like stuck at one point in a surrounding medium and having a free end, the combination comprising: a rotary drive means for said pipe, torque transmission means operatively connecting said drive means to the free end of said pipe, a freely operating elastic wave vibration generating apparatus interposed between said rotary drive means and the free end of said pipe said apparatus including freely operating vibration generating means drivingly connected to said rotary drive means, and a vibration output body reactively connected to said generating apparatus and drivingly connected to said transmission means.

6. The apparatus of claim 5 wherein said vibration generating apparatus includes further a rotary driving member operatively interconnected with and driven by said rotary drive means, means driven by said last named member drivingly connected to said vibration generating apparatus, and a torque reaction member, interconnected between said rotary driving means and said pipe to apply a bias torque thereto.

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