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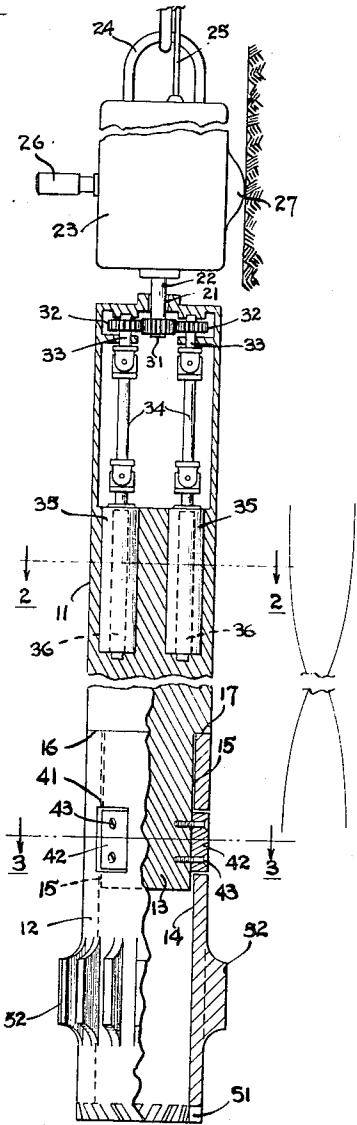
[54] **TORSIONAL RECTIFIER DRILLING DEVICE**
8 Claims, 11 Drawing Figs.

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173/49, 173/93, 175/56
[51] Int. Cl. **E21c 3/02**
[50] Field of Search **175/55, 56,**
19; 173/49, 93, 14

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ABSTRACT: The sonic energy output of a sonic generator is coupled to a torsional resonant circuit. The output of the torsional resonant circuit is in turn coupled through an acoustic rectifier device to a drive member such as a cutting tool. The rectifier provides unidirectional high level pulses of resonant sonic energy to a cutting tool causing such cutting tool to be rotationally driven in a pulsating manner.



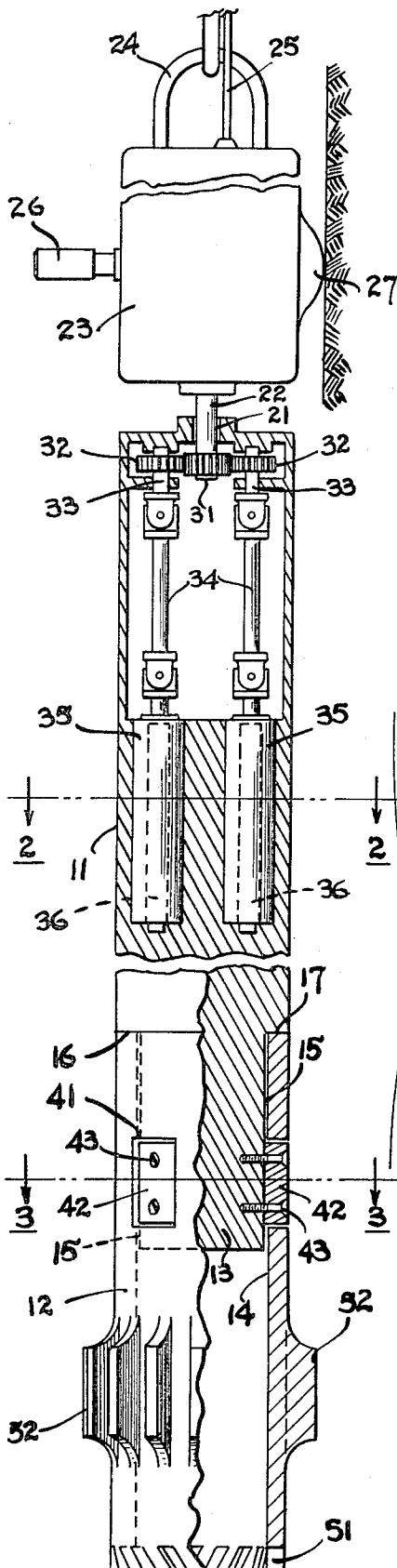


Fig. 1

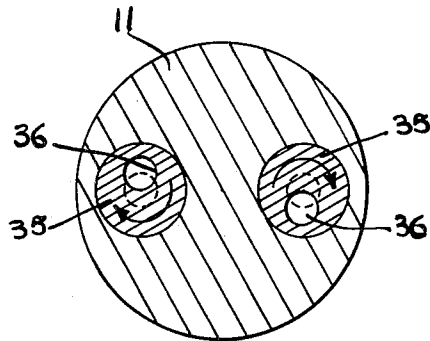


Fig. 2

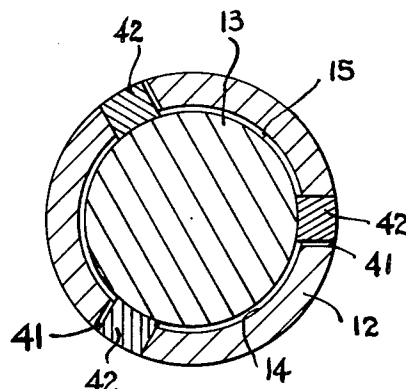
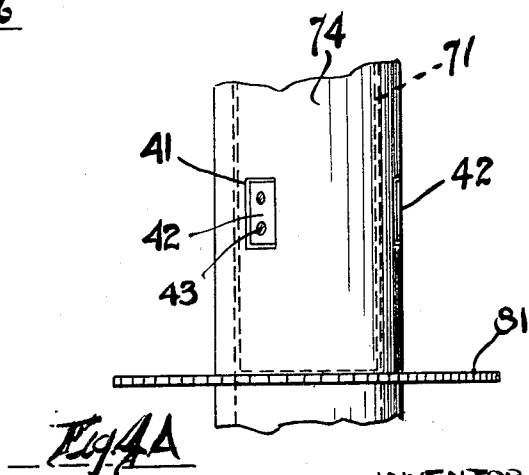
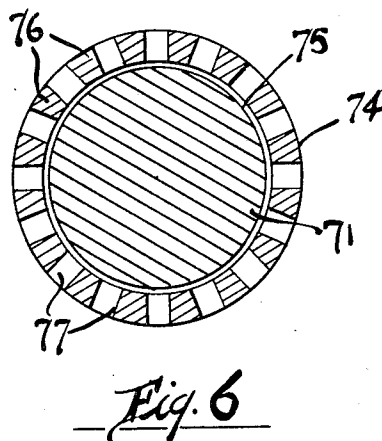
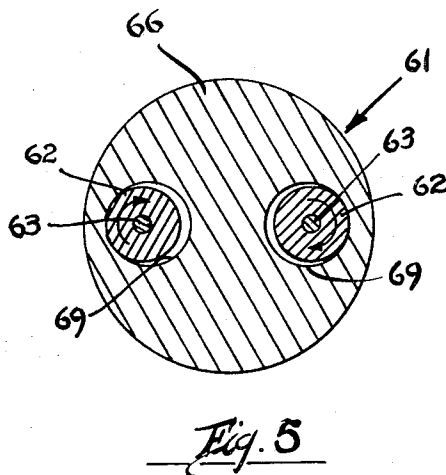
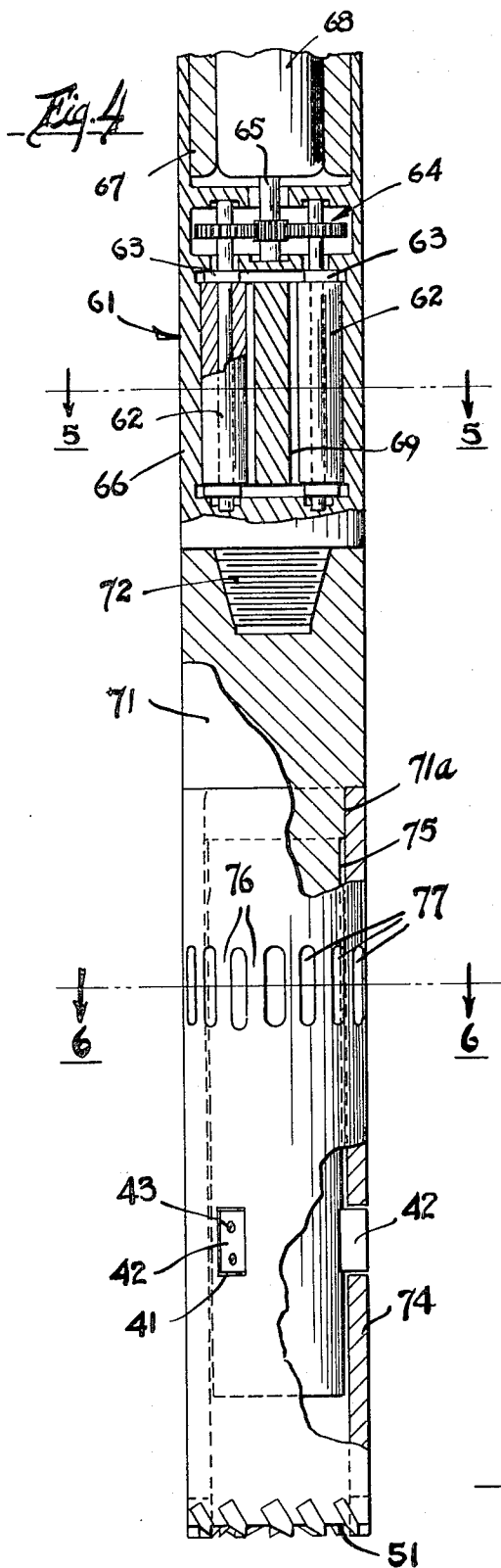


Fig. 3

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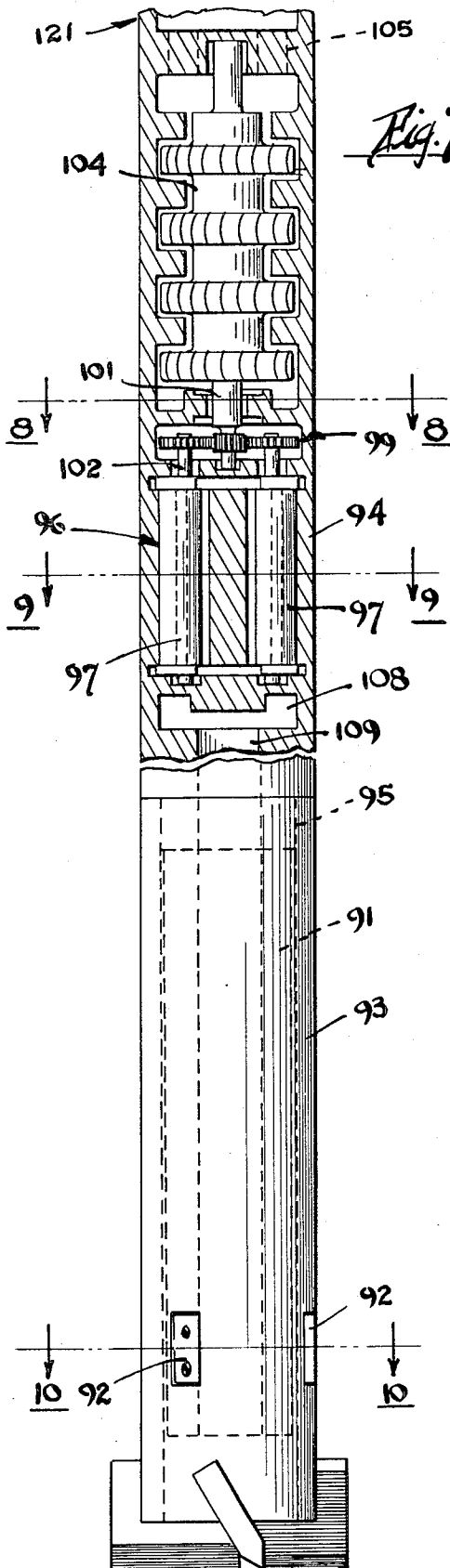


Fig. 7

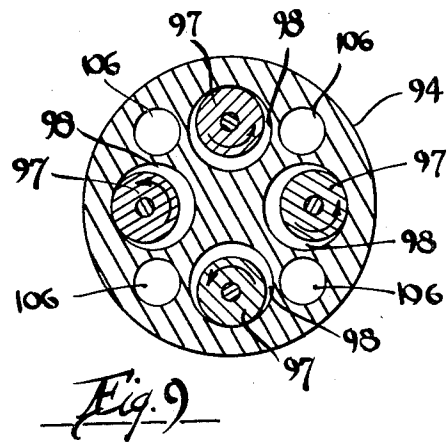


Fig. 9

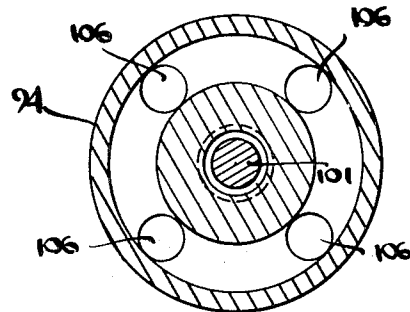


Fig. 8

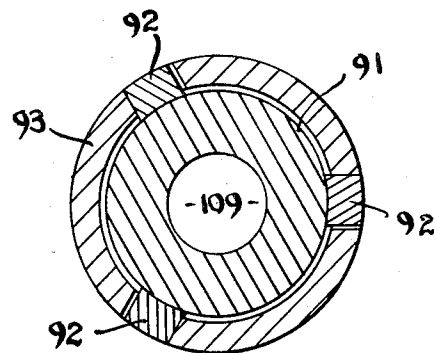


Fig. 10

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TORSIONAL RECTIFIER DRILLING DEVICE

This invention relates to a method and apparatus utilizing sonic energy to drive a cutting tool, and more particularly to such method and apparatus in which an orbiting mass oscillator is utilized in conjunction with a torsional resonant circuit and acoustic rectifier to provide unidirectional high level pulses of energy to the cutting tool.

In the field of rock drilling, both rotational and torsionally oscillating drills have been used. It has been found in each of these types of tools that the continuous cutting action can cause overheating and rapid dulling of the drill bits. In a torsionally oscillating drill it is not possible to utilize drill bits which are designed for optimum cutting because it is necessary to provide a bit which can withstand the reversing motion and cut in both directions. Reversing drills have been effective in earth boring because the high Q elastic vibrations transmitted to the rock formation by a torsionally oscillating drill bit subjects such formation to a stress pattern which tends to more efficiently fatigue the formation. It should be noted that a torsional system has a large stroke at any given frequency compared to other types of vibratory systems. Because of its large stroke, the torsional system inherently provides a low impedance output. If such a system is intimately coupled to a load it is susceptible to substantial stroke reduction and energy drainage, with the result that the system Q is greatly reduced. The technique and apparatus of this invention effectively alleviates this problem of Q reduction. Further, it greatly extends the life of the bit and enables highly efficient cutting action.

This significant improvement is achieved by utilizing an acoustic rectifier for coupling the sonic energy from the resonant vibration system to the cutting bit.

As used herein, the term "rectifier" means a device which transmits vibrational energy in one direction only, and is thus analogous to an electric rectifier which converts AC to DC. This acoustic rectifier couples unidirectional pulses of sonic energy to the cutting bit during a portion only of a torsional vibration cycle.

Means are provided for generating a torsional resonant vibration mode in an elastic member and coupling the elastic member to an acoustic rectifier, so that unidirectional high Q energy impulses are transmitted to the cutting tool. Since the cutting tool motion is unidirectional, the cutting edge is not dragged backwards against the work, and it is possible to utilize a cutting tool designed for high efficiency cutting in one direction. The rectifier also provides an intermittent rather than a continuous cutting effect, so that tool bit overheating and resultant wear are reduced. An important feature of the acoustic rectifier is its ability to extract energy from the resonant torsional system for a time interval which is only a portion of the vibration cycle, so that the resonant system is not so intimately coupled to the load. The acoustic rectifier thus is able to extract a high energy pulse from the high Q resonant circuit and therefor transmits a very high force output into the workpiece for relatively short intervals of time. The rectifier thus operates as an impedance transformer, and converts the low impedance output of the torsionally resonant system into a series of relatively short duration, high force pulses to the workload. In certain embodiments of this invention it is possible to use a low impedance, torsionally resonant system to drive a tool intended for high impedance workload situations such as rock drilling and concrete cutting.

It is therefore the principal object of this invention to provide an improved technique and apparatus for sonic drilling.

Other objects of this invention will become apparent from the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a partially sectioned view of a first embodiment of the device of the invention as incorporated into core-drilling equipment,

FIG. 2 is a cross-sectional view taken along the plane indicated by 2—2 in FIG. 1,

FIG. 3 is a cross-sectional view taken along the plane indicated by 3—3 in FIG. 1,

FIG. 4 is a partially sectioned view of a second embodiment of the device of the invention as incorporated into core-drilling equipment,

FIG. 4a is a partially sectioned view of a saw which may be utilized in conjunction with the second embodiment,

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

FIG. 6 is a cross-sectional view taken along the plane indicated by 6—6 in FIG. 4,

FIG. 7 is a partial sectioned view of a third embodiment of the device of the invention as incorporated into well-drilling equipment,

FIG. 8 is a cross-sectional view taken along the plane indicated by 8—8 in FIG. 7,

FIG. 9 is a cross-sectional view taken along the plane indicated by 9—9 in FIG. 7; and

FIG. 10 is a cross-sectional view taken along the plane indicated by 10—10 in FIG. 7.

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

Thus, it can be shown that if a member is elastically vibrated by means of an acoustical sinusoidal force F₀sinωt (ω being equal to 2 times the frequency of vibration,) that

$$Z_m = R_m + j \left(\omega M - \frac{1}{\omega C_m} \right) = \frac{F_0 \sin \omega t}{u} \quad (1)$$

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

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

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

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

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

With reference first to the embodiment shown in FIGS. 1-3, there is seen in FIG. 1 a partially sectioned view of the drill, comprising an elastic drill stem and housing 11, and core barrel 12, each of which is formed of a suitable alloy steel having good elastic fatigue properties, preferably of circular cross section as shown and of a diameter suitable for accommodating the components installed therein. Typically though without limitation, the elastic drill stem 11 and core barrel 12 may comprise a length of 5 to 20 feet. The lower end of stem 11 is machined to a reduced diameter to form the drill stem pin 13, which fits loosely within the inside bore 14 of core barrel 12, leaving an annular gap 15 between the pin and the barrel. The shoulder of the juncture between stem 11 and drill pin 13 is provided with a highly polished annular bearing surface 16 which is transverse to the longitudinal axis of the stem. The upper surface of core barrel 12 is machined to a polished bearing surface 17 which mates with surface 16 of the drill stem and permits relative rotary motion between stem 11 and core barrel 12.

The upper end of the stem housing 11 is provided with an opening 21 through which the shaft 22 of motor 23 is disposed. The motor and drill assembly is provided with suspension means 24 and an electric cable 25 to provide electric current to the motor. There are commercially available cables, which can be used here, to provide both suspension and electrical conductor. The motor may also be provided with a handle 26 if the drill is used above ground such, for example, as in pavement-cutting work, and wall-engaging bails 27 if the drill is used for deep well drilling. Inside the upper end of stem housing 11, mounted on shaft 22 is a gear 31, permanently engaged with gears 32 which are fixedly mounted on shafts 33. Shafts 33 are coupled through universal drive shafts 34 containing two universal joints each, to unbalanced oscillator rotors 35. Each oscillator rotor has been unbalanced by drilling out a hollow core 36 eccentric to its center. Each rotor is fitted with a journal bearing fit into a lubricant retaining cavity bored into the stem 11.

In the operation of the oscillator the rotors 35 are driven in the same direction by means of motor 33, the gear train including gears 31 and 32 and drive shafts 34, and are caused to rotate inside the cavities provided in the oscillator housing. The hollow cores of the rotors are relatively positioned in such a manner so as to cause torsional elastic vibration of housing 11, which is resonantly transmitted through the stem 11 into the drill stem pin 13.

Turning attention now to the core barrel 12 there is seen the mechanism comprising the acoustic rectifier. Cut into the walls of the core barrel are three rectifier windows 41 spaced around the circumference of the core barrel. Each window 41 is formed by radially machining through the wall of the core barrel an elongated slot, the major axis of which is parallel to the longitudinal axis of the core barrel. The drill pin 13 extends for a sufficient length inside the core barrel so that three rectifier hammers 42 may be secured by means of bolts 43 to the drill stem 13 in such a manner as to protrude through the rectifier windows 41.

In the operation of the acoustic rectifier, the drill stem 11 is caused to oscillate in a resonant torsional mode, so that pin 13 oscillates inside the core barrel 12. This causes the rectifier hammers 42 to strike against one side of each rectifier window 41, thus accomplishing the rectification and thereby causing the core barrel 12, with its attached coring bit 51 and reaming teeth 52 to be driven rotationally in one direction only. In addition to causing the oscillator to operate, the torque

developed by the motor 23 also tends to cause the stem 11 to rotate. The greater resistance there is to the operation of the oscillator, due, for example, to hard rock cutting, the greater will be the torque tending to turn the entire tool. This turning of the tool results in a rotary bias of the hammers in their windows which helps implement the rectifier action by causing the rectifier to be acoustically coupled to the load only for torsional impulses in the direction of the biasing action. In this manner the acoustic rectifier is able to extract a small portion of the stroke of the drill stem, and transmit to the working tool a high energy unidirectional pulse of short duration. The average loading of the load on the resonating drill collar is therefore greatly reduced, resulting in a decreased energy drainage and high Q. It is therefore seen that the acoustic rectifier provides the advantage of permitting the acoustic energy to remain well established at a high Q level in the resonant system, effectively transforming the low impedance vibration cycle of the torsionally resonant system into a series of high impedance, high force pulses for the workload. The sliding bearing formed by the surfaces 16 and 17 allows the core barrel 12 to rotate relative to the drill pin 13. In the operation of the tool, the motor, which can be driven by means of electrical power provided through cable 25, drives the oscillator, which may be of the type described in my U.S. Pat. No. 3,291,228, causing a standing wave to be developed in the drill stem 11, the oscillator preferably being driven at a frequency such as to cause resonant elastic vibration in the drill stem. The cutting action generated by this tool is particularly suited for applications such as the drilling or cutting of concrete and rock.

In FIGS. 4-6 I have shown a second embodiment of the invention suited for rock and concrete cutting, utilizing elastic pillars to provide torsional compliance between the core barrel and the drill stem.

Referring to FIG. 4 there is shown a second embodiment of the invention suited for rock and concrete cutting, utilizing elastic pillars to provide torsional compliance between the core barrel and the drill stem.

Referring to FIG. 4 there is shown an oscillator 61 comprising rollers 62 driven by crank member 63 and gear system 64, through which torque is transmitted from motor shaft 65. The rollers are driven so they roll in the same direction but are positioned 180° out of phase, so that to and fro torsional vibrations are thereby generated. A common housing 66 is employed to contain the oscillator, and the stator 67 of an electric motor of which the armature 68 is supported on shaft 65. Drill collar 71 is threadably attached to the lower end of housing 66 by means of tapered threads 72. The drill collar may be formed of a suitable alloy steel having good elastic fatigue properties and of a circular cross section having a lower region diameter suitable for containment within the tool tube 74.

The tool tube comprises an elastic cylindrical member formed of a suitable alloy steel having good elastic fatigue properties, of circular cross section, mounted by a secure press fit on a suitable diameter 71a machined on drill collar 71. The drill collar is formed such that a sufficient area is provided for a press fit with the tool tube and the balance of the drill collar extends axially inside the tool tube with a loose fit, leaving an annular gap 75. The tool tube 74 is also provided with "elastic pillars" 76 which are formed by radially machining elongated slots 77 through the annular wall of the tool tube. The tool tube is additionally provided with three rectifier windows 41 spaced about the circumference of the tool tube. Acoustic rectification is accomplished by the same means as in the first embodiment, the rectifier of which is shown in the cross sectional view in FIG. 3. The tool tube is fitted with a core bit 51 comprising a plurality of teeth made, for example, from tungsten carbide. The tool tube may also be fitted with a rotary saw blade 81 for the purposes of stone or concrete cutting.

In the operation of this embodiment of the invention, torque supplied by the motor shaft 65 sets into rotation gear system 64 and oscillator crankshafts 63. The gear system is designed such as to cause the two parallel oscillator crankshafts to

rotate in the same direction with the same rotational velocity. Each cylindrical oscillator roller 62 is thereby caused to rotate eccentrically in its respective cavity 69 formed in the oscillator housing 66. The rotors are aligned such that they are 180° out of phase in their positioning in their raceways thus causing a torsional elastic vibration to be generated in the oscillator housing 66. The oscillator is preferably driven at a frequency such as to cause resonant elastic vibration along the drill stem or collar 71, including the portion of the drill collar 71 which is loosely fitted inside tool tube 74. A standing wave is therefore established in said resonant drill collar 71. The mechanism of acoustic rectification is of the same general character as that described earlier for the first embodiment, but this second embodiment is modified by the presence of the elastic pillars 76 instead of the sliding bearing that was utilized in the first embodiment. The function of the elastic pillars is to allow the drill collar to move inside the tool tube. The portion of the tool tube in the region of the press fit must move with the drill collar. However, the elastic pillars, because they are long and narrow and therefore elastically soft, effectively isolate the full cycle motion of the drill collar from the lower portion of the tool tube. Thus the only motion experienced by the lower portion of the tool tube is the rectified torsional oscillation delivered to the tool tube by the rectifier hammers 42. The core bit illustrated in the present case is shown to have a series of individual cutting teeth, FIG. 4, but it will be understood that the form of the bit is subject to wide variation.

The rotary torsional saw 81, shown in FIG. 4a, is intended as an alternative form of tool mounted on the rectifier end of the tool tube. The saw would be used alternatively to, and not in addition to the core bit, and can be used by orienting the tool in such manner that the longitudinal axis of the tool tube is approximately parallel to the surface being cut, so that the saw can cut along the surface in the fashion of a conventional rotary saw. This device is especially effective for saw cutting concrete and rock.

FIGS. 7-10 show a third embodiment of the invention in which a torsionally elastic tube is utilized to couple the acoustic rectifier to the torsionally resonant member. Referring now to FIG. 7 and turning attention to the lower end of the resonant bar 91 carrying rectifier hammers 92, torsional oscillation of this end portion of the bar about its longitudinal axis oscillates the hammers 92 in such manner as to transmit unidirectionally rotational pulses to the torsionally elastic tube 93. Rectification is accomplished in much the same manner as in the previous embodiments, with the modification in this third embodiment that the acoustic rectifier is coupled to the oscillator housing 94 by means of a torsionally elastic tool tube 93 and rotary bias is supplied by rotating the entire drill pipe from above. The tool tube comprises a hollow, thin wall cylindrical member 93 formed of a suitable alloy steel having good elastic fatigue properties, so that the tube is torsionally limber in relation to the heavy resonant drill collar 91 which is loosely fitted inside. Therefore, the drill tube transmits very little of the full cycle motion of the drill collar, onto which the tool tube is press fitted at its upper extremity 95. The torsional oscillation of the drill collar is therefore delivered to the lower region of the tool tube where the rectifier is located, primarily by the action of the rectifier itself. The rectifier delivers rectified rotary action to the drill bit primarily in response to the impulses transmitted to the drill tube in the region of the drill bit by the local action of the rectifier hammers 92. The backward rotation of the drill collar on each cycle is not strongly delivered to the drill bit because the torsionally elastic tool tube 93 is limber enough that it does not transmit very strong torsional force.

Torsional elastic vibrations are generated by a four-roller oscillator 96 driven through gear system 99 by a turbine shaft 101. As can be seen in FIG. 9 each roller 97 is fitted into a roller cavity 98 machined into the oscillator housing 94. Each roller is rotationally driven in the same direction by the crank members 102 coupled to gear system 99. The rollers are aligned in their respective cavities in such manner as to

generate torsional oscillation. Turbine shaft 101 is coupled to the output stage of mud turbine 104, the axis of which is parallel to the longitudinal axis of the oscillator 96. Mud outlet passages 106 are provided by forming holes in the oscillator housing 94 parallel to the rotor cavities 98, so that the mud may flow downward through the housing past the oscillator without effecting the gear system or oscillator mechanism. At the bottom of the oscillator housing, mud which has flowed through passages 106 collects in the annular cavity 108 and continues to flow downward through the hollow core 109 of drill collar 91 so as to deliver the mud out the bottom of the drill for lubricating the drill bit and washing chips out of the hole. In addition to the rectified torsional pulses applied to the drill bit by means of the rectifier, a constant rotary bias is also applied by slowly rotating the drill pipe from above the surface of the earth, such as, for example, at 20 revolutions per minute. The rotary bias which, as for the other embodiments, is utilized to implement the rectifier action can be delivered through the elastic tool tube to a small degree because the transmitted force is normally much lower than the delivered by the rectifier action. Nevertheless, even this rotary torsional force is primarily transmitted through the rectifier. As in the other embodiments of the invention there is a downward bias due to the mass of the tool itself, which can be controlled by adjusting the suspension force supporting the drill pipe at the earth's surface.

The techniques and devices of this invention thus provide means for more effectively delivering torsional energy into the cutting bit of a tool intended for drilling or cutting earthen material, rock or concrete. By virtue of the rectification action of the invention, high force pulses may be extracted from a high Q torsionally resonant system to provide optimum coupling of energy to the load. Further, such rectification of the torsional cycle provides a unidirectional cutting action, which permits the utilization of efficiently designed cutting tools without causing undesirable overheating and short tool life due to backwards dragging of the cutting tool over the work surface.

I claim:

1. In a torsional sonic drill member and the like the combination of:

a torsionally elastic member

periodic torsional force means directly coupled to said member for torsionally oscillating said member about its longitudinal axis at a torsional resonant frequency of the member,

means for driving said torsional force means,

a cutting tool, and

torsional rectifier means coupled to said elastic member and located between said elastic member and said cutting tool for transmitting a unidirectional portion of the oscillator cycle of said member to said cutting tool, whereby said cutting tool is caused to be unidirectionally driven in a pulsating manner.

2. The combination of claim 1 wherein the periodic force means comprises an orbiting mass oscillator having multiple rotors phased for causing torsional vibration of said member.

3. In a torsional sonic drill member and the like, the combination of:

a torsionally elastic member,

periodic torsional force means coupled to said member for torsionally oscillating said member about its longitudinal axis at a torsional resonant frequency of the member, said force means comprising an orbiting mass oscillator having multiple rotors phased for causing torsional vibration of said member,

means for driving said torsional force means,

a cutting tool, and

torsional rectifier means coupled to said elastic member for transmitting a unidirectional portion of the oscillatory cycle of said member to said cutting tool, said rectifier means comprising rectifier hammer means securely affixed to said elastic member about the outer wall thereof,

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a tool tube member attached to said cutting tool and having rectifier window means formed in the wall thereof and means for rotatably biasing said hammer means toward a wall of said window means, whereby said tool is caused to be unidirectionally driven in a pulsating manner.

4. The combination of claim 3 additionally including an annular sliding bearing wherein the tool tube member is coupled to the torsionally resonant member by means of said annular sliding bearing.

5. The combination of claim 93 additionally including a torsionally elastic tube wherein the tool tube member is coupled to the torsionally resonant member by means of a torsionally elastic tube.

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6. The combination of claim 3 wherein said means for driving said oscillator comprises a mud turbine, said turbine adapted to be activated by the downward gravitational flow of drilling mud.

7. The combination of claim 3 additionally including elastic pillars wherein the tool tube member is coupled to the torsionally resonant member by means of said elastic pillars.

8. The combination of claim 7 wherein said elastic pillars comprise the structure formed by radially forming through the wall of said cylindrical tool tube member, a plurality of elongated slots, the longitudinal axes of which are parallel to the longitudinal axis of said tool tube.

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