

Jan. 22, 1963

D. H. CLEWELL

3,074,492

WELL DRILLING SYSTEM

Filed June 5, 1957

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Fig. 1

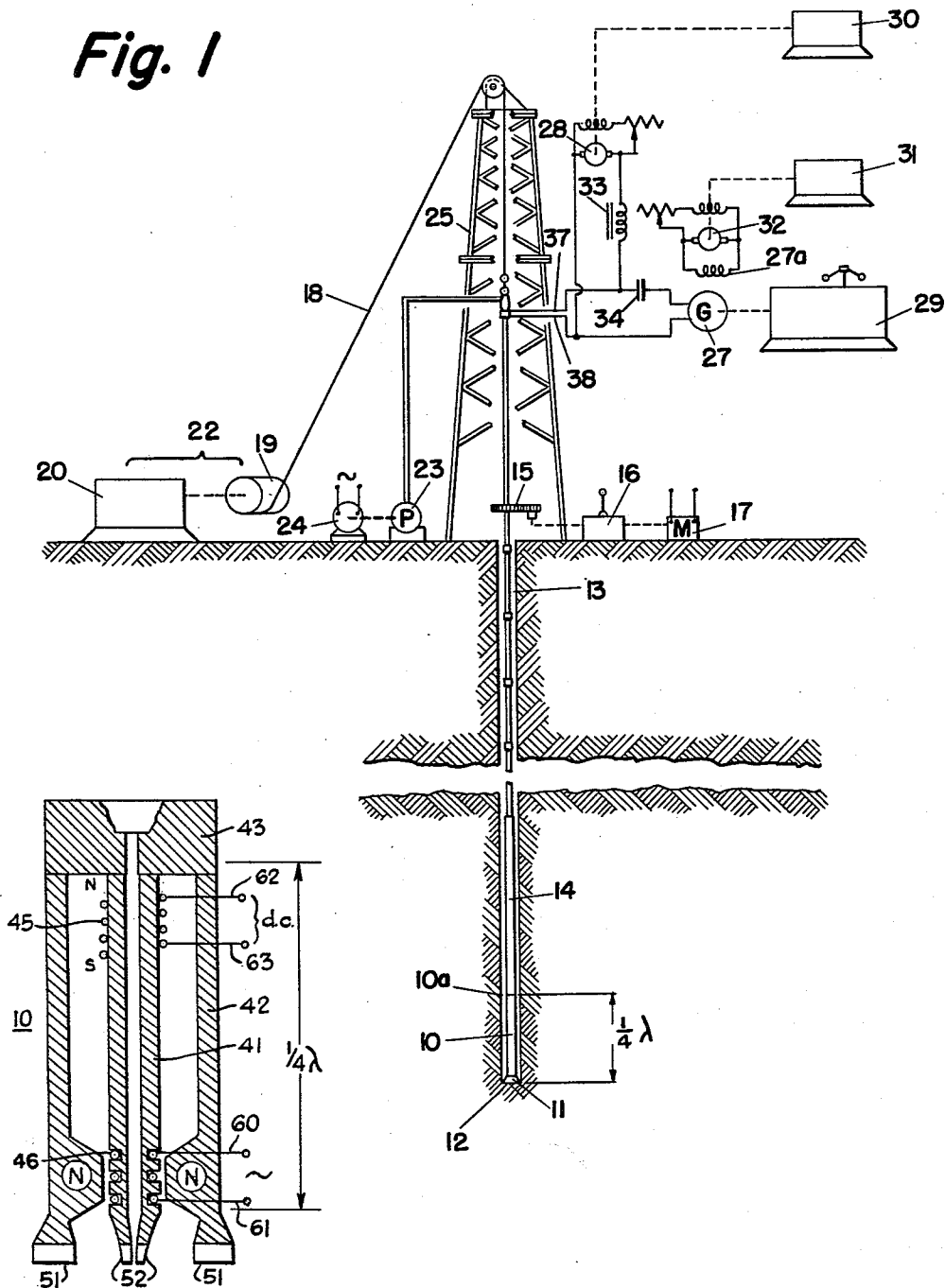


Fig. 1A

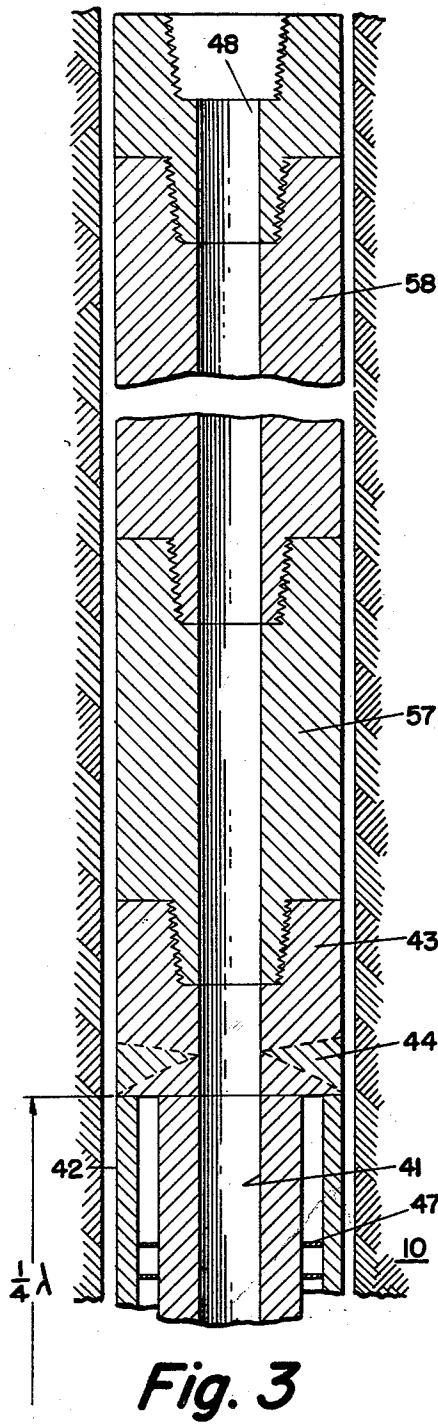
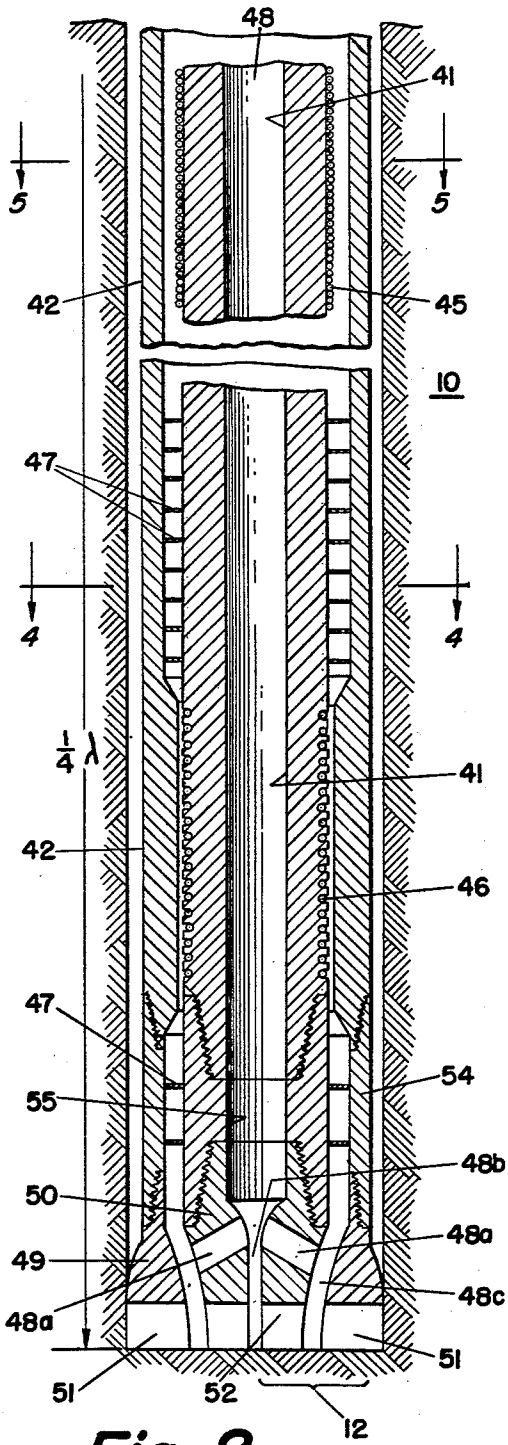
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Fig. 4

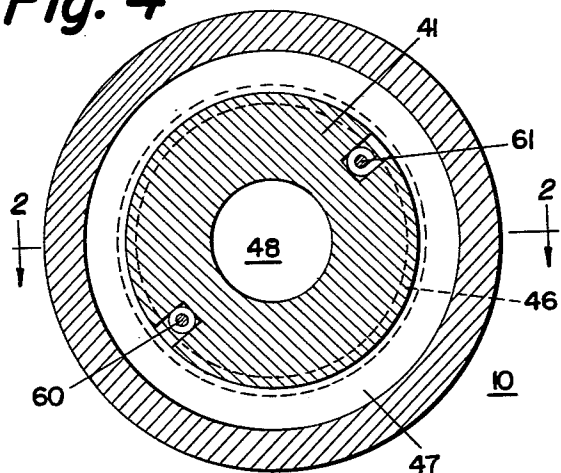


Fig. 5

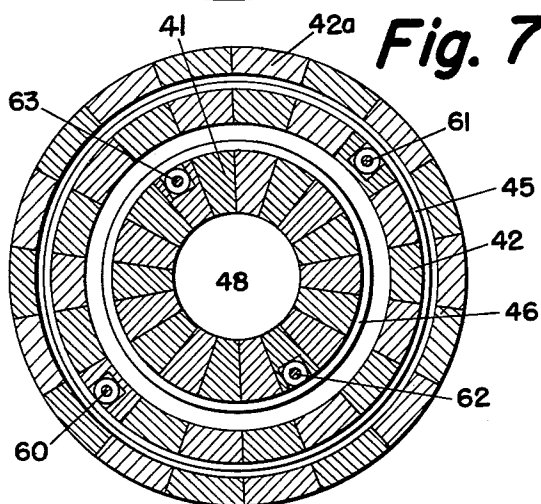
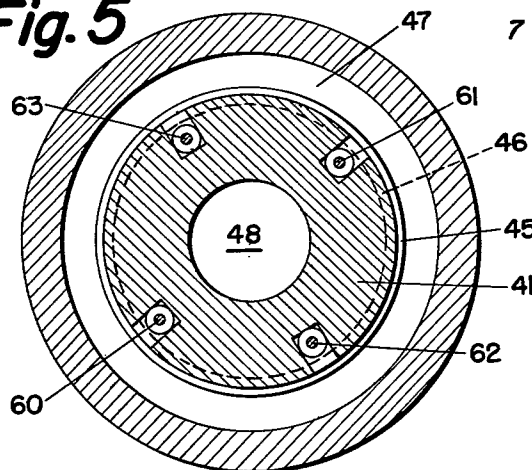
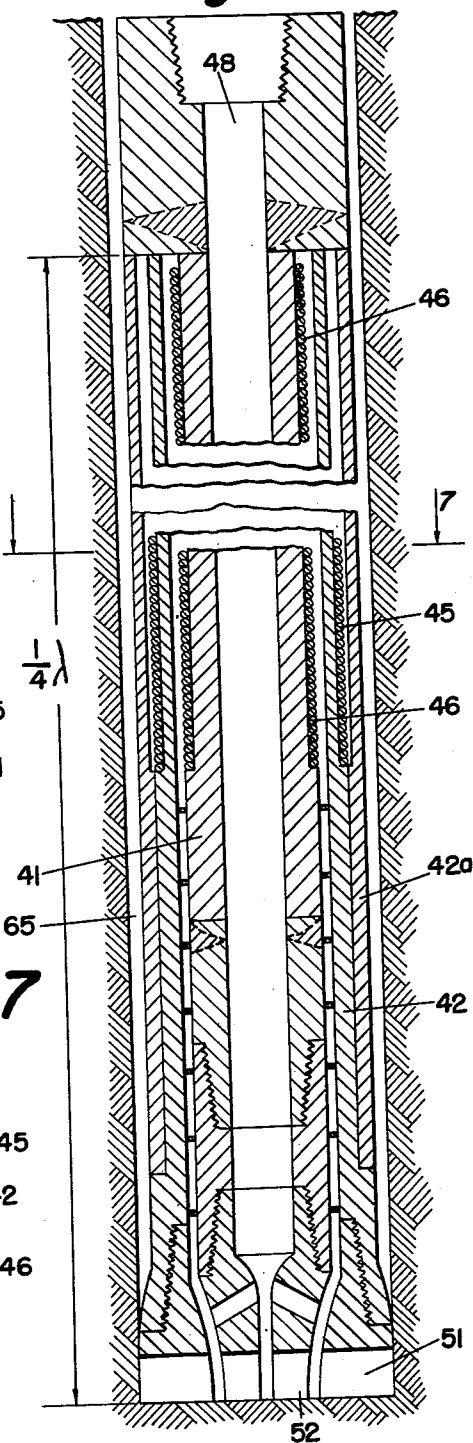


Fig. 7

Fig. 6



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3,074,492

WELL DRILLING SYSTEM

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5 Claims. (Cl. 175—56)

This invention relates to systems and apparatus for drilling wells, particularly deep wells needed to penetrate oil deposits, and has for an object the provision of an improved transducer for developing adequate power to drive a bit through the strata encountered in the drilling of a well.

In well drilling systems of the type disclosed in McPherson Patent 2,745,998, a magnetostrictive motor of a specialized type is utilized at the lower end of the drill string. It includes a filter of substantial length to minimize loss of energy from the motor to the drill string.

In accordance with the present invention, a filter need not be used, nor need there be interposed a mechanical impedance for preventing loss of energy to the drill string from a transducer embodying the present invention. In carrying out the invention in one form, there is provided a vibratory type of transducer characterized in part by the fact that there is a direct connection from the drill string to the transducer at a nodal point, namely, a point or region on a vibrating structure which is stationary. Accordingly, with the drill string attached to a point or region which is stationary, there can be no transmission to or loss of energy in the drill string. Such movement as may occur in the region of the connection will be inconsequential in terms of loss of energy. Accordingly, the efficiency of the transducer will be materially increased by reason of the fact that nearly 100% of the energy available will be utilized to cause vibration or reciprocatory movement of the transducer and the bit disposed against the strata to be penetrated. The transducer of the present invention is further characterized by the provision of two cylinders which form the driving members for the bit, which cylinders move in instantaneously opposed senses. As one moves a section of the bit downwardly, the other moves another section of the bit upwardly. This feature aids in preventing loss of energy to the mud stream used to carry away chips and drilling debris.

Further in accordance with the invention, the two-part bit utilized in association with the two-element transducer and alternately moving in opposite directions are cylindrical in shape and of differing diameter to increase the effectiveness of penetration and to provide a structure which vibrationally provides the nodal point at which the transducer and bit assembly as a whole is connected to the drill string.

For further objects and advantages of the invention and for a more detailed understanding thereof, reference is to be had to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 diagrammatically illustrates a drilling system as used in the field in accordance with the present invention;

FIG. 1A more or less diagrammatically illustrates the transducer and drilling bit of FIGS. 1—5 with clearances exaggerated;

FIG. 2 is a sectional view of the lower end of the transducer taken on the line 2—2 of FIG. 4;

FIG. 3 is a sectional view which includes the upper end of the transducer and the lower end of the drill string;

FIG. 4 is a sectional view taken on the line 4—4 of FIG. 2;

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FIG. 5 is a sectional view taken along the line 5—5 of FIG. 2;

FIG. 6 is a sectional view of a modified transducer embodying the invention; and

FIG. 7 is a sectional view taken on the line 7—7 of FIG. 6.

Referring now to FIG. 1, a transducer 10 embodying the present invention is arranged to drive a bit 11 against strata 12 to be penetrated in the drilling of an oil well 13. The transducer 10 has a length of $\frac{1}{4}\lambda$ where λ is equal to the wavelength of sound in the transducer at the frequency at which the transducer 10 operates. While the length of $\frac{1}{4}\lambda$ is to be preferred, it may also have a length of $\frac{3}{4}\lambda$, or any other length which produces a nodal point at the upper end 10a where the drill string 14 is secured. The drill string 14 is of conventional construction and through the provision of conventional driving apparatus, such as a rotary table, serves to rotate the bit. Such driving apparatus including the rotary table and the driving connection, referred to by those skilled in the art as the "Kelly," are symbolically represented by the driving gears 15, one of which is shown connected to a speed-changing mechanism 16 driven by a motor 17. The drill string itself is supported from a cable 18 extending about a drum 19 driven by a motor or prime mover 20.

The motor 20 and the drum 19 represent the apparatus known in the art as the draw works 22. A mud pump 23 driven by a motor 24 is utilized to force mud downwardly through the drill string, a connection thereto being illustrated about midway of the supporting derrick 25. Electrical conductors form a part of the drill string and serve to carry to the transducer 10 alternating current power generated by a generator 27, and direct current power generated by a generator 28. Prime movers 29 and 30 are provided to drive the generators 27 and 28, and a third prime mover 31 is provided to drive an exciter 32 for the generator field winding 27a of generator 27. A choke coil 33 isolates the direct current generator 28 from the alternating current from the generator 27, and a blocking capacitor 34 isolates the alternating current generator 27 from the direct current from the generator 28.

With the above understanding of a system embodying the present invention, reference will now be had to FIGS. 2—5 directed primarily to the construction of a double-acting well-drilling tool 10 embodying one form of the invention. Two concentric magnetizable members shown as cylinders 41 and 42 form the driving elements. Their upper ends, FIG. 3, terminate in a coupling member 43, a welded area 44 being illustrated as a suitable way of attaching the element 43 to their upper ends.

Surrounding the inner driving element 41 is a bias coil 45. Preferably, this coil as a whole is impregnated and covered with a sealing compound. Also encircling the inner driving element 41 is a driving coil 46 insulated and imbedded in the grooves of element 41.

As shown in FIG. 5, channels are provided in the inner cylindrical member 41 to receive conductors 60 and 61. These conductors carry the alternating current for energization of the coil 46. Channels are also provided for conductors 62 and 63 which carry the direct current for energization of the bias coil 45. As shown by FIG. 4, only the conductors 60 and 61 and associated channels extend below the region of the bias coil 45. Preferably the channels extend inwardly of cylinder 41 beyond the inner limits of the respective coils 45 and 46.

The spiral or helical grooves for the turns of coil 46 provide a driving connection between the coil and the member 42. It is to be noted the coil 46 has its turns located near the lower end of the transducer. Addi-

tionally, the air gap or separation distance between cylinders 41 and 42 is made small in the region of the coil 46 to provide in that region a low reluctance path between said cylinders 41 and 42. Thus with each reversal of flux produced by the coil 46, the cylinder 41 has applied to it a force first in a downward direction and then in an upward direction. The resultant motion of cylinder 41 is instantaneously in opposite sense to the motion of the outer cylinder 42. The relative movements are used to drive the bit 51—52 as will later be described in more detail. The cylinders 41 and 42 may be of laminated steel of electrical transformer grade but in some cases only that part of cylinder 41 need be laminated in the region of the coil 46. For ease in construction the cylinder 41 will be laminated as shown in FIG. 7 but for the modification of FIG. 2 the laminations may be welded together in regions spaced endwise from the coil 46. By making the connecting elements 54 and 55 of stainless steel, the magnetic flux path terminates in the region of the lower end of the coil 46 which terminates adjacent the lower end of cylinder 41 and will be therefore, as will be later explained, of maximum effectiveness in driving the cylinder 41.

Suitable means are provided to maintain the spacing between the inner driving element 41 and the outer driving element 42. As shown in FIG. 2, the spacing means comprises a plurality of disk-springs 47 which, though exerting substantial resistance to compressive forces, offer a low order of resistance to movement of one element relative to the other along the axis of the assembly. Leaf springs or bow springs may be used in place of the springs 47.

The inner cylindrical element 41 is hollow, the central opening 48 thereof providing a flow channel for drilling mud pumped downwardly through the drill string by the pump 23.

A double-acting bit at the lower end of the transducer comprises an outer section having a circular array of penetrating elements 51. The inner section of the bit likewise has a circular array of penetrating elements 52 of lesser diameter. The body portion 49 of the outer section is rigidly connected to a connecting collar 54 as by threaded relation therewith, while the body portion 50 of the inner section is similarly connected to a coupling element 55. Elements 54 and 55 are preferably non-magnetic and may be made of stainless steel.

In operation, the double-acting bit 51, 52, is pressed downwardly against the strata 12 to be penetrated either by a fractional part of the weight of the drill string, but generally by reason of the provision of fairly thick drill collars 57 and 58, FIG. 3, there being enough of them to provide the desired weight to force the bit toward the strata 12.

For a better understanding of the principles of operation of the embodiment of FIGS. 2-5, the bit-driving transducer 10 has been schematically illustrated in FIG. 1A. With coil 45 energized with direct current as by conductors 62 and 63, magnetic flux will be produced in the concentric cylindrical steel members 41 and 42. With polarities as indicated, there will be produced between the north pole N and the south pole S a unidirectional magnetic flux which radially crosses the annular narrow air gap in the region of the driving coil 46. With coil 46 energized by alternating current as by conductors 60 and 61, the current flowing through turns of coil 46, carried in the slots of member 41, will develop in conjunction with the radial flux, on member 41 axially directed forces which are first in one direction and then in the opposite direction as the alternating current reverses in direction.

When the current flow through the coil 46 is in one direction it develops forces to drive it downwardly. With change in direction of the alternating current corresponding with the next half cycle, the coil 46 will develop forces tending to drive it upwardly. Corresponding reac-

tion forces respectively of opposite direction are simultaneously developed upon member 42.

With a frequency of the alternating current from lines 60 and 61 equal to the natural resonant frequency of the mechanical system comprising members 41 and 42, these members will be set into vibratory motion, the one elongating as the other is contracting. The action is similar to the elongation and contraction of the magnetostrictive members later described.

Since members 41 and 42 from their upper ends to their lower ends correspond with $\frac{1}{4}\lambda$, the region of interconnection at member 43 will be at a node with zero movement while the region of maximum movement will be at the antinode in the region of the bit sections 51 and 52.

With the coil 46 mechanically secured to the lower extremity of member 10, the forces developed upon that member and upon member 42 act upon the maximum lengths for maximum elongation and contraction thereof. Thus the described position is the one for maximum effectiveness.

Upon energization of the bias coil 45 and the driving coil 46, respectively with direct current and alternating current, there will be produced an alternating magnetic flux throughout the elements 41 and 42. While the element 41 is moving downwardly under the influence of such magnetic flux, the element 42 will be moving upwardly. This movement occurs by reason of the alternate attraction and repulsion arising between the magnetic fields produced by the coils 45 and 46. Since the coil 46 is anchored to the member 41, as the polarity of the flux produced by the current through coil 46 reverses, that member is driven in one direction, as downwardly, as the other member 42 moves in the other direction, as upwardly. The foregoing movements occur relative to the upper ends of members 41 and 42 located at a nodal point in the assembly. Thus there is produced a vibratory system having the two elements 41 and 42 moving in opposite directions relative to the nodal point located at their upper ends, i.e., in the vicinity of the arrowhead, FIG. 3, where substantially zero motion occurs. The region of the arrowhead in FIG. 3 for $\frac{1}{4}\lambda$ corresponds with a node, whereas the antinode, i.e., the region of maximum displacement is located in the region of the arrowhead for $\frac{1}{4}\lambda$ of FIG. 2 and at the location of the penetrating surfaces 51 and 52 of the bit. Thus, the bit itself has the respective sections thereof alternately driven into and out of engagement with the strata to be penetrated by driving elements 41 and 42 each of a length equal to $\frac{1}{4}\lambda$. Such dimensions are shown in FIG. 6. The operation of the bit will be varied in dependence upon the kind of strata being penetrated. In some instances the weight or pressure applying the bit against the strata 12 will be such as to permit each section thereof to move out of engagement with the strata and thence with an impact blow to be moved against the strata. In other instances, the pressure on the bit will be increased so that the "on time" will be increased, i.e., the time during which the bit remains in contact with the strata 12.

During the drilling, mud flowing down the passage 48 divides between branch passages 48a and a central passage 48b to remove from the central area of each of sections 51 and 52 of the bit the chips, etc., resulting from penetration of strata. The mud then passes upwardly around the drill string carrying the debris of drilling to the surface.

The central passage 48b and the branch passages 48a form a restriction in the mud passage. Such a restriction while desirable from the standpoint of increasing the velocity of the mud stream in the region of the bit gives rise to further problems. In some instances the higher velocity of the mud stream—the jet action—is needed to clear away the drilling debris. On the other hand, as the lower end of cylinder 41 moves upwardly, the restriction

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in the region of the mouth of passage 48b tends to lift the mud stream. Stated differently, a part of the vibrational energy is coupled to the mud stream.

In accordance with a further feature of the invention, loss of energy to the mud stream is avoided by providing the annular flow passage 48c of a cross-sectional area varied by relative movement of bit sections 51 and 52. More particularly, the branch passages 48a extend into an annular passage 48c which passage 48c because of its inclination increases in cross-sectional area each time the outer bit-section 49 moves downwardly. This changing area in the mud passage 48c prevents "pumping" of mud due to reciprocation of the sections of the bit and thus minimizes the coupling and resultant loss of energy to the drilling mud. As the inner body portion 50 of the bit moves upwardly the volume of the flow passage 48c is increased. The resistance to flow of mud in the flow passage 48 is decreased for flow through the inclined passages 48a and into sections 51 and 52 of the bit. Thus there is minimized any tendency of upward movement of the mud by the inner section 50. Loss of energy to the mud column in passage 48 is avoided or greatly minimized by reason of the changing volume of the passage 48c taken in conjunction with the inclined passages 48a.

As the inner section of the bit 50 moves downwardly there is displacement of mud from the passage 48c into the blade-portions of the bit, this action being in the direction to assist in the flow of mud in the direction for removal of chips and the like from the drilling area at the bottom of the well.

Where jet action is unnecessary in connection with removal of drilling debris, the mud passage 48 may be of uniform diameter throughout the well-drilling tool with avoidance of the restriction in the region of the bit. Where the restriction or increased resistance to flow of the mud be absent, the special provisions, including the inclined channel 48c, can be omitted. In accordance with this modification it will be noted that the average position of the bit 51, 52 will be constant. As one section 51 of the bit is moving in the one direction, the other section 52 is moving in the other direction. Thus the average position remains constant in avoidance of "pumping" and loss of energy to the mud stream.

In the modification thus far described, the double-acting bit is driven by reason of the forces applied to the inner cylinder 41 by the coil 46 anchored thereto. The same action will be achieved by locating the coil 46 within grooves of or otherwise by securing it in driving relationship with the outer cylinder 42. The vibratory movement of the cylinders 41 and 42 relative to the nodal point with the antinode at the bit in the aforesaid modification takes place by elongation and contraction of the cylindrical elements 41 and 42. Accordingly, by making such elements 41 and 42 respectively of an alloy such as permendur, an alloy of iron 50% and cobalt 50%, having a positive coefficient of expansion when subjected to a magnetizing force and of an alloy of nickel having a negative coefficient of expansion when subjected to a magnetizing force the above-described double-action will be achieved. With elements of this character there need only be provided the driving coil 46 energized from alternating current. In this case, the driving coil 46 and the polarizing coil 45 are one and the same coil. The single coil can conveniently be located in the same position as coil 45 in FIG. 2 and it will extend a substantial distance along the transducer. If only alternating current is fed to the coil, the operation will be as described above in that one of elements 41 and 42 will move downwardly as the other moves upwardly and vice versa as the magnetization changes, i.e., as the magnetic flux rises and falls in magnitude. Accordingly there will be positive driving of both elements 41 and 42. Their lengths will change due to extension and contraction arising from the fact their coefficients of expansion with change in magnetization are respectively of positive and negative sign. In this modifi-

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cation of the invention the exciting coil 46 will be operated at half the frequency as for the modification of FIGS. 2 and 3 if it be desired to produce operation at the same resonant frequency of a transducer of the same dimensions as the modification of FIGS. 2 and 3. The single coil can be polarized with direct current by superimposing this current upon the alternating driving current. In this case, the transducer will be driven at the same frequency as the alternating current rather than at twice the frequency.

In FIG. 6 there is illustrated a further modification of the invention. The double-action at the bit 51, 52 is produced by making at least one, preferably both, of members 41 and 42 of magnetostrictive material. When of such material, it is preferred to assemble elements 41 and 42 by adhesively securing together laminations. While the laminations will in general extend radially and lengthwise of the transducer with the inner edges facing toward the center, in FIG. 7 the individual segments have been illustrated in section without illustration of the direction of the individual laminations. FIG. 7 does illustrate the manner in which the laminations are first assembled into segments. The segments, as units, are then adhesively secured together to form the cylindrical members 41 and 42. The alternating current driving coil 46, though it need not be, is shown imbedded in a recess provided in the laminations forming the inner element 41. Coil 46 extends a substantial distance along the transducer and in particular it extends along the upper end portion for high efficiency of operation. The polarizing coil 45, though it need not be, is shown located in a recess extending along the outer surface of the outer driving element 42 to produce magnetic flux in the same direction in both elements 41 and 42. Besides the magnetostrictive laminations 42 there are also included laminations 42a of soft iron forming a low reluctance return path for the flux developed by the flow of current in coil 45.

The laminations 42a of the outer element have not been individually illustrated, but like the laminations of elements 41 and 42, they are assembled into segments with the laminations extending radially and lengthwise of the transducer and with the inner edges of the laminations facing toward the center of the assembly.

In operation, the alternating current supplied to the coil 46 will produce large changes of magnetic flux within the magnetostrictive elements 41 and 42. They will contract and lengthen with change in said magnetic flux. The length of the transducer including elements 41 and 42 is equal to one-fourth the wavelength of sound in the elements 41 and 42. The alternating current for coil 46 has a frequency for driving the elements 41 and 42 to produce a resonant system with the nodal point at the region of attachment of the transducer to the drill string, (the upper end of FIG. 6). The elements 41 and 42 alternately elongate and contract to drive the outer and inner sections 51 and 52 of the bit toward and away from the strata being penetrated. As one section of the bit is driven toward that strata the other is moving away from it. As in the preceding modification, the downward force applied by the drill string to the nodal point maintains stationary the upper end of the transducer while the lower end at the antinode is effective for drilling the formations encountered whether hard, as rock, or soft, as sand.

It is to be understood that the embodiments of the invention of FIGS. 1-7 are to be taken as illustrative, and that modifications may be made within the scope of the appended claims.

What is claimed is:

1. A double-acting well-drilling tool carried at the lower end of a drill string comprising
two elongated concentric cylinders,
means including connecting structure for attachment of
the upper ends of said cylinders to said drill string

for application by the drill string to said cylinders of a downward force,
 cylindrical coupling members attached to the lower ends of said cylinders,
 a bit having two sections each in circular array and respectively attached to said coupling members,
 said coupling members being made of non-magnetizable material and said driving cylinders being made of a magnetizable material,
 electrical means including a winding magnetically coupled to said cylinders,
 an alternating current supply circuit connected to said electrical means for developing a strong alternating magnetic flux for producing upon said cylinders forces for lengthwise reciprocation of the lower ends of said cylinders in instantaneously opposed senses at a frequency which establishes a vibrational node for said cylinders in the region of said connecting structure and a vibrational antinode for said cylinders in the region of said bit,
 said winding consisting of a plurality of turns, and means forming a mechanical driving connection with at least one of said cylinders near the lower end thereof,
 said lower end of the other of said concentric cylinders being in close proximity to form a low reluctance path between said lower ends of said cylinders for producing said reciprocation of said cylinders.

2. The well-drilling tool of claim 1 in which there is provided an additional winding comprising a plurality of turns magnetically coupled to said cylinders, and a direct current supply circuit connected to said additional winding for developing a magnetic flux which crosses said low reluctance path between said lower ends of said cylinders.

3. The well-drilling tool of claim 2 in which said first-named winding is disposed within the region of said low reluctance path whereby said strong alternating magnetic flux in conjunction with said flux developed by said additional winding enhances the lengthwise elongation and contraction of said tubular members.

4. The well-drilling tool of claim 2 in which said first-named winding and said additional winding are disposed about and in driving relationship with the inner one of said concentric cylinders with said first-named winding within the region of said low reluctance path.

5. A double-acting well-drilling tool carried at the lower end of a drill string comprising

a bit including two sections disposed for alternate engagement with strata to be penetrated,
 two concentric cylindrical driving members,
 one of said cylinders being connected at its lower end to one section of said bit and the other of said cylinders being connected at its lower end to the other of said two sections of said bit,
 means including connecting structure for attachment of the upper ends of said cylinders to said drill string for application by the string to said cylinders of a downward force,
 said cylinders being made of a magnetizable material and having their lower ends in close proximity to each other to form a low reluctance path,
 a first winding magnetically coupled to the inner one of said concentric cylinders,
 means for energizing said first winding with direct current to produce a unidirectional magnetic flux which crosses said low reluctance path,
 a second winding magnetically coupled to said inner cylinder and disposed within the region of said low reluctance path, and
 means for energizing said second winding with alternating current for developing a strong alternating magnetic flux which in conjunction with said unidirectional magnetic flux produces forces on said inner cylinder first in one lengthwise direction and then in the other lengthwise direction as said alternating current reverses in direction to produce reaction forces on the outer one of said concentric cylinders of instantaneous opposite direction, respectively.

References Cited in the file of this patent

UNITED STATES PATENTS

801,072	Frieh	Oct. 3, 1905
1,062,050	Stewart	May 20, 1913
1,932,891	Harner	Oct. 31, 1933
1,966,446	Hayes	July 17, 1934
2,672,322	Bodine	Mar. 16, 1954
2,715,192	Kelly	Aug. 9, 1955
2,717,763	Bodine	Sept. 13, 1955
2,745,998	McPherson	May 15, 1956
2,761,077	Harris	Aug. 28, 1956
2,830,791	Smith	Apr. 15, 1958
2,858,108	Wise et al.	Oct. 28, 1958
2,970,660	Bodine	Feb. 17, 1961