June 17, 1969 B. A. WISE 3,450,217

HYDROACOUSTIC APPARATUS WITH FILTER ISOLATION MEANS

Filed Feb. 10, 1967 Sheet 1 of 2

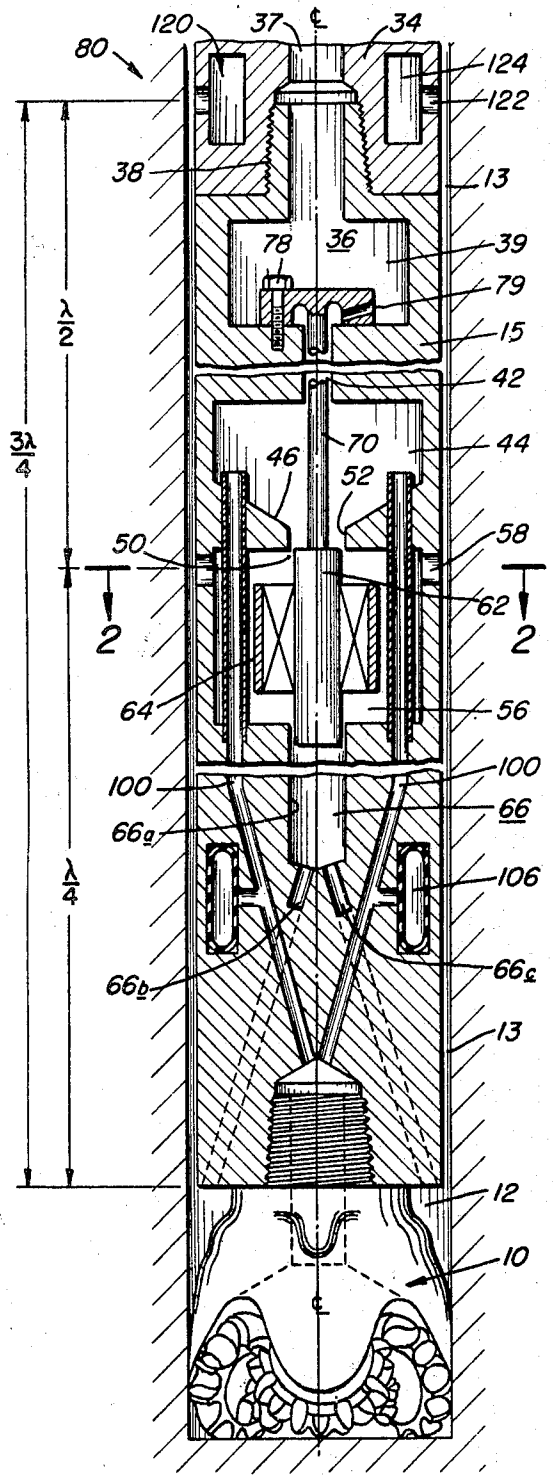


FIG. 1.

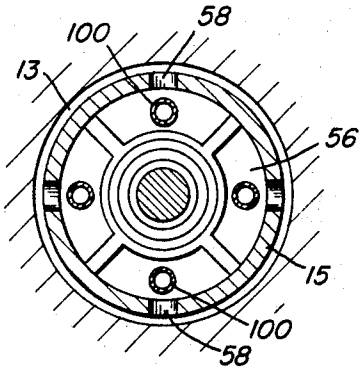


FIG. 2.

INVENTOR.
BOYD A. WISE

BY Samuel R. Tesca

HIS ATTORNEY

HYDROACOUSTIC APPARATUS WITH FILTER ISOLATION MEANS

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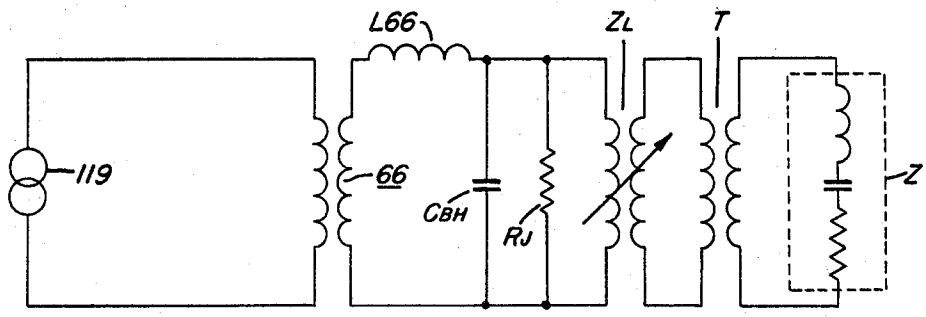


FIG. 3.

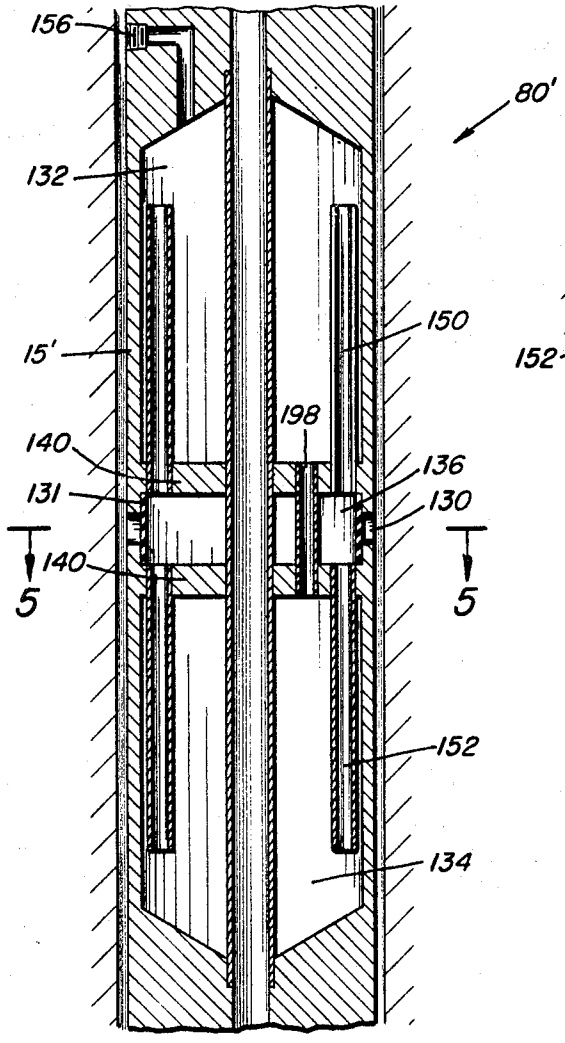


FIG. 4.

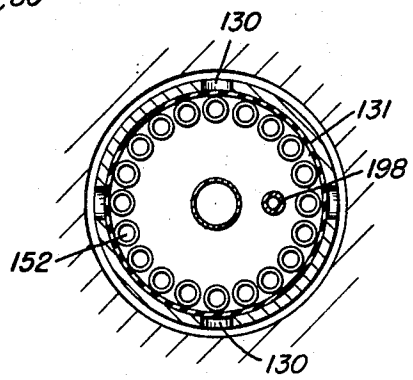


FIG. 5.

INVENTOR.
BOYD A. WISE

BY Samuel R. Genca

HIS ATTORNEY

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3,450,217

HYDROACOUSTIC APPARATUS WITH FILTER ISOLATION MEANS

Boyd A. Wise, Webster, N.Y., assignor to General Dynamics Corporation, a corporation of Delaware

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Int. Cl. E21b 7/04
U.S. Cl. 175—56 11 Claims

ABSTRACT OF THE DISCLOSURE

A hydroacoustic drilling apparatus is described. The apparatus modulates a column of liquid acted upon by a self-excited valving member in the apparatus. A driven rotating drill string, coacting with the modulating fluid column penetrates the earth formation while fluid jets urge chips and cuttings up the bore hole. Modulation of the fluid is substantially confined to the bottom of the bore hole by filter elements on the driven drill string.

The invention relates to hydroacoustic apparatus, and more particularly to a method and apparatus for drilling and boring holes in the earth formation.

The invention is especially suitable for use in oil well drilling and other apparatus where deep bore holes are drilled into the earth formation with the assistance of drilling fluids.

When drilling to great depths in the earth formation, steady state or DC fluid pressures acting upon the bottom of the bit cavity tend to hold down chips broken off the earth formation by the drill bit. This action results in relatively low drilling speeds and increases high drill bit wear. This problem of low drill speed, bit wear and low efficiency is of long standing in the field of oil well drilling.

Accordingly, it is an object of the present invention to provide an improved method and apparatus for drilling or boring holes.

It is yet another object of the present invention to provide an improved method and apparatus for drilling or boring holes in the earth formation, especially at great depths.

It is a further object of the present invention to provide improved methods and apparatus for facilitating the removal of chips, cuttings and the like from the bottom of deep bit cavities in the earth formation.

It is a still further object of the present invention to provide an improved apparatus for modulating a fluid pressure in the bottom of a bore hole or bit cavity and for substantially isolating the pressure variations within the bit cavity.

It is a still further object of the present invention to provide an improved hydroacoustic apparatus especially suitable for use in drilling and boring tools.

It is a still further object of the present invention to provide an improved acoustic vibration generating apparatus which efficiently operate with drilling fluids, such as muds.

Another object of the present invention is to provide improved apparatus for boring holes in the earth formation which will not enlarge cavities or damage the side walls of bored holes in the earth formation.

Briefly described, the apparatus includes a hydroacoustic generator and a mechanical drilling bit which coact to drill or bore a hole in the earth formations with the use of drilling fluid. The hydroacoustic generator modulates the pressure in the bore hole region adjacent to the drill bit, herein called the bit cavity, and further provides jets of fluid which facilitate the removal of chips and other debris from the bit cavity. Embodied within

the acoustic apparatus is a Helmholtz resonator for isolating or confining the pressure fluctuations within the bit cavity to prevent damage to the side walls of the bored hole in a return path of the mud carrying the chip and cuttings from the bit cavity.

An important feature of the invention resides in the configuration and arrangement of the valve, isolating means, and the jets and drill bit to permit effective power transmission from the oscillating valving member to the bit cavity with a maximum transfer of power or energy.

The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof will become more readily apparent from a reading of the following description in connection with the accompanying drawings in which:

FIG. 1 is a diagrammatic sectional view showing a hydroacoustic apparatus in accordance with one embodiment of the invention;

FIG. 2 is a cross-sectional view taken along the lines 2—2 of FIG. 1;

FIG. 3 is a schematic diagram of an acoustic circuit of the apparatus shown in FIG. 1;

FIG. 4 is a fragmentary diagrammatic sectional view showing a Helmholtz resonator in accordance with another embodiment of the invention; and

FIG. 5 is a cross-sectional view taken along the lines 5—5 of FIG. 4.

The present invention may be embodied within a number of different varieties of drilling tools. One such type may be used in the oil well drilling art which includes a rotatable bit head, a rotating table driven by a driving motor for rotating the bit head, a mud pump, and all the other standard equipment known to the art.

Turning now to FIGS. 1 and 2 a jet drill bit **10** is shown in the bit cavity **12**. Such types of drill bits are well known in the art (see for example, those shown in catalog No. 22 (1962) published by the Reed Roller Bit Company of Houston, Tex., U.S.A.). As the drill bit **10** is rotated, it penetrates deeper and deeper into the earth formation.

The mechanical efficiency of the drilling operation progressively decreases as the drill bit penetrates into the earth formation. By modulating the pressure in the bit cavity **12** (viz., the excavated bore hole region adjacent the drill bit **10**), the mechanical efficiency of the drilling operation may be greatly increased. Moreover, it is important to isolate the pressure fluctuations within the bit cavity **12** to prevent damage to the side walls in an annular return annulus **13**, defined between the tool and the earth's formation. Drilling mud carring the cuttings from the bit cavity **12** is recirculated back up to a mud pump, not shown.

A hydroacoustic drilling tool incorporating the invention is shown in FIG. 1 and includes a cylindrical drill string **34** connected to an acoustic vibration generator **36**, having a housing **15**. The drill string **34** and the generator **36** may be cylindrical in shape. The drill string **34** includes an axial bore **37** communicating between the cylindrical cavity **39** in the generator **36** and the mud pump (not shown). In order to simplify the drawing and to show the structure of the apparatus, the drilling mud has not been shown in the apparatus and the bore hole.

In addition, although a screw connection **38** is shown between the drill string **34** and the housing **15** of the generator **36**, it should be understood that other types of fasteners may be provided to connect these two sections.

Leading downwardly from the cavity **39** is an annular path **42** which opens into an active cavity **44**, of substantially cylindrical configuration. Preferably, the length

of the channel **42** should be approximately one-quarter of a wavelength (at the operating frequency) so that the cavity **39** will be viewed as a high impedance, as seen by the active cavity **44**. It will be noted that the active cavity **44** has a lower surface **46** which is conically shaped, for reducing turbulence in the flow path. By active cavity is meant that the cavity supports dynamic (AC) pressure variations at the frequency of oscillation of the valve.

From the active cavity **44**, the fluid or drilling mud passes by a metering edge of orifice **50** and a stator port **52** out into a cylindrical discharge cavity **56**. From the cavity **56**, fluid flows through a series of annually disposed ports **58** in a wall **15** of the generator **36** into a return annulus **13** defined by drill string **34**, the generator **36** and the earth's formation. In the annulus **13** the fluid combines with the flow of the drilling mud from the bit cavity **12** and passes up into the input section of the mud pump. It is desirable to have the return flow of the mud or the fluid to the mud pump in a steady state or a DC flow; in other words, the fluid flow should be characterized by an absence of fluid pressure or modulation fluctuations. The structure for accomplishing this function will be discussed hereinafter.

The acoustic generator **36** includes a valve **62** partially disposed in the cavity **56** and coaxially aligned and guided by a journal bearing **64**. The valve **62**, longitudinally reciprocates in the cavity **56** in a manner so that its top surface is movable into and out of the stator port **52**, closing and opening the orifice defined by the metering edge **50**, thereby modulating an otherwise steady flow of fluid. The lower or piston portion of the piston **62** is disposed within a transmission line **66** which couples the modulating fluid pressure to the bit cavity **12**.

The valve **62** moves back and forth between its open and closed positions about a center position in the stator port **52** in a self-excited mode in response to the circulation of the drilling mud. The lower piston portion of the valve **62** operates on the transmission line **66** to transmit acoustical vibrations down into the bit cavity **12**.

Coupled to the top surface of the valve **62** is an elongated cylindrical member **70** of resilient material which provides a mechanical spring function. More specifically, the spring **70** extends in coaxial relationship through the cavity **44** and the bore hole **42** up into the cavity **39** where it is fastened by means of a series of bolts **78** to the housing **12**. The diameter of the hole **42** is greater than that of the spring, thereby providing an annular flow path. Holes **79** are provided in the top portion of the spring **70** to permit mud to flow from the cavity **39** to the hole **42**. By means of this arrangement, the spring member will not interfere with the flow pattern of the drilling mud. It should be mentioned that the mechanical termination for the spring **70** does not necessarily have to be placed within the cavity **39**, but could be disposed in some other location such as in the region of the joint **38**.

Inasmuch as the average pressure of the upper surface of the valve **62** is greater than the average pressure on the return side of the valve, there is a static force on the valve **62** which is proportional to the net difference between the supply and return pressures and which creates a static elongation of the mechanical spring member **70**, placing the spring member under tension which permits it to better be able to resist buckling.

For more efficient operation of the generator **36** the average or center position of the valve member **62** during oscillation should be in line with the metering edge **50** or within the stator port **52** (viz., Class C operation). In the absence of supply pressure, the edge of the valve **62** would thus be within the stator port **52**. However, as the supplied pressure increases, the valve would move downwardly until its edge is approximately in line with the metering edge **52**. At this point, oscillations commence, and reach a full amplitude. A reduction in the supply pressure causes the average position of the top surface of the valve to be slightly above the edge **52**, thus providing Class C operation.

It is to be noted that the valve **62** is terminated or acted upon on both its end surfaces by fluid columns that provide reflection feedbacks upon the valve **62** to support self-sustained oscillations. The valve is centered by the mechanical spring member **70** whose stiffness controls the static or average valve position and also affects the oscillator's resonant frequency.

The transmission line **66** actually branches from a single coaxial line **66***a* into two channels **66***b* and **66***c* aligned with respect to the center line of the drilling tool, so as to form a Y-shaped transmission line **66**. When the valve **62** oscillates, the lower end of the valve **62**, by way of the transmission line **66**, modulates the pressure in the bit cavity **12**. The mud is returned to the earth's surface pump by the annular return channel **13** between the earth formation and the outer periphery of the generator **36** and the drill string.

The center line path from the bore hole along either the channel path **66***a* and **66***b* or **66***a* and **66***c* has been dimensioned to be somewhat less than one-quarter of a wavelength at the operating frequency. This is an important consideration which will be seen when the equivalent acoustical circuit of FIG. 3 is described. Suffice it here to say, however, one of the roles of the transmission line **66** is to transform the relatively high impedance of the load to a suitable low load impedance, as seen by the valve **62**, to effect proper impedance matching, thereby permitting the valve **62** to oscillate with sufficient amplitude.

In order to prevent appreciable transmission of vibratory energy along the mud return channel **13** and thereby isolate or confine pressure fluctuations within the bit cavity **12**, an acoustic termination **120** (FIG. 1) has been provided, substantially three-quarters of a wavelength at the oscillation frequency, up from the bit cavity. The acoustic termination can also be provided by a Helmholtz resonator **80**, to be described hereinafter.

Four jet channels **100** provide communication between the cavity **44** and the bit cavity **12** and are adapted to force jets of high pressure mud into the bit cavity **12**, thereby providing the needed fluid flow for cleansing action for the drill bits and removal of the cuttings from the bit cavity **12**. A gas desurger **106** in communication with each line **100** is spaced in the flow path about one-quarter wavelength from the cavity **44**. With this arrangement the desurger **106** is viewed by the bit cavity **12** to be a fluid reservoir at constant pressure, and so that when the pressure is reduced in the bit cavity **12**, the desurger **106** will cause high velocity jet stream to be injected into the bit cavity **12**, whereas when the modulation pressure increases, the flow from the jets will be retarded. By way of illustration only, an example of a desurger which may be used in the practice of this invention may be a relatively inert (e.g., nitrogen) gas filled rubber bag confined within a cavity. Conduits communicate the fluid pressure in the lines **100** to the bag.

The resonator **80** is provided by a cavity **120** which, as mentioned above, is spaced approximately three-quarters of a wavelength at the operating frequency from the bit cavity **12**. The cavity **120** consists of a relatively small port or ports **122** which open up into a larger annular volume **124**. Effectively, the cavity **120** performs the role of a Helmholtz resonator. Helmholtz resonators are well known. See for example, 11 McGraw-Hill Encyc. of Sci. and Tech., pp. 505–506 (1960). As viewed from bit cavity **12**, the Helmholtz resonator appears as serially connected impedance consisting of inertance, compliance, and resistance.

The Helmholtz resonator **80** provides a low impedance shunt even though the pressure modulation within the bore hole departs somewhat from the designed frequency of oscillation. In other words, it is adapted to provide for

energy isolation over the desired frequency range of operation of the acoustic generator which will compensate for variations in the operation frequency thereof.

The reason that the cavity **120** is spaced three-quarters of a wavelength from the cavity **12** is that a low-impedance "clamp" at this position will be transformed to a high AC impedance at the bit cavity **12** and will thus limit transmission of dynamic (AC) fluid pressure variations along the annulus **13** above the cavity **120** thereby preventing damage to the bore hole walls. It will be understood, however, that although the location is preferred, it is not essential to the practice of this invention.

A second version of Helmholtz resonator **80'** is shown in FIGS. 4 and 5. The resonator **80'** is provided with a relative small annular inlet port or ports **130** which is separated from a larger volume by means of a rubber diaphragm **131**. The larger volume comprises an upper cavity **132**, a lower cavity **134**, and an intermediate cavity **136** of annular cross-section area formed within a flange **140** of the housing **15'**. Communication between all three cavities is provided by means of a series of circularly arranged upper and lower hollow pipes **150** and **152**, respectively. More particularly, the upper pipes **150** are fixedly secured within the flange **140** and terminated with their upper open ends in the intermediate cavity **132** and their lower in the cavity **136**. Similarly, the lower pipes **152** have their upper ends fastened in the flange **140** and open into the intermediate cavity **136**. The free ends of the pipes **152** into the lower cavity **134**. The cavity is filled with a liquid, such as water with suitable additives, say a rust inhibiter through a port **156** which opens into the cavity **132** and **134** through a tube **198**. The unit is completely self-contained.

Referring to FIG. 3, there is shown an equivalent acoustical circuit of the apparatus of FIG. 1. A generator **119** provides the modulating mud pressure established by the rear portion of the valve **62** which operates on a transmission line **66**. The length of the line **66** is made such that the net impedance includes a value of inertance L**66** that will resonate with the bit cavity compliance C_{BH}. It is desirable to tune the load in this manner to reduce the variation in driving point impedance presented to the generator **119** in the frequency range on either side of the operating frequency. The termination **120** (FIG. 1) may be the Helmholtz resonator or a desurger similar to the gas bag **106**. The acoustic circuit includes an impedance Z which is representative of the Helmholtz resonator. The Helmholtz resonator is the equivalent of an LCR network tuned to the generator operating frequency. This Helmholtz resonator is effectively coupled to the annulus **13** at the port **130** of the resonator. The transformer T includes a 1:1 turns ratio represented by the letter T. This transformer T represents the half-wavelength portion of the annulus **13** between the discharge port **58** and the port **130** of the resonator. Note that variation of the annular spacing **13** does not change the turns ratio or impedance transfer function of the transformer T.

The impedance Z_L may be represented as a transformer with a variable turns ratio, depending on the annular spacing between the housing and bore hole wall in the discharge path or annulus **13**. The effect of using a quarter-wavelength dimension from the bit cavity **12** to the discharge port **58** and a half-wavelength dimension from the port **122** to the port **58** (represented by T), is to provide the desired low value of acoustic impedance at the port **58** and the desired high value of acoustic impedance at the bit cavity **12** by reflecting the inverse or reciprocal of the normalized value of the impedance of the Helmholtz resonator to the cavity **12** via the annulus **13**. In other words, the low value of the impedance Z of the Helmholtz resonator is transformed to a high impedance at the bit cavity **12** and the transformation is effected in such a manner that the impedance presented is resistive (nonreactive) so as not to interfere with the tuning of the bit cavity **12** hereinbefore described. By these means, it is possible to diminish to a small value the transmission of acoustic energy from the region in the bit cavity **12**, where high values are desired, to other regions, such as the annular space **13** up the bore hole, above the port **130**, where low values are desired. This combination of elements and their placement with respect to one another constitute an isolation system, and more particularly, an isolation system that is relatively insensitive to changes in the spacing in the path **13** between the housing and the side of the hole.

In operation, flow from the mud pump is delivered to the cavity **39** and then passes along the annular path **42** until it enters the active cavity **44** of the tool. As noted above, the annular feed path **42** should be approximately one-quarter of the wavelength in dimension so that the cavity **39** is viewed by the active cavity **44** as having high impedance. From the active cavity **44**, the fluid passes by the metering edge **50** of the stator port **52** into the discharge cavity **56** and then out through the side ports **58** into the return annulus **13** between the tool and the earth's formation. As a result of this fluid flow, the valve **62** oscillates in a self-excited manner and causes the transmission line **66** to couple energy from the valve **62** to the bore hole region, thereby modulating pressure in that region. The pressure modulation is effectively isolated within the bore hole region by means of the Helmholtz resonator **80** which tunes the resonant acoustical circuit in the manner just previously described.

It will be appreciated that variations and modifications of the herein described illustrative embodiments of the invention will be apparent to those skilled in the art and should be taken merely as illustrative and not in a limiting sense.

I claim:

1. Hydroacoustic drilling apparatus for drilling a bore hole in the earth's formation, said apparatus comprising:

(a) a drill string having an axial bore for the flow of fluid therethrough under pressure to said hole,

(b) a drill bit connected to said drill string for forming a bit cavity in a bottom region of said bore hole,

(c) a hydroacoustic generator means coupled between said drill bit and said string responsive to the steady flow of fluid therethrough for modulating said fluid pressure in said bit cavity at an operating frequency, and

(d) Helmholtz resonator means for isolating said modulating fluid pressure at said bit cavity.

2. The invention defined in claim **1** wherein said Helmholtz resonator means is disposed three-quarters of a wavelength from said bit cavity.

3. The invention defined in claim **1** wherein said generator means includes an acoustic termination.

4. The invention defined in claim **3** wherein said acoustic termination is a gas desurger.

5. The invention defined in claim **3** wherein said acoustic termination is a Helmholtz resonator.

6. The invention defined in claim **1** wherein said Helmholtz resonator includes spaced first and second fluid filled cavities and a third fluid filled intermediate cavity disposed between said first and second cavity and having a diaphragm acted upon by said modulating pressure in said bit cavity.

7. The invention as set forth in claim **6** wherein said Helmholtz resonator comprises a series of upper pipes having one end open in said first cavity and a second end open in said intermediate cavity and a series of lower pipes having openings in said intermediate and third cavity.

8. The invention as set forth in claim **7**, wherein said upper and lower pipes are disposed in a direction axially of said drill string.

9. Hydroacoustic drilling apparatus for drilling a bore hole in the earth's formation, said apparatus comprising:

(a) a drill string having an axial bore for the flow of

fluid therethrough under pressure to said hole,

(b) a drill bit connected to said drill string for forming a bit cavity in a bottom region of said bore hole,

(c) a hydroacoustic generator means coupled between said drill bit and said string responsive to the steady flow of fluid therethrough for modulating said fluid pressure in said bit cavity at an operating frequency,

(d) isolation means for isolating said modulating fluid pressure at said bit cavity, and

(e) said generator means including a first port disposed one-quarter of a wavelength at said operating frequency from said bit cavity for discharging a portion of said fluid into the region between said generator and the walls of said bore hole.

10. The invention as defined in claim **9**, wherein said isolation means includes a cavity having a second port opening into said region, said port being disposed one-half of a wavelength of said operating frequency from said first port.

11. Hydroacoustic drilling apparatus for drilling a bore hole in the earth's formation, said apparatus comprising:

(a) a drill string having an axial bore for the flow of fluid therethrough under pressure to said hole,

(b) a drill bit connected to said drill string for forming a bit cavity in a bottom region of said bore hole,

(c) a hydroacoustic generator means coupled between said drill bit and said string responsive to the steady flow of fluid therethrough for modulating said fluid pressure in said bit cavity at an operating frequency,

(d) isolation means for isolating said modulating fluid pressure at said bit cavity,

(e) said generator means including an active cavity wherein said fluid pressure modulations are derived, at least one jet line connected between said active cavity and said bit cavity, and

(f) a gas desurger in said jet line disposed a one-quarter wavelength of said operating frequency from said active cavity.

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CHARLES E. O'CONNELL, *Primary Examiner.*

R. E. FAVREAU, *Assistant Examiner.*